Measurement and Verification (M&V) Guideline for Federal Energy Projects

FEDERAL ENERGY MANAGEMENT PROGRAM

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Prepared for the Federal Energy Management Program of the U.S. Department of Energy by Schiller Associates under the direction of Lawrence Berkeley Laboratory with the Assistance from the National Renewable Energy Laboratory

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ATTENTION

Thank you for you interest in Federal Energy Management and the Federal Energy Management Program's *Measurement and Verification (M&V) Guidelines for Federal Energy Projects*. This document is designed for use in contracts between **federal agencies** and energy service companies, utilities and others.

The FEMP M&V Guidelines contain specific procedures for applying concepts originating in North-American Energy Measurement and Verification Protocol (NEMVP). The NEMVP Protocol was developed through a collaborative effort including industry, government, financial and other organizations. NEMVP provides the framework for M&V procedures and addresses issues related to the use of M&V in third-party financed and utility projects.

For more information, see section 1.4 of this document. To obtain a copy of the NEMVP, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-EREC

The document can also be found on the World Wide Web via DOE's Energy Efficiency and Renewable Energy Network (EREN):

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Tell us what you think!

We're interested in your response to the M&V Guidelines. We will use the information you provide below to help us improve future versions of the guideline and create other ways to help you verify energy savings.

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Measurement and Verification (M&V) Guidelines for Federal Energy Projects

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This document follows the Department of Energy's National Energy Measurement and Verification Protocols (NEVMP). Portions of this document are based on the concepts and methods defined in PG&E's Power Savings Partners Measurement and Verification Procedures Manual (1994) and Southern California Edison's DSM Bidding Program Guidelines and Recommended Procedures (1995).

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SECTION I

Chapter 1

Introduction and ESPC Program Description

This document provides procedures and guidelines for quantifying the savings resulting from the installation of Energy Conservation Measures (ECMs) implemented with federal Energy Savings Performance Contracts (ESPCs) or task orders implemented under a federal IDIQ contract. The first section of this document provides an overview of measurement and verification (M&V) options and procedures. The second, third, and fourth sections provide standardized measurement and verification (M&V) methods for common types of ECMs.

Note: Terms and conditions of individual contracts between federal agencies and energy service companies (ESCOs) take precedence over the information in this document.

1.1 Purpose and Scope of Document

The purpose of this document is to provide M&V options and methods, which have varying levels of accuracy and cost, for verifying the energy and cost savings associated with federal agency performance contracts.

This document is to be used for developing site-specific M&V plans for federal ESPC projects. This document covers M&V options and methods for estimating the energy savings from retrofit ECMs. It does not cover new construction projects, operations and maintenance projects, or cogeneration projects.

Federal energy managers/agencies will choose M&V options and methods for their projects that provide an appropriate level of verification accuracy and that allocate the various risks associated with achieving energy cost savings to either the federal agency or the ESCO. This document provides some guidance on selecting the appropriate M&V effort for each project. However, detailed cost/benefit guidelines on how to select an M&V approach, accuracy and budget for the myriad of different ECMs and contract situations is not provided.

By using this document, federal agencies will have confidence that their projects are verified (with respect to what was installed and the savings achieved) through the use of procedures that: (a) can be applied with consistency to similar projects throughout all geographic regions; and (b) are impartial, reliable, and repeatable.

Modifications and additions suggested by users of this document may be incorporated into this document.

1.1.1 General Approach to Measurement and Verification

There are two components of measurement and verification (M&V) for ESPC projects:

- **Verifying the ECM's potential to perform and generate savings** by confirming that (a) the baseline conditions are accurately defined and (b) the appropriate equipment components or systems were properly installed, they are performing per specification, and they have the potential to generate the predicted savings; and

- **Verifying the ECM's performance (i.e. savings)** by determining the actual energy savings achieved by the installed ECM.

As the ESPC program is based on "pay for performance," each ECM or site will have a site-specific verification process to determine its savings.

1.1.2 Level of Verification Effort

Accuracy requirements for measuring and verifying savings is either defined by the federal agency in its Request For Proposals (RFP) or negotiated with the ESCO. The required level of measurement and verification effort is then specified in the contract between the federal agency and ESCO.

This document is not intended to prescribe the contractual terms between the parties. It is intended to provide guidelines for the parties to choose the best fit of verification methodology with:

- Project costs and expected savings;
- Technology-specific ECM requirements; and
- Risk allocation between the parties, i.e. which party is responsible for performance of the installed equipment and which party is responsible for achieving long term energy savings.

Users of this document must base a choice of an M&V approach on the level of accuracy required and costs. In general, the more rigorous the verification, the more expensive it will be to verify energy savings.

1.2 Background and Program Description

The Federal Energy Management Program (FEMP) was established to assist federal agencies to reduce energy and water costs to the government and make facilities operate more effectively through energy efficiency, use of renewable energy, and water conservation. FEMP assists federal energy managers in identifying and procuring energy-saving projects through proactive problem solving and reducing barriers to successful project implementation. This assistance includes an aggressive attempt to increase the number and quality of projects and effective partnerships among agencies and the private sector.

As the lead organization for implementing federal energy management legislation and Presidential direction, FEMP administers an interagency energy committee and task force, and collaboratives with the U.S. Department of Energy's (DOE's) national laboratories. FEMP works in four major areas:

- Energy service performance contracting;
- Technical guidance and assistance;
- Coordination and reporting; and
- New initiatives.

This document addresses the guidelines for ESPC projects. **These guidelines should also be used for utility program projects to document and report verifiable energy savings, particularly when private sector financing and performance-based energy services are offered to a federal agency utility customer (see range of energy services in ESPC described in next paragraph).**

ESPC is a mandated five-year pilot program of energy savings performance contracts designed to accelerate investment in cost-effective energy efficiency measures in existing federal buildings and thereby save taxpayer dollars. The legislative authority for ESPC is found in Title 42, United States Code 8287. The ESPC program allows federal agencies to contract energy efficiency services with performance guarantees and pay for them in the future from the resulting utility bill and related operations and maintenance cost savings. Energy services may range from conducting audits, designing projects, installing equipment, documenting and reporting verifiable energy savings, training personnel, and operation and maintenance of equipment.

The ESPC program, in other words, promotes the installation of energy efficiency measures financed by private sector funds. This partnership between the federal agency and the private sector is expected to lead to a $1 billion investment by companies in return for a share of the energy cost savings.

Additionally, the ESPC program allows federal agencies to make improvements to facilities to meet energy use reduction mandates in compliance with the National Energy Conservation Policy Act at a time when there are limited capital investment funds. In general, a federal facility enters into a performance contract in order to obtain new, more energy-efficient equipment that, among other benefits, will reduce overall energy use and costs. The realized energy savings will provide an income stream that will finance the project. In many cases older, outdated, equipment will be replaced with new equipment containing state-of-the-art control systems.

As a direct result of the equipment changeout, the federal facility may also realize savings from:

- Decreased maintenance;
- Increased production;
- Improved operational control;
- Improved quality control; and
- Reduced particulate emissions.

Note: While each portion of the above mentioned benefits may be quantifiable, the scope of this document is to detail methods for quantifying only energy savings from installation of ECMs.

1.3 Program and M&V Definitions

If any discrepancy arises between the definitions provided in this document and those in the ESCO / federal agency contract, the definitions in the contract prevail.

Baseline Usage or Demand: The calculated or measured energy usage (demand) by a piece of equipment or a site prior to the implementation of the project ECMs. Baseline physical conditions, such as equipment counts, nameplate data, and control strategies, will typically be determined through surveys, inspections, and/or metering at the site.

Contract: The executed (between federal agency and ESCO) document and appendices, as amended from time to time, that outline provisions of the project.

Commissioning: The process of documenting and verifying the performance of HVAC systems so that the systems operate in conformity with the design intent. An independent party may complete system/equipment commissioning rather than an ESCO. Current editions of the American Society of Heating, Refrigerating, and Air Conditioning Engineers' (ASHRAE) commissioning guideline GPC-14P can be the basis for commissioning activities.

Demand Reduction Estimates: Energy demand reductions (e.g., in kW or Btu/hr) derived from metering and/or calculations in accordance with the provisions of the federal agencies' approved measurement and verification plans, and documented in regular true-up reports.

Energy Savings Estimates: Energy savings (e.g., in kWh or therms) derived from metering and/or calculations in accordance with the provisions of the federal agencies' approved measurement and verification plans, and documented in regular interval reports.

Energy Services Company (ESCO): An organization that designs, finances, procures, installs, and possibly maintains one or more ECMs at a federal facility or facilities.

M&V Option: One of three generic M&V approaches defined for ESPC projects. These Options are defined in the DOE's National Energy Measurement & Verification Protocol (NEMVP) document and in Chapter 3 of this document.

M&V Method: A generic, not-project-specific, M&V approach that applies one of the three M&V Options to a specific ECM technology category. Examples of ECM categories are lighting efficiency retrofits and constant load motor retrofits.

M&V Technique: An evaluation tool for determining energy and cost savings. M&V techniques discussed in this document include engineering calculations, metering, utility billing analysis, and computer simulation.

Performance Factors: Factors which influence energy use, e.g. outdoor air temperature, lighting levels and timeclock settings.

Project Pre-Installation Report: Documentation that provides a description and inventory of existing and proposed energy efficiency equipment, estimates of energy savings, and a site-specific M&V plan (if not included in contract). The ESCO, prior to the installation of energy efficient equipment, provides pre-specified documentation that indicates the proposed equipment/systems, estimates associated energy savings, and defines maintenance and operation procedures that will ensure continued performance.

Project Post-Installation Report: Documentation that provides a description and inventory of old and installed energy-efficiency equipment, estimates of energy savings, and M&V results. The ESCO, after the installation of energy efficient equipment, provides pre-specified documentation that verifies the installed equipment/systems and associated energy savings, and demonstrates proper commissioning that ensures the potential to generate the predicted savings.

Pre-Installation Energy Use or Demand: The calculated energy usage (or demand) by a piece of equipment or a site before implementation of the project. Pre-installation energy use is verified by the ESCO and the federal agency. They also verify that the existing equipment components or systems were properly documented and can be retrofitted to generate savings.

Post-Installation Energy Use or Demand: The calculated energy usage (or demand) by a piece of equipment or a site after implementation of the project. Post-installation energy use is verified by the ESCO and the federal agency. They also verify that the proper equipment components or systems were installed, are operating correctly, and have the potential to generate the predicted savings.

Project: The implementation of energy efficiency services at a federal facility or group of facilities.

Regular Interval Report: Pre-specified documentation provided by the ESCO at defined intervals (e.g., annually) during the term of the contract but after the first Project Post-Installation Report. This documentation verifies continued operation of the installed equipment components or systems and the associated energy savings, demonstrates proper maintenance, and provides M&V results. The energy savings documented in the report serves as the basis for the ESCO's invoice once the regular interval report has been reviewed and approved by the federal agency.

Site-Specific M&V Plan: Plan providing details on how a specific project's savings will be verified based on the general M&V approaches contained in this document and the contract between the federal agency and ESCO.

Usage Group: A collection of equipment (e.g., motors or rooms with light fixtures) with similar characteristics (e.g., operating schedule).

1.4 Relationship Between Three M&V Documents

The following describes the relationship of three M&V documents.

- The North American Energy Measurement and Verification Protocol (NEMVP) is a voluntary consensus document written for technical, procurement and financial experts in government, commerce and industry. The NEMVP provides an overview of current M&V techniques and sets a framework for verifying third-party financed energy projects for public (including Federal) and private sector projects. The document addresses a variety of M&V issues as they relate to actual contracts for energy services. Application of the NEMVP helps insure accurate verification of project savings in a nationally accepted, impartial and reliable manner.

- The FEMP Measurement and Verification (M&V) Guideline for federal energy projects is written for Federal procurement teams and for contractors engaged in energy projects with federal agencies. The FEMP M&V Guideline is a specific application of the NEMVP to be used on federal sector projects, and is intended to be fully compatible and consistent with the NEMVP. The document outlines procedures for specifying M&V in the preparation of a request for proposals (RFP), evaluation of proposals, and establishing the basis of payment for energy savings during the contract. The FEMP guideline assists the user in choosing the most appropriate M&V option and method for specific projects.

- The ASHRAE Guideline Project Committee GPC-14P (Measurement of Energy and Demand Savings) is being written under ASHRAE consensus standards to provide guidance for measurement activities at a level of detail most appropriate for the M&V specialist. The measurements will be used to support an approach that uses pre-retrofit and post-retrofit data to calculate the energy and demand savings performance of energy projects involving energy service companies, utilities and others.

1.5 Organization of This Document

Program guidelines and recommended procedures are presented in four sections. Each section in this document is divided into chapters as follows:

Section I

Chapter 1—Introduction and ESPC program description.

Chapter 2—General approach and policies regarding measurement and verification.

Chapter 3—Summaries of different M&V options and methods as well as considerations for selecting the appropriate option and method for specific projects.

Chapter 4—Overview of general M&V procedural steps and submittals.

Section II

Chapters 5 through 9—Option A measurement and verification methods for such ECMs as lighting efficiency projects, lighting controls projects, constant load motor efficiency projects, variable speed drives, and chiller replacement projects.

Section III

Chapters 10 through 17—Option B measurement and verification methods for the same ECMs covered in Section II plus variable load/operating projects.

Section IV

Chapters 18 and 19—Option C utility billing analysis and computer simulation.

Appendices

Appendices A and B contain sample forms. Appendix C contains guidelines for sampling.

SECTION I

Chapter 2

General Measurement and Verification (M&V) Overview

This chapter provides an overview of the M&V approaches that can be used for ESPC projects. The plans and procedures summarized in this chapter and described in more detail later in this document are "programmatic," generic M&V approaches. Details of each project's M&V activities will need to be determined and then defined in site-specific M&V plans.

2.1 General Approach

There are two components in the measurement and verification (M&V) of ESPC projects:

- **Verifying the ECM's potential to perform and generate savings,** also stated as confirming that (a) the baseline conditions were accurately defined and (b) the proper equipment/systems were installed, they are performing to specification and they have the potential to generate the predicted savings; and

- **Verifying the ECM's performance (i.e., savings)** or, in other words, determining the actual energy savings achieved by the installed ECM.

The general approach to verifying baseline and post-installation conditions involves inspections, spot measurement tests, and/or commissioning activities. Commissioning is the process of documenting and verifying the performance of systems so that the systems operate in conformity with the design intent. The commissioning activities include:

- Documentation of design assumptions for the ECM;

- Documentation of the design intent for use by contractors, owners, and operators;

- Functional performance testing and documentation necessary for evaluating the ECM for acceptance; and

- Adjusting the ECM to meet actual needs and operating performance within the capability of the system.

The general approach to determining energy savings involves comparing the energy use associated with a facility, or certain systems within a facility, before installation of the ECM (baseline) and after installation of the ECM (post-installation). Therefore, in general:[1]

energy savings = (baseline energy use) – (post-installation energy use)

As ESPC projects are based on "pay for performance," each ECM or site will have a site specific verification process to determine its savings. For each site or project, the baseline and post-installation energy use will be defined using any or all of the following: metering, billing analysis, and/or engineering calculations (possibly including computer simulation). In addition, values for certain factors that affect energy use and savings, *and that are beyond the control of the ESCO*, ***may*** be stipulated by the federal agency sponsoring the site.

After each project is completed, the ESCO submits a report that defines projected energy savings for the first year. This post-installation report must be accepted and approved by the federal agency. Typically, first year payments to the ESCO will be based on the projected savings values submitted in the report.

For the remaining years of the contract, the ESCO provides annual (or at some other regular interval) "true-up" reports. These reports include inspection documentation of the installed equipment/systems and (perhaps) updated savings values using data obtained and analyzed during each year of the contract. Previous payments would be reconciled as necessary based on the results of the periodic report. Future year payments would be calculated based on information in the periodic report.

2.2 Verifying ECMs' Potential To Perform

2.2.1 Maintaining Service Quality

The DSM measures installed under ESPC programs should maintain or improve the quality of service provided to the federal agency by the affected equipment or systems. For example, lighting projects that reduce lighting levels must maintain some minimum standards, i.e. the minimum IES standard for the space's primary use.

[1] Exceptions to this simple equation are new construction projects and projects in which the baseline energy use is determined from similar facilities, not the one where the retrofit occurred.

However, in this document verifying the performance standards is not addressed. Specific facility performance requirements are defined in the solicitations for ESCO services.

2.2.2 Baseline Verification

Baseline conditions may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, then the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, then the federal agency will verify the baseline.

Baseline physical conditions such as equipment counts, nameplate data, energy consumption rate, and control strategies will typically be determined through surveys, inspections, and/or spot or short-term metering activities.

2.2.3 Post-Installation Verification

In a post-installation M&V verification, the ESCO and the federal agency agree that the proper equipment components or systems were installed, are operating correctly and have the potential to generate the predicted savings. Verification methods may include surveys, inspections, and/or continuous metering.

The ESCO, or third party, is expected to complete the system/equipment commissioning. Current editions of ASHRAE's commissioning guideline GPC-1[2] can be the basis for commissioning activities.

2.2.4 Regular Interval Post-Installation Verification

The ESCO and federal agency, at defined intervals during the term of the contract, will verify that the installed equipment components or systems have been properly maintained, continue to operate correctly, and to generate savings. It should be noted that under the ESPC program 10 CFR Part 436.37 the verification of savings is required on an annual basis.

2.3 Verifying ECMs' Performance

Either after the ECM is installed, continuously, or at regular intervals, the ESCO and federal agency will determine energy savings in accordance with an agreed-to M&V method with the verification techniques that are defined in a site-specific M&V plan.

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[2] *Guidelines for Commissioning of HVAC Systems*, ASHRAE Guideline 1 (1989).

2.3.1 Verification Techniques

Baseline energy use, post-installation energy use, and thus energy (and cost) savings will be determined using one or more of the following M&V techniques:

- Engineering calculations;
- Metering and monitoring;
- Utility meter billing analysis;
- Computer simulations (e.g., DOE-2 analysis);
- Mathematical models (e.g., regression formulas); and
- Agreed-to stipulations by the federal agency and the ESCO.

2.3.2 Estimating Energy Savings

There are numerous factors that can affect energy savings during the term of a contract, such as weather, operating hours, process loads and heat exchanger fouling. *In general, but not always,* an ESPC contract objective will be to adjust the baseline energy use up or down for factors beyond the control of the ESCO (e.g., building occupancy or weather) and adjust the post-installation energy use for ESCO-controlled factors (e.g., maintenance of equipment efficiency).

In order to calculate energy savings, the federal agency may stipulate the value of factors that are difficult to determine or that may vary during the term of the contract. For a lighting project, for example, the federal agency (or ESCO) measures the before and after lighting fixture power draw and then stipulates the operating hours of the facility. For a chiller replacement project, for example, the federal agency measures the baseline and post-installation chiller performance factors (e.g., IPLV kW/ton) and then stipulates the ton-hours of cooling at the facility in order to calculate annual energy savings. Stipulated values will need to be checked for reasonableness through comparisons between (a) total predicted savings against utility energy consumption data and/or (b) values of actual conditions observed during site inspections. These are Option A techniques to measure and verify savings (introduced in Section 3.1).

In other situations, continuous or regular interval measurements throughout the term of the contract will be compared against baseline energy measurements to determine energy savings. For a constant speed motor to variable speed drive motor conversion project, for example, post-installation motor energy use may be continuously metered and compared against baseline measurements of motor energy use. These are Option B techniques to measure and verify energy savings.

There are many factors that affect energy consumption and many methods for estimating savings. A sampling of typical methods is contained in Sections II, III, and IV.

2.4 Factors Affecting Appropriate Level of M&V

The level of certainty required for verifying an ECM's potential to perform (generate savings) and performance (actual savings) will vary from project to project. The necessary confidence level used for establishing savings is a function of the value of the project and cost-effectiveness of the level of M&V sophistication.

Factors that will affect the level of effort and cost (how much the effort costs), are:[3]

- Value of ECM in terms of projected savings;
- Complexity of ECM and M&V procedures;
- Number of ECMs at a single facility and the degree to which their savings are interrelated;
- Number of interrelated ECMs at a single facility.
- Uncertainty of savings;
- Risk allocation between the ESCO and the federal agency for achieving the savings; and
- Other uses for M&V data and systems.

Factors that typically affect M&V accuracy and costs are (some of these are interrelated):

- Level of detail and effort associated with verifying baseline and post-installation surveys;

[3] These factors are discussed in more detail in Chapter 3.

- Sample sizes (number of data points) used for metering representative equipment;
- Duration and accuracy of metering activities;
- Number and complexity of dependent and independent variables which are metered or accounted for in analyses;
- Availability of existing data collecting systems, e.g. energy management systems.
- Contract term; and
- Confidence and precision levels specified for energy savings analyses.

A discussion and definitions of site-specific M&V plans should include consideration of accuracy requirements for M&V activities and the importance of relating M&V costs and accuracy to the value of the ECM savings. For certain types of projects, a statistical definition of accuracy could be included in a contract. For other types of projects, it may be possible only to define a subjective accuracy range or percent of payment budget for M&V.

For each M&V method discussed in Chapter 3 and throughout this document, varying levels of effort and accuracy can be defined.

2.5 Metering and Monitoring Protocols

A site-specific M&V plan should demonstrate that any metering and monitoring will be done in a consistent and logical manner. Metering and monitoring reports must address exactly what was measured, how, when, by whom it was measured, and with what meter it was measured. Calibration is required. Appendix A contains sample forms. These forms are *not* required, but they are provided to give an indication of the level of detail typically required. Both "raw" and "compiled" data should be submitted to the federal agency with the post-installation and regular interval reports.

The duration of metering and monitoring must be sufficient to ensure an accurate representation of the amount of energy used by the affected equipment both before and after project installation. The measurements should be taken at typical system outputs within a specified time period, such as one month. These measurements can then be extrapolated to determine annual and time-of-use period energy consumption.

The required length of the metering period depends on the type of project.

- If, for instance, the project is a system that operates according to a well-defined schedule under a constant load, such as a constant-speed exhaust fan motor, the period required to determine annual savings could be quite short. In this case, short-term energy savings can be easily extrapolated to the entire year.
- If the project's energy use varies both across the day and across seasons, as with air-conditioning equipment, however, a much longer metering or monitoring period may be required to characterize the system. In this case, long-term data or a model correlated to short term data are used to determine annual and time-of-use period energy savings.
- For some types of projects, there will be uncertainty as to how long the metering must be conducted. For example, there is still controversy over how long lighting operating hours must be measured in office buildings to determine a representative indication of annual operating hours. For these situations, a discussion is required between the project participants to determine the appropriate answer for the ECM under consideration.
- If the energy consumption of the metered equipment or systems varies by more than about 10% from month to month, sufficient measurements should be taken to account for these variances. Any major energy consumption variances due to seasonal activity or periodic fluctuations should also be monitored. If these variances cannot be monitored for whatever reason, they must be built into the annual energy consumption figure through an agreed-on adjustment.

Extrapolation can take the form of measuring and normalizing energy consumption as a function of some independent parameter, such as ambient temperature, humidity, or percent occupancy of a building. Once the relationship between the energy consumption of the equipment and the parameter(s) are established, then extrapolation can be done by extending the relationship over a year's time. Therefore, the site-specific M&V plan should identify critical variables, explain how they will be measured or documented, and discuss how they will be used in the extrapolation. The assumptions and mathematical formulas that are used in the M&V plan must be clearly stated.

Any auxiliary energy-consuming equipment must be metered or accounted for if its energy consumption changes as a result of the project installation.

2.6 Energy Costs

The ultimate goal of ESPC is to reduce energy costs at federal facilities. The M&V protocol is designed to provide energy savings information in such a way that cost savings can be estimated.

Energy cost savings will be calculated using energy savings and the appropriate cost per unit of energy saved. In most cases the unit cost of energy will be based on a servicing utility's energy rate schedules at the time the project is implemented. The unit cost of energy that will be used in calculating energy cost savings must be defined in sufficient detail in the contract to allow calculation of savings using each of the factors that affect cost savings. These factors include items such as (for electric bills) kWh saved, kW saved, power factor, kW ratchets, and energy rate tiers.

For performance contracts based on energy cost savings, an M&V method will need to be selected that provides energy savings data by time-of-use periods of the facilities' rate structure. For example, at a Federal prison, the water heating peak load over a two minute averaging period might be 252 kW, 228 kW over 15 minutes, or 192 kW using 60 minute time periods of analysis.

Considerable error in cost savings estimates are introduced by data that does not correspond to the rate structure (15 minutes, in this case). Thus, it is critical that M&V plans should be able to reflect the effects of time-of-use and block rate schedules.

2.7 Minimum Energy Standards

When a certain level of efficiency is required by law or federal agency standard practice, savings ***may*** be based on the difference between the energy usage of the new equipment and baseline equipment which meets the legal or standard practice requirements. In these situations, the baseline energy and demand consumption must be equal to or less than any applicable minimum energy standards. If this requirement exists, it will be specified in the federal agency's RFP and/or government defined baseline.

2.8 Standardized Forms

Sample survey forms for lighting and motors projects are presented in Appendix B. These forms, which are subject to change, may be required by the sponsoring federal agencies. The forms are based on a particular seasonal and time-of-use utility rate structure. Other rate structures will require different reporting formats for operating hours. Equipment surveys submitted by ESCOs are expected to be comprehensive, accurate (for example, ± 5%) and current (completed within a reasonable time before submittal).

Data and surveys submitted should be provided in both electronic and hard copy formats as specified by the federal agency.

2.9 Inspections

Pre-installation, post-installation, and regular interval inspections (e.g., annual) by federal agency representatives may be conducted to confirm the documentation submitted to the federal agency by the ESCO. These inspections, or confirmation visits, by federal agency representatives are very important. If the federal agency believes that the conditions at the site are not accurately represented by the ESCO's submittals, the ESCO will be allowed the opportunity to address the problem and make a new submittal. **If the ESCO and federal agency cannot agree on site conditions, however, a contract or project may be modified or terminated.**

The federal agency's inspection personnel do not have authority to approve changes to contract documents or ESCO submittals to the federal agency. Any changes must be approved by the federal agency's authorized representative.

2.10 Interactive Effects

It is commonly understood that various ECMs interact with each other. Reduced lighting loads, for example, can reduce air conditioning energy consumption but increase heating consumption. However, the detailed relationship between most dissimilar but interactive ECMs is not known, and the methods for measuring interactive effects are not cost-effective for many applications.

For lighting projects, three approaches for accounting for savings associated with interactive effects are to:

1. Ignore interactive effects.

2. Use mutually agreed-on default values that are applicable based on the site-specifics associated with building type and HVAC equipment type. The default values can be assigned based on either available information for typical buildings or developed based on computer model simulation for typical building conditions. A critical element of this approach is for the ESCO or federal agency to demonstrate in the baseline lighting survey that the measures are in air-conditioned

space. If the space is also heated, the post-installation energy consumption needs to be adjusted upwards to account for the increase in the heating load caused by losses in internal heat gains from efficient lighting equipment.

3. Propose a method to measure and estimate interactive effects. The federal agency and/or ESCO will need to come to agreement on the merit and reasonableness of the proposed approach that may include either (a) directly measuring; (b) simulating the HVAC (heating and cooling) interactive effects, using a fully documented computer program; or (c) using a utility meter billing analysis approach that captures interactive effects in the total predicted savings. All methods will need to be proposed and reviewed on a site-specific basis.

SECTION I

Chapter 3

Measurement and Verification Options

The Measurement and Verification guidelines contain methods for determining energy savings from energy conservation projects. All of the methods for determining energy savings are based on the same concept; namely, energy savings are derived by comparing the energy usage after the retrofit to what the energy usage would have been without the retrofit (i.e. the baseline). It is relatively easy to measure post-retrofit consumption. However, it is impossible to "measure" what the energy usage would have been, therefore it is impossible to "measure" energy savings. Energy savings can only be determined, based on assumptions about the baseline.

This document contains measurement guidelines grouped into three categories, Options A, B and C. These options are consistent with those defined in the North American Energy Measurement and Verification Protocols (NEMVP). Three options are provided in order to provide flexibility in determining energy savings. A particular option is chosen based on the expectations of the agency and on site specific features.

The options differ in their approach to the level and duration of the retrofit verification measurements. For instance, Options A and B both focus at the system level, while Option C uses measurements taken at the whole-building, or whole-facility level. Option A uses short term measurements, while Options B and C use continuous or regular interval measurements during the term of the contract.

None of the options are necessarily more expensive or more accurate than the others. Each has advantages and disadvantages based on site specific factors and the needs and expectations of the agency.

The three options are described below. Following the option descriptions is a discussion of the factors that affect selection of an M&V option and method for a particular project. The last portion of this section describes M&V methods, categorized by option and ECM technology. The federal agency and the ESCO will select an M&V option and method for each project and then prepare a site-specific M&V plan that incorporates project specific details.

3.1 M&V Options

As mentioned above, the M&V options have been defined to help organize the selection of an appropriate M&V plan for each ESPC project. Table 3.1 is a quick overview of the three options.

Table 3.1
M&V Options Summary

M&V Option	Verification of Potential To Perform (and generate savings)	Verification of Performance (savings)	Performance Verification Techniques
Option A Verifying that the measure has the potential to perform and to generate savings	Yes	Stipulated	Engineering calculations (possibly including spot measurements) with stipulated values
Option B Verifying that the measure has the potential to perform and verifying actual performance by end use	Yes	Yes	Engineering calculations with metering and monitoring throughout term of contract
Option C Verifying that the measure has the potential to perform and verifying actual performance (whole building analysis)	Yes	Yes	Utility meter billing analysis, possibly with computer simulation

3.1.1 Option A

Option A is a verification approach that is designed for projects in which the potential to perform needs to be verified, but the actual can be stipulated based on the results of the "potential to perform and generate savings" verification and engineering calculations. Option A involves procedures for verifying that:

- Baseline conditions have been properly defined;
- The equipment and/or systems that were contracted to be installed have been installed;
- The installed equipment components or systems meet the specifications of the contract in terms of quantity, quality, and rating;
- The installed equipment is operating and performing in accordance with the specifications in the contract and meeting all functional tests; and

- The installed equipment components or systems *continue, during the term of the contract,* to meet the specifications of the contract in terms of quantity, quality and rating, and operation and functional performance.

Option A, therefore, enables the contracting parties to confirm that the proper equipment components or systems were installed and that they have the potential to generate the predicted savings. Achieving this level of verification is all that is contractually required for certain types of performance contracts. For example, baseline and post-installation conditions (e.g., equipment quantities and ratings such as lamp wattages, chiller kW/ton, motor kW, or boiler efficiency) represent a significant portion of the uncertainty associated with many projects.

Verification of the potential to perform may be done with inspections and/or spot or short-term metering conducted right before and/or right after project installation. Annual (or some other shorter, regular interval) inspections may also be conducted to verify the ECMs' continued potential to perform and generate savings.

With Option A, actual achieved energy or cost savings are predicted using engineering or statistical methods that **do not involve long term measurements**. All end-use technologies can be verified using Option A. Within Option A, various methods and levels of accuracy in verifying performance are available. The level of accuracy ranges from an inventory method of ensuring nameplate data and quantity of installed equipment to short-term measurements for verifying equipment ratings, capacity and/or efficiency.

Performance can be quantified using any number of methods, each depending on the accuracy requirements of the contract. Performance of equipment can be obtained either directly, such as actual measurement, or indirectly, such as the use of manufacturer data. There may be sizable differences between published information and actual operating data. Where discrepancies exist, or at least are believed to exist, field operating data should be obtained. These data could take the form of a spot measurement for a constant load application. Short term M&V can be used if the application is not proven to be a constant load.

Verification of baseline and post-installation equipment should occur at the same level of thoroughness. Either formally or informally, all equipment baselines should be verified for accuracy and for agreement with stated operating conditions. **Actual field audits will almost always be required.**

3.1.2 Option B

Option B is for projects in which:

(a) The potential to perform and generate savings needs to be verified; and

(b) Actual performance during the term of the contract needs to be measured (verified).

Option B involves procedures for ***verifying the same items as Option A (see bullets on previous page) plus verifying actual achieved energy savings during the term of the contract***. Performance verification techniques involve engineering calculations with metering and monitoring.

Option B M&V involves:

- Confirming that the proper equipment/systems were installed and that they have the potential to generate the predicted savings, and

- Determining an energy (and cost) savings value **using measured data** taken throughout the term of the contract.

All end-use technologies can be verified with Option B; however, the degree of difficulty and costs associated with verification increases exponentially as the complexity of the metering increases.

How accurate the energy savings value must be is defined by the federal agency or negotiated with the ESCO. The steps used in measuring or determining energy savings can be more difficult and costly than those used in Option A; however, the results will typically be more precise.

Methods used in this option will involve long term measurement of one or more variables. Long term measurement accounts for operating variations and will more closely approximate actual energy savings than the use of stipulations as defined for Option A. Long term measurements do not necessarily increase the accuracy.

Measurement of all end-use operating systems may not be required if a statistically valid sampling method is used to select a sub-set of operating systems. Examples of this include measurement of operating hours for a selected group of lighting fixtures or power draw of certain motors which have been pre-determined to operate in a similar manner. Sampling guidelines for calculating sample sizes and sample selection are discussed in Appendix C.

3.1.3 Option C

Option C is also for projects in which (a) the potential to perform needs to be verified and (b) actual performance during the term of the contract needs to be verified. Option C involves procedures for **verifying the same items as Option A plus verifying actual achieved energy savings during the term of the contract.**

Performance verification techniques involve **utility whole building meter analysis and/or computer simulation calibrated with utility billing data**. As such Option C is the one M&V option that addresses aggregate, coincident demand and energy savings from multiple resources at a single site. Option C also provides procedures for determining and verifying the impact of ECMs which are not directly measurable, or affect loads indirectly, such as increasing building insulation, or installing low-e windows[4].

Option C M&V involves:

- Confirming that the proper equipment/systems were installed and that they have the potential to generate the predicted savings, and

- Determining an energy savings value using measured utility meter data taken throughout the term of the performance contract.

All end-use technologies can be verified with Option C. This option would be used when there is a high degree of interaction between installed energy conservation systems and/or the measurement of individual component savings would be difficult. Accounting for changes other than those caused by the ECMs is the major challenge associated with Option C—particularly for long term contracts.

3.2 Criteria For Selecting The Appropriate M&V Option and Method

As noted previously, the level of certainty, and thus effort, required for verifying an ECM's potential to perform and actual performance will vary from project to project. Drafting of an RFP to select an ESCO or the actual contract should be done with serious consideration of what M&V requirements, reviews and costs will be specified.

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[4] As discussed in 3.1.3, Option C is very similar to Option B except that utility billing meter and/or computer simulation analysis is used for the purpose of verifying performance of complex and/or multiple measures in a single facility.

Factors that affect the decision of which M&V option, method, and technique to use for each ESPC project include:

- **Value of ECM in terms of projected savings**. Scale of a project, energy rates, term of contract, comprehensiveness of ECMs, benefit sharing arrangement, and magnitude of savings can all affect the value of the ESPC project. The M&V effort should be scaled to the value of the project so that the value of the information provided by the M&V activity is appropriate to the value of the project itself. "Rule of thumb" estimates put M&V costs at 3% to 10% of typical project cost savings.

- **Complexity of ECM.** More complex ECM projects may require more complex, and thus expensive, M&V methods to determine energy savings. In general, the complexity in isolating the savings is the critical factor. A complicated HVAC measure may not be difficult to assess if there is a utility meter dedicated to the HVAC system.

  When defining the appropriate M&V requirements for a given project, it is helpful to consider projects as being in one of the following categories (listed in order of increasing M&V complexity):

  - Constant load, constant operating hours

  - Constant load, variable operating hours
    - ⇒ Variable hours with a fixed pattern
    - ⇒ Variable hours without a fixed pattern; e.g., weather dependent

  - Variable load, variable operating hours
    - ⇒ Variable hours or load with a fixed pattern
    - ⇒ Variable hours or load without a fixed pattern; e.g., weather dependent

- **Number of interrelated ECMs at a single facility.** If there are multiple ECMs being installed at a single site, then the savings from each measure may be, to some degree, related to the savings of other measure(s) or other non-ECM activities at the facility. Examples include: interactive effects between lighting and HVAC measures or HVAC control measures and a chiller replacement. In these situations, it is probably not possible to isolate and measure one system in order to determine savings. Thus, for multiple, interrelated measures, Option C is almost always required.

- **Uncertainty of savings**. The importance of the M&V activities is often tied to the uncertainty associated with the estimated energy or cost savings. A common ECM that the facility staff is familiar with may, subjectively, require less M&V rigor than other ECMs that are less common. In addition, if the ECM is similar to other projects that have been completed and for which savings have been documented, the M&V results may be applied from the other project. If the ESCO specifies the baseline, it may be more appropriate to use M&V Options B or C to verify savings.

- **Risk allocation between the ESCO and the federal agency**. If an ESCO's payments are not tied to actual savings, M&V activities are not required. Likewise if an ESCO is not held responsible for certain aspects of a project's performance, then these aspects do not need to be measured or verified. The contract should specify how payments will be determined and thus what needs to be verified. For example, variations in the operating hours of a facility during the term of a contract may be a risk the federal agency takes on and thus operating hours need not be continuously measured for purposes of payment. For this example, Option A may be appropriate.

- **Other Uses for M&V Data and Systems.** Often the array of instrumentation installed and the measurements collected for M&V can be used for other purposes, including commissioning and system optimization. Data and systems are more cost-effective if combined with the objectives of the M&V activities. In addition, savings could be quantified beyond the requirements of the performance contract. Information could be useful for cost allocation between different tenants, information for future projects, or for research purposes.

3.3 M&V Methods By ECM

This sub-section summarizes M&V methods for different ECMs. The ECMs covered are the most common ones currently being implemented though performance contracts. These ECMs are:

- Lighting efficiency retrofit projects and constant load motor retrofit projects that are representative of constant load, constant operating hours projects;

- Lighting controls retrofit projects that are representative of constant load, variable operating hours projects; and

- Variable speed drive (VSD) retrofits and chiller replacement projects that are representative of variable load, variable operating hour projects.

Generic variable load, variable operating hours, utility billing analysis and computer simulation M&V methods are also presented.

Information on these methods is presented in three ways in this sub-section:

- Table 3.2 is a summary of 24 methods that have been defined for the different ECM categories (these are representative of most of the situations expected to be seen).

- Tables 3.3 through 3.6 provide summary points about M&V methods by end-use technology:

  - Table 3.3 is for lighting efficiency retrofits.
  - Table 3.4 is for lighting controls retrofits.
  - Table 3.5 is for constant load motor retrofits.
  - Table 3.6 is for variable speed drive retrofits.
  - Table 3.7 if for chiller retrofit projects.

- Sections 3.3.1 through 3.3.25 provide paragraph-long descriptions of the different options.

In addition, Sections II, III and IV of this document provide stand-alone Chapters on these M&V methods.

Table 3.2
Summary of M&V Methods by Technology and M&V Approach

M&V Method Name and Chapter Ref.	Technology	M&V Option	Method
LE-A-01, Chapter 5	Lighting Efficiency	Option A	no metering
LE-A-02, Chapter 5	Lighting Efficiency	Option A	spot metering of fixture wattage
LE-B-01, Chapter 10	Lighting Efficiency	Option B	continuous metering of operating hours
LE-B-02, Chapter 11	Lighting Efficiency	Option B	continuous metering of lighting circuits
LE-C-01, Chapter 18	Lighting Efficiency	Option C	utility billing analysis
LC-A-01, Chapter 6	Lighting Controls	Option A	no metering
LC-A-02, Chapter 6	Lighting Controls	Option A	spot metering of fixture wattages
LC-B-01, Chapter 12	Lighting Controls	Option B	continuous metering of operating hours
LC-B-02, Chapter 13	Lighting Controls	Option B	continuous metering of lighting circuits
CLM-A-01, Chapter 7	Constant Load Motors	Option A	spot metering of motor kW
CLM-B-01, Chapter 14	Constant Load Motors	Option B	continuous metering of motor kW
CLM-C-01, Chapter 18	Constant Load Motors	Option C	utility billing analysis
VSD-A-01, Chapter 8	VSD Retrofit	Option A	spot metering of motor kW
VSD-B-01, Chapter 15	VSD Retrofit	Option B	continuous metering of motor kW, speed frequency, or controlling variables
VSD-C-01, Chapter 18	VSD Retrofit	Option C	utility billing analysis
CH-A-01, Chapter 9	Chiller Retrofit	Option A	no metering
CH-A-02, Chapter 9	Chiller Retrofit	Option A	verification of chiller kW/ton
CH-B-01, Chapter 16	Chiller Retrofit	Option B	continuous metering of new chiller
CH-B-02, Chapter 16	Chiller Retrofit	Option B	continuous metering of new chiller and cooling load
CH-C-01, Chapter 18	Chiller Retrofit	Option C	utility billing analysis
CH-C-02, Chapter 19	Chiller Retrofit	Option C	computer simulation
GVL-B-01, Chapter 17	Generic Variable Load Project	Option B	continuous metering of end-use energy use
GVL-C-01, Chapter 18	Generic Variable Load Project	Option C	utility billing analysis
GVL-C-02, Chapter 19	Generic Variable Load Project	Option C	computer simulation

Table 3.3 Lighting Efficiency Retrofits - M&V Methods

M&V Method	Method LE-A-01: No Metering	Method LE-A-02: Metering of Fixture Wattages	Method LE-B-01: Metering of Operating Hours	Method LE-B-02: Metering of Lighting Circuits	Method LE-C-01: Utility Billing Analysis
M&V Option	Option A	Option A	Option B	Option B	Option C
Fixture Counts	survey which is checked to defined accuracy	same as LE-A-01	same as LE-A-01	same as LE-A-01	same as LE-A-01
Fixture Wattages	fixture wattage table or manufacturer data	one time (before and after) measurements of representative fixture wattages	fixture wattage table or fixture measurements	measured circuit wattage	required - as a check, and for future baseline modifications
Pre-Installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre-monitoring	same as LE-A-01	assumed equal to post-installation hours which are monitored	same as LE-B-01	not required - unless as a check, or for future baseline modifications
Post-Installation Operating Hours	same as pre-installation operating hours	same as LE-A-01	monitoring of operating hours	measurement of circuit average power draw implies operating hours	not required - unless as a check
Interactive Factors	a) not allowed, or b) stipulated percentage, or c) based on simulation	same as LE-A-01	same as LE-A-01	same as LE-A-01	Included in billing analysis results

Table 3.4 Lighting Controls Retrofits - M&V Methods[5]

M&V Method	Method LC-A-01: No Metering	Method LC-A-02: Metering of Fixture Wattages	Method LC-B-01: Metering of Operating Hours	Method LC-B-02: Metering Lighting Circuits
M&V Option	Option A	Option A	Option B	Option B
Fixture Counts	survey which is checked to defined accuracy	same as LC-A-01	same as LC-A-01	same as LC-A-01
Fixture Wattages	fixture wattage table or manufacturer data	one time measurements of representative fixture wattages	fixture wattage table or one time fixture measurements	measured circuit wattage
Pre-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre- monitoring	same as LC-A-01	operating hours are monitored for representative sample(s) of fixtures	the circuit measurement of average power draw also provides operating hours
Post-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term post-monitoring	same as LC-A-01	operating hours are monitored for representative sample(s) of fixtures	the circuit measurement of average power draw also provides operating hours
Interactive Factors	a) not allowed, or b) stipulated percentage, or c) based on simulation	same as LC-A-01	same as LC-A-01	same as LC-A-01

[5] It is assumed that the savings from a lighting controls project will not be significant enough for utility billing analysis

Table 3.5 Constant Load Motor Retrofits - M&V Methods

M&V Method	Method CLM-A-01: Metering of Motor kW	Method CLM-B-01: Metering of Operating Hours	Method CLM-C-01: Utility Billing Analysis
M&V Option	Option A	Option B	Option C
Motor Counts	survey which is checked to defined accuracy	same as CLM-A-01	same as CLM-A-01
Baseline and Post-Installation Motor Power Draw	spot wattage/rpm measurements	spot and short-term wattage/rpm measurements	not required - unless as a check or for future baseline modifications
Pre-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre-monitoring	assumed equal to post-installation hours which are monitored	not required - unless as a check or for future baseline modifications
Post-installation Operating Hours	same as pre-installation operating hours	monitoring of operating hours or kWh	not required - unless as a check
Confirmation of Constant Load	a) stipulated, or b) short-term metering of sample of motors	same as CLM-A-01	not required - unless as a check

Table 3.6 Variable Speed Drive Retrofits - M&V Methods

M&V Method	Method VSD-A-01: Metering of Motor kW	Method VSD-B-01: Continuous Metering of Motor kW or Controlling Variables	Method VSD-C-01: Utility Billing Analysis
M&V Option	Option A	Option B	Option C
Inventory of Motors and Drives/Controls	survey which is checked to defined accuracy	same as VSD-A-01	same as VSD-A-01
Verification of System Operation	functional verification of VSD operation	same as VSD-A-01	same as VSD-A-01
Baseline Motor Power Draw at different operating conditions	stipulated based on a) spot or short-term wattage/rpm measurements (baseline is constant load), or b) short-term wattage/input measurements (baseline is variable load)	a) spot or short-term wattage/rpm measurements (baseline is constant load), or b) short-term wattage/input measurements (baseline is variable load)	not required - unless as a check or for future baseline modifications
Baseline Operating Hours[6]	stipulated based on estimates or some short-term pre-monitoring	a) assumed equal to post-installation conditions - which are monitored, or b) if variable, then long-term pre-monitoring	not required - unless as a check, or for future baseline modification
Baseline[7] Operating Conditions - independent variables that impact energy use, operating hours e.g. weather	not used for method	assumed equal to post-installation conditions - which are monitored	not required - unless as a check, or for future baseline modifications
Post Installation[8] Motor Power Draw at different operating (input) conditions	a) stipulated based on manufacturer data, or b) spot or short-term wattage/ rpm measurements	continuous or regular interval wattage measurements	not required
Post-installation[9] Operating Conditions - independent variables that impact energy use	not used for method	long-term post-monitoring for input into post- (and pre-) installation model	not required

[6] With some VSD projects the replaced motors are always at constant load so that the baseline energy use is equal to the product of motor kW and motor operating hours
[7] With some VSD projects the replaced motors have variable loading depending on the independent factors such as weather which impact valve or damper positions
[8] post-installation energy use can be directly measured
[9] post-installation energy use can be calculated based on measurement of independent variables, e.g. weather, once a correlation has been established between post-installation energy use and the independent variable

Table 3.7 Chiller Retrofit - M&V Methods
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M&V Method	Method CH-A-01: No Metering	Method CH-A-02: Verification of Chiller kW/ton Ratings	Method CH-B-01: Continuous Metering of Chiller (post-installation)
M&V Option	Option A	Option A	Option B
Inventory of Chillers and Auxiliary Equipment	survey which is checked to defined accuracy	same as CH-A-01	same as CH-A-01
Verification of System Operation	functional verification of chiller system operation	same as CH-A-01	same as CH-A-01
Baseline Chiller and Auxiliary Equipment Power Draw (at different cooling loads)	stipulated based on manufacturer data and/or other sources	a) stipulated, or b) spot or short-term kW/cooling load measurements to determine "performance curve" or kW vs. cooling load	same as CH-A-02
Baseline Cooling Load (stated in average ton hours per year or percent time at different cooling loads)	stipulated based on estimates e.g., computer model simulation	same as CH-A-02	a) stipulated, or b) assumed equal to post-installation cooling load which is determined from measurement of new chiller kW and use of new chiller performance curve
Post-Installation Chiller and Auxiliary Equipment Power Draw (at different cooling loads)	stipulated based on manufacturer data, and/or other sources	a) stipulated, or b) spot or short-term kW/cooling load measurements to determine "performance curve" or kW vs. cooling load	continuous or regular interval metering of chiller kW to determine post-installation energy use
Post-Installation Cooling Load (stated in average ton hours per year or percent time at different cooling loads)	stipulated based on estimates	same as CH-A-01	not required for this method

Table 3.7 Chiller Retrofit - M&V Methods
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M&V Method	Method CH-B-02: Continuous Metering of Chiller and Cooling Load (post-installation)	Method CH-C-01: Utility Billing Analysis	Method CH-C-02: Computer Simulation Calibrated to Whole Building Utility Data
M&V Option	Option B	Option C	Option C
Inventory of Chillers and Auxiliary Equipment	same as CH-A-01	same as CH-A-01	same as CH-A-01
Verification of System Operation	same as CH-A-01	same as CH-A-01	same as CH-A-01
Baseline Chiller and Auxiliary Equipment Power Draw (at different cooling loads)	same as CH-A-02	not required - unless as a check, or for future baseline modifications	use of: (a) typical data, (b) manufacturer data, or (c) spot or short-term wattage/cooling load measurements to determine "performance curve"
Baseline Cooling Load (stated in average ton hours per year or percent time at different cooling loads)	assumed equal to post-installation load which is continuously measured	not required - unless as a check, or for future baseline modifications	determined with computer simulation with possible calibration check against utility metering or end-use metering
Post-Installation Chiller and Auxiliary Equipment Power Draw (at different cooling loads)	same as CH-B-01	not required - unless as a check	use of: (a) typical data, (b) manufacturer data, or (c) spot or short-term wattage/cooling load measurements to determine "performance curve"
Post-Installation Cooling Load (stated in average ton hours per year or percent time at different cooling loads)	post-installation cooling load is determined from measurement of water or air flows and temperatures	not required - unless as a check	determined with computer simulation with possible calibration check against utility metering or end-use metering

3.3.1 Lighting Efficiency Projects, M&V Method LE-A-01 - No Metering

Surveys are required to document existing (baseline) and new (post-installation) conditions. The surveys should include an inventory (in a set format) of fixture, lamp, and ballast types, usage area designations, and identification and counts of operating and non-operating fixtures. Fixture wattages are taken from a standard fixture wattage table that contains wattage per fixture values for common fixtures. For new fixtures, documentation on wattages can be submitted and, if approved, used on a project by project basis. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that reduce lighting levels. Hours of operation are assumed to be the same for baseline and post-installation energy calculations. Hours of operation will be stipulated and based on estimates or some short term, pre-installation monitoring. HVAC interactive factors may be ignored, stipulated based on assumed averages, or calculated with computer simulation programs.

3.3.2 Lighting Efficiency Projects, M&V Method LE-A-02 - One Time Metering of Fixture Wattages

Same as LE-A-01 except:
Fixture wattages are based on spot or short-term measurements of representative baseline and post-installation fixtures or fixture circuits.

3.3.3 Lighting Efficiency Projects, M&V Method LE-B-01 - Metering of Operating Hours

Same as LE-A-01 or LE-A-02 except:
Hours of operation will be determined periodically by the post-installation monitoring of a statistically valid sample of fixtures for each usage area (e.g. offices, hallways, libraries). The monitoring time period (e.g. once a month, twice a year; continuous, etc.) must be reasonable and account for seasonal variations.

3.3.4 Lighting Efficiency Projects, M&V Method LE-B-02 - Metering of Lighting Circuits

This M&V method involves measuring lighting circuits for determining baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and demand savings.

Baseline and post-installation fixture power draw (kW) and energy use (kWh) are measured at circuits which have only a lighting load (e.g. 277 volt circuits) or a well defined minimal non-lighting load. Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The post-installation monitoring time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels. HVAC interactive factors may be ignored, stipulated based on assumed averages, or calculated with computer simulation programs.

3.3.5 Lighting Efficiency Projects, M&V Method LE-C-01 - Utility Billing Analysis

Surveys are required to document existing (baseline) and new (post-installation) conditions. The surveys should include an inventory (in a set format) of fixture, lamp, and ballast types, usage area designations, and identification and counts of operating and non-operating fixtures. Statistical analysis of utility meter billing data will be used to explain changes between baseline and post-installation energy use for the impacted facility (or facilities) from all installed energy conservation measures. The analysis should take in to account all substantive explanatory variables that affect these changes (e.g., occupancy changes). The models and/or estimates must meet criteria for statistical validity as defined by the federal agency.

3.3.6 Lighting Controls Projects, M&V Method LC-A-01 - No Metering

Surveys are required to document existing (baseline) and new (post-installation) conditions. The surveys should include (in a set format) an inventory of fixture, lamp, and ballast types, lighting control types, usage area designations, and identifications and counts of operating and non-operating fixtures. Fixture wattages are taken from a standard fixture wattage table that contains wattage per fixture values for common fixtures. For new fixtures, documentation on wattages can be submitted and, if approved, used on a project by project basis. Corrections are required for non-operating fixtures. Baseline and post-installation hours of operation will be stipulated and based on estimates or some short term, pre-and post-installation monitoring. HVAC interactive factors may be ignored, stipulated based on assumed averages, or calculated with computer simulation programs.

3.3.7 Lighting Controls Projects, M&V Method LC-A-02 - Metering of Fixture Wattages

Same as LC-A-01 except:
Fixture wattages are based on spot or short-term measurements of representative baseline and post-installation fixtures or fixture circuits.

3.3.8 Lighting Controls Projects M&V Method - Metering of Operating Hours

Same as LC-A-01 or LC-A-02 except:
Baseline and post-installation hours of operation will be determined periodically by monitoring a statistically valid sample of fixtures for each usage area (e.g. offices, hallways, libraries). The monitoring time period must be reasonable and account for seasonal variations.

3.3.9 Lighting Efficiency Projects M&V Method - Metering of Lighting Circuits

This M&V method involves measuring lighting circuits for determining baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and demand savings.

Baseline and post-installation fixture power draw (kW) and energy use (kWh) are measured at circuits which have only a lighting load (e.g. 277 volt circuits) or a minimal, well defined non-lighting load. Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The pre-installation metering period will be for some reasonable length of time to establish baseline energy use. The post-installation monitoring time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels. HVAC interactive factors may be ignored, stipulated based on assumed averages, or calculated with computer simulation programs

3.3.10 Constant Load Motor Retrofit Projects, M&V Method CLM-A-01 - Metering of Motor kW

Surveys are required to document existing and new motors. The surveys should include nameplate data, spot and short-term metering data (3-phase amps, volts, PF, kWs etc.), motor speed and motor application. Metering is required on at least a sample of baseline and new motors to determine motor power draw and to confirm constant loading. Demand savings are based on the average kW measured before minus the average kW measured after new motors are installed. Hours of operation before and after measure installation are stipulated.

3.3.11 Constant Load Motor Retrofit Projects, M&V Method CLM-B-01 - Metering Of Operating Hours

Same as CLM-A-01 except:
Hours of operation are monitored for a statistically valid sample of motors. The period of monitoring varies with motor application and must be reasonable and account for seasonal variations.

3.3.12 Constant Load Motor Retrofit Projects, M&V Method CLM-C-01 - Utility Billing Analysis

Surveys are required to document existing and new motors. The surveys should include nameplate data, spot and short-term metering data (3-phase amps, volts, PF, kW, etc.), motor speed and motor application. Statistical analysis of utility meter billing data will be used to explain changes between baseline and post-installation energy use for the impacted facility (or facilities) from all installed energy efficiency measures. The analysis should take into account all substantive explanatory variables that effect these changes (e.g., occupancy changes). The models and/or estimates must meet criteria for statistical validity as defined by the federal agency.

3.3.13 Variable Speed Retrofits, M&V Method VSD-A-01 - Metering Of Motor kW

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include nameplate data, spot and short-term metering data (3-phase amps, volts, PF, kW, etc.), and motor application. Commissioning of VSD operation is expected.

Spot-metering is required on at least a sample of the existing motors to determine baseline motor power draw under different operating scenarios. Constant load motors may require only one spot measurement as the power draw does not vary with time or operating scenario. Operating scenarios may include different control valve or damper positions (for baseline) or motor speeds (for VSDs).

Post-installation spot-metering is required on at least a sample of motors with VSDs. Post installation spot-metering is done while the motors' applicable systems are modulated over their normal operating range (or range of motor speeds).

Demand and energy savings are based on:

- Baseline motor kW (calculated, if required, as a function of different operating scenarios);
- Post-installation motor kW calculated as a function of different operating scenarios; and
- Stipulated hours per year for each operating scenario.

3.3.14 Variable Speed Retrofits, M&V Method VSD-B-01 - Continuous Metering of Motor kW or Controlling Independent Variables

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include nameplate data, spot and short-term metering data (3-phase amps, volts, PF, kW), and motor application. Commissioning of VSD operation is expected.

Metering is required on at least a sample of the existing motors to determine baseline motor power draw. Constant load motors may require only short term metering to confirm constant loading. For baseline motors with variable loading, the short term metering is done while the motors' applicable systems are modulated over their normal operating range. For variable load baseline motors, an average kW demand or a kW demand profile as a function of appropriate independent variables (e.g., outside air temperature) may be used for calculating baseline energy use. If baseline independent variable values are required for calculating the baseline, they will be monitored during the post-installation period.

Post-installation metering is required on at least a sample of motors with VSDs. Post installation short term metering is done while the motors' applicable systems are modulated over their normal operating range (or range of motor speeds).

Baseline demand and energy use are based on:

- Motor operating hours which are measured before or after the VSDs are installed, and
- A constant motor kW value that is determined from pre-installation metering; or
- Motor kW calculated as a function of independent variables that are monitored during the post-installation period.

Post-installation demand and energy use are based on:

- Motor operating hours which are measured after the VSDs are installed, and
- Motor kW, which is continuously metered or metered at regular intervals during the term of the contract; or
- Motor kW calculated as a function of independent variables that are monitored during the post-installation period.

3.3.15 Variable Speed Retrofits, M&V Method VSD-C-01 - Utility Billing Analysis

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include nameplate data, spot and short-term metering data (3-phase amps, volts, PF, kW), and motor application. Commissioning of VSD operation is expected.

Statistical analysis of utility meter billing data will be used to explain changes between baseline and post-installation energy use for the impacted facility (or facilities) from all installed energy efficiency measures. The analysis should take in to account all substantive explanatory variables that effect these changes (e.g., occupancy changes). The models and/or estimates must meet criteria for statistical validity as defined by the federal agency.

3.3.16 Chiller Retrofit, M&V Method CH-A-01 - No Metering

Surveys are required to document existing and new chillers. The surveys should include nameplate data, any spot and short-term metering data (3-phase amps, volts, PF, kW, etc.), control strategies, estimated annual operating hours and chiller application. Commissioning of chiller operation is expected. Baseline and post-installation chiller ratings (e.g. kW/ton, IPLV) are based on manufacturer and/or other data. Annual cooling loads (e.g., annual or monthly ton-hours) are stipulated. Energy savings are based on the product of (a) the difference between average baseline kW/ton and post-installation kW/ton, and (b) cooling load in tons.

3.3.17 Chiller Retrofit M&V Method CH-A-02 - Verification of Chiller kW/ton

Same as CH-A-01, except:
Baseline and post-installation chiller ratings (e.g. kW/ton, IPLV) are based on metering of chiller (and perhaps auxiliary pump and fan kW) and cooling load supplied by chiller. Annual cooling loads (e.g. annual or monthly ton-hours) are stipulated. Energy savings are based on the product of (a) the difference between baseline kW/ton and post-installation kW/ton (at each load rating), and (b) cooling load in tons.

3.3.18 Chiller Retrofit, M&V Method CH-B-01 - Continuous Metering of New Chiller

Same as CH-A-01 or CH-A-02, except:
Post-installation chiller energy use is continuously measured or measured during set intervals throughout the term of the ESPC contract. Baseline energy use is based on:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV); and
- Stipulated cooling loads or cooling loads calculated from the measurement of post-installation chiller energy use.

3.3.19 Chiller Retrofit, M&V Method CH-B-02 - Continuous Metering of New Chiller and Cooling Load

Same as CH-A-01 or CH-A-02, except:
Post-installation chiller energy use and cooling loads are continuously measured or measured during set intervals throughout the term of the ESPC contract. Baseline energy use is based on:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV); and

- Cooling loads measured during the post-installation period.

3.3.20 Chiller Retrofit, M&V Method CH-C-01 - Utility Billing Analysis

Surveys are required to document existing and new chillers. The surveys should include chiller and auxiliary equipment nameplate data, spot metering data (3-phase amps, volts, PF, kW, etc.), and chiller applications. Commissioning of chiller operation is expected.

Statistical analysis of utility meter billing data will be used to explain changes between baseline and post-installation energy use for the impacted facility (or facilities) from all installed energy conservation measures. The analysis should take in to account all substantive explanatory variables that effect these changes (e.g., occupancy changes). The models and/or estimates must meet criteria for statistical validity as defined by the federal agency.

3.3.21 Chiller Retrofit, M&V Method CH-C-02 - Computer Simulation

Surveys are required to document existing and new chillers. The surveys should include chiller and auxiliary equipment nameplate data, spot metering data (3-phase amps, volts, PF, kW, etc.), and chiller applications. Commissioning of chiller operation is expected

Accepted computer simulation models (e.g., DOE-2.1E) will be used to estimate energy savings from the chiller retrofit. Calibration of the model will be done using utility metering data and short term metering at the site. The simulation analysis should take into account all substantive explanatory variables that effect the ECM savings. The models must meet criteria for validity as defined by the federal agency.

3.3.22 Generic Variable Load Project, M&V Method GVL-B-01

The ESCO will audit existing systems to document relevant components; e.g., piping and ductwork diagrams, control sequences, and operating parameters. The ESCO will also document the proposed project and expected savings. All, or a representative sample, of the existing systems will be metered by the ESCO 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.

Once the ECM is installed, there are two general approaches for determining savings:

1. Continuously measuring post-installation energy use and the appropriate variables. The post-installation variable data are used with the baseline "equations" to calculate baseline energy use; and

2. Continuously measuring the appropriate post-installation variables. The post-installation variable data are used with the baseline and post-installation "equations" to calculate baseline and post-installation energy use. With this approach, the ESCO will conduct metering to determine the post-installation relationship between input energy and the appropriate variables after the project is installed.

The ESCO will apply the results of the post-installation metering to determine the difference between pre-installation and post-installation input energy use (and demand). This difference represents the system savings.

3.3.23 Generic Variable Load Project, M&V Method GVL-C-01 - Utility Billing Analysis

Surveys are required to document existing and new systems. The surveys should include nameplate data, any spot and short-term metering data (3-phase amps, volts, PF, kW, therms/hour, thermal efficiencies, etc.), control strategies, estimated annual operating hours and equipment applications. Commissioning of ECM operation is expected.

With billing analysis, there are different statistical techniques that range from simple comparisons to multivariate regression. There is no single correct technique. The analysis techniques and regression models must meet criteria for statistical validity as defined by the federal agency.

3.3.24 Generic Variable Load Project, M&V Method GVL-C-02 - Computer Simulation Analysis

Surveys are required to document existing and new systems. The surveys should include nameplate data, any spot and short-term metering data (3-phase amps, volts, PF, kW, therms/hour, thermal efficiencies, etc.), control strategies, estimated annual operating hours and equipment applications. Commissioning of ECM operation is expected.

Commercially available computer building simulation models can be used to develop base case and post-installation facility descriptions. The computer simulations can then be used to predict energy savings. To make the simulations more accurate and reliable, the facility descriptions can be calibrated with either actual utility bills and/or end-use metering data. The models must meet criteria for validity as defined by the federal agency.

SECTION I

Chapter 4

Overview Of General Procedural Steps And Submittals

This Chapter provides an overview of general M&V activities associated with implementing ESPC projects.

4.1 M&V Activities

Expected M&V activities can be broken down into the following items:

- Define M&V requirements for inclusion in the contract between the federal agency and ESCO based on the federal ESPC M&V guidelines in this document.

- Either before or after the contract is signed, define a site-specific M&V plan for the particular project being installed once the project has been fully defined.

- Define the pre-installation baseline, including (a) equipment/systems, (b) baseline energy use (and cost), and/or (c) factors that influence baseline energy use. The baseline can be defined through site surveys; spot, short term, or long term metering; and/or analysis of billing data. This activity may occur before or after the contract is signed.

- Define post-installation situation, including (a) equipment/systems, (b) post-installation energy use (and cost), and/or (c) factors that influence post-installation energy use. Site surveys; spot, short term, or long term metering; and/or analysis of billing data can be used for the post-installation assessment.

- Calculate energy savings for the first year of the contract.

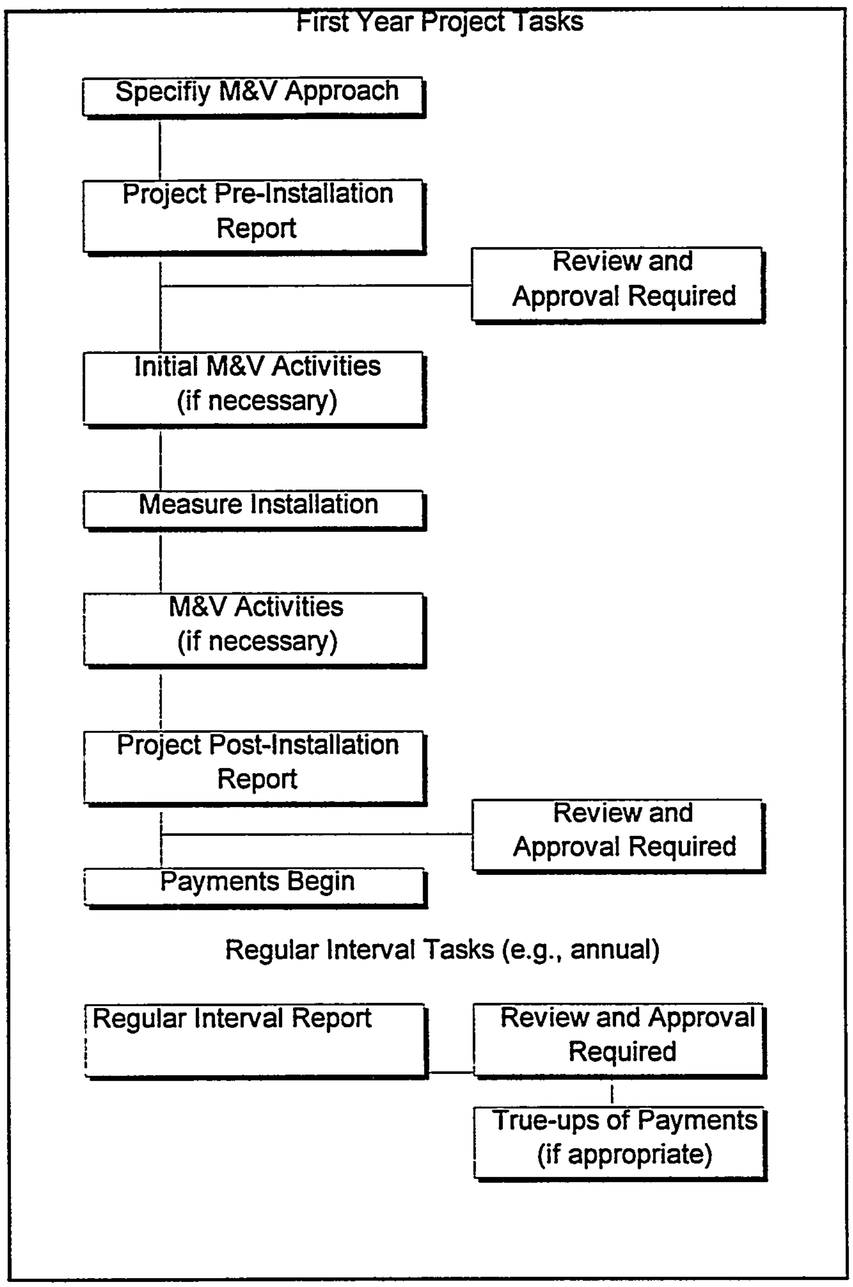
- Conduct annual M&V activities to (a) verify operation of the installed equipment/systems, (b) calculate current year savings, and (c) estimate savings in subsequent years.

4.2 M&V Activity Details

As a contract is implemented, both the federal agency and ESCO take certain steps with respect to the measurement and verification of each project.

Figure 4.1 presents a flow chart of the steps.

Figure 4.1
Overall Project Procedures



The roles of each party in these steps will be specified in their contract depending on type of specific business agreements, risk allocation, and accuracy of desired verification. In general, the ESCO will provide documentation on equipment and demonstrated savings. The federal agency will verify submittals for accuracy and provide approval before the project can proceed on to the next step. The submittals include the Project Pre-Installation Report, Project Post-Installation Report, and Regular Interval Reports. As part of the review of the submittals, the federal agency may or may not conduct site inspections to confirm submittal data.

It should be noted that these steps should be applicable to most projects; however, some M&V activities (outlined below) might be unnecessary if certain variables in estimating savings are stipulated in the contract. The steps identified above are briefly described in the following paragraphs.

4.2.1 Site-Specific M&V Plan

A site specific M&V plan that is based on the federal M&V guidelines must be defined. The approach will also be based on the type of energy efficiency measure and the desired confidence and accuracy of verification.

In some cases that plan will be included by the agency as part of the solicitation, in other cases the ESCO will propose a site specific plan to be finalized after the awarding of the contract. The decision as to whether the agency will specify the site specific plan or the contractor will be asked to provide a site specific plan will be based on the resources available to the agency when constructing the solicitation.

4.2.2 Project Pre-Installation Report

A Project Pre-Installation Report is generated for each project selected for installation. The report is generated by the ESCO. The federal agency must review and approve the report before the ESCO can proceed with the project. At its sole discretion, the federal agency may or may not conduct site inspections to confirm submittal data.

The Project Pre-Installation Report should include a project description, facility equipment inventories with recommended energy conservation measures, energy and cost savings estimates, cost-effectiveness calculations, a site-specific measurement and verification plan, budget documentation (construction and M&V budgets), and proposed construction and M&V schedules.

4.2.3 Initial M&V Activities and Measure Installation

Once the federal agency accepts the Project Pre-Installation Report, metering (if necessary) and/or project installation may proceed. Pre-installation metering is conducted in accordance with the approved, site-specific M&V plan in the contract, and/or Project Pre-Installation Report. Commissioning of the metering is conducted, and the calibration may be witnessed by the federal agency. When any required pre-installation metering has been completed and accepted by the federal agency, the project can be installed. During metering and project installation by the ESCO, the federal agency may request progress reports or conduct inspections.

The major tasks associated with M&V work prior to measure installation are as follows[10]:

- Pre-installation M&V activities are conducted and the federal agency and the ESCO agree on an M&V, an inspection, and an installation schedule based on terms of contract.
- As identified in the contract and/or Project Pre-Installation Report, pre-installation metering is conducted for a period of time required to capture all operating conditions of affected systems and/or processes. If the ESCO is responsible for metering, the federal agency will conduct progress inspections (and/or reports), as required.
- The federal agency notifies the ESCO that project installation may start. If no pre-installation M&V activities are required, project installation approval may be given upon acceptance of the Project Pre-Installation Report.
- Project installation begins.
- The ESCO notifies the federal agency that project installation is complete.

4.2.4 Project Post-Installation Report

When the measures are installed, the ESCO notifies the federal agency that the project installation is complete by submitting the Project Post-Installation Report. The report includes baseline and post-installation calculations with energy and cost savings estimates. Post-installation M&V work may be conducted prior to submitting a Project Post-Installation Report.

[10] If M&V work is not required prior to measure installation, the first two tasks are not required.

The federal agency, as required, inspects the installed project and any post-installation metering.

The major post-installation tasks associated with this submittal are as follows[11]:

- Post-installation M&V activities are scheduled to start, and if conducted by the ESCO, coordinated with federal facility personnel.
- As identified in the contract and/or Project Pre-Installation Report, post-installation metering may be conducted by the ESCO for a period of time required to capture all operating conditions of the measure and/or impacted process. If applicable, federal facility personnel will conduct progress inspections of metering.
- The metering documentation for verification is included in the Project Pre-installation Report.
- A Project Post-Installation Report is generated. The federal agency will (a) either give its approval if the approval project and documentation are acceptable or decline its approval (b) project and documentation are unacceptable or issues exist that prevent a review decision.
- Upon the federal agency's acceptance of the Project Post-Installation Report, ESCOs may submit invoices for first-year payment based on savings estimates in the accepted Project Post-Installation Report.

4.2.5 Regular Interval Reporting

Regular "true-up" M&V activities are conducted periodically based on terms in the contract between the federal agency and the ESCO. It should be noted that the program requirements (10 CFR Part 436.37) specify annual verification of savings.

Periodic reports are generated that present energy and cost savings. If the ESCO is responsible for metering, it analyzes current M&V data and submits periodic reports for federal agency review and approval. The periodic reports include measurement-based kWh savings data. The periodic report data are used for correcting, if necessary, the previous period's payments by the federal agency to the ESCO. These same data are also used for projecting energy savings for subsequent contract periods and are the basis for contract payments in the following period.

[11] If M&V work is not required prior to submittal of the Project Post-Installation Report, then the first three are not required.

The major tasks associated with periodic reports are as follows:

1. If the ESCO is responsible for metering, it notifies the federal agency that periodic "true-up" activities are scheduled to begin. Periodic true-up metering may be conducted for a period of time required to capture all operating conditions of the projects(s) and/or affected processes. The federal agency can conduct progress inspections of metering, as required.
2. Metering and verification documentation are presented in Regular Interval Reports. Federal facility personnel review and approve the report.
3. Federal facility personnel ensure the that report and verification documentation are complete and accurate and in compliance with the contract and approved site-specific M&V plan. Based on the results, payments during the previous period are reconciled and adjusted in subsequent contract payments. This payment reconciliation would not apply if fixed payments are specified in the contract.

4.2.6 Payments

The project payment process is described below:

- The federal facility accepts both the Project Pre-Installation Report and the Project Post-Installation Report.
- The Terms and Conditions of the Purchase Order issued by the federal facility covers what must be in the invoice. The amount of the invoice is also specified.
- The federal agency pays the ESCO upon approval of the invoice in accordance with the terms and conditions of the contract.
- Some projects will be set up so that payments will be based on results in the Regular Interval Report, which indicates the verified energy and cost savings results of the previous period.

Based on the contract, the federal agency may use the report to reconcile payments made to the ESCO for the previous billing periods since previous payments were made based on estimated savings that now need to be trued up to reflect actual savings. This true-up and payment reconciliation would not apply if fixed payments are specified in the contract. The estimates in the report may also be used as the basis for subsequent payments.

SECTION II

Descriptions Of Selected Option A M&V Methods

The chapters in this section describe technology-specific M&V methods associated with Option A. Option A is one of the three M&V options that are defined for implementation of federal ESPC projects. The methods described here are for the more typical ECMs, such as lighting retrofits, and are representative of the range of methods available.

The M&V methods presented are summarized in the following Table:

Option A, M&V Methods Presented In Section II

Section/ Chapter	ECM	Method Number
II/5	Lighting Efficiency	LE-A-01 LE-A-02
II/6	Lighting Controls	LC-A-01 LC-A-02
II/7	Constant Load Motors Efficiency	CLM-A-01
II/8	Variable Speed Drive Retrofit	VSD-A-01
II/9	Chiller Replacements	CH-A-01 CH-A-02

SECTION II

Chapter 5

Measurement and Verification Plan (Option A)
Lighting Efficiency:
No Metering and Metering of Fixture Wattages Only
Methods LE-A-01 and LE-A-02

5.1 ECM Definition

The lighting ECM projects covered by this verification plan are:

- Retrofits of existing fixtures, lamps, and/or ballasts with an identical number of more energy-efficient fixtures, lamps, and/or ballasts; and

- Delamping with or without the use of reflectors.

These lighting efficiency projects cause a reduction in demand. However, the fixtures are assumed to have the same pre- and post-retrofit operating hours.

5.2 Overview of Verification Methods

Two verification methods are covered in this chapter. For both methods, the hours of operation are stipulated. The methods differ in how the fixture wattages are determined.

Surveys are required of existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

M&V Method LE-A-01 requires no metering of fixtures. Fixture wattages will be from a standard table unless other documentation, such as manufacturer data, is provided.

M&V Method LE-A-02 requires spot or short-term wattage measurements of a representative sample of baseline and post-installation fixtures or fixture circuits to establish demand. This method is more time consuming and expensive but may result in more accurate savings estimates if fixture wattage measurements are done carefully.

5.3 Calculation of Demand and Energy Savings

5.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. Room location of the equipment and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp and ballast types, usage area designations, counts of operating and non-operating fixtures, and whether the room is air conditioned and/or heated.

Method LE-A-01 - No Metering. Fixture wattages will be from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. In the event that a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) conduct instantaneous wattage measurements for a representative sample of fixtures or (b) provide an approved, documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures and documented manufacturers' data should be used for post-installation fixtures.

Method LE-A-02 - Fixture Wattage Metering. Fixture wattages will be measured. An example of a metering protocol is:

> The ESCO will take 15-minute, true RMS wattage measurements from at least six[12] fixtures representative of the baseline and post-installation fixtures. Readings will be averaged to determine per fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of +/- 2% of reading or better.

[12] Actual values may vary by application.

5.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** but which have broken lamps, ballasts, and/or switches that are **intended for repair**.

A delamped fixture is **not** a non-operating fixture, and delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility; e.g., 10%**. If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

5.3.3 Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency.

Method LE-A-01 - No Metering. Fixture wattages will be from a standard table unless other, approved, documentation is provided. See Section 5.3.1

Method LE-A-02 - Fixture Wattage Metering. Fixture wattages will be measured. See Section 5.3.1.

5.3.4 Operating Hours

Operating hours will be stipulated; i.e., agreed to by the federal agency and the ESCO. Sources of stipulated hours can be:

- Results from other projects in similar facilities;

- Studies of lighting operating hours;
- Building occupancy hours multiplied by a lighting load factor; and/or
- Pre-metering of representative areas by the ESCO or federal agency.

Operating hours should be defined for each unique usage group within a building or facility that is being retrofitted.

Usage groups are areas with similar operating hours (either annual operating hours, seasonal operating hours, or operating hours per the electric utility's time-of-use periods). Examples of usage groups are private offices, open offices, conference rooms, classrooms, and hallways. Within each group, the range of operating hours should be narrow. Each usage group type should have similar use patterns and comparable average operating hours.

5.4 Equations for Calculation of Energy and Demand Savings

5.4.1 Energy

To determine estimates of energy savings for lighting efficiency projects use the following equation:

$$kWh\ Savings_t = \sum_u \left[(kW/fixture_{baseline} \times Quantity_{baseline} - kW/Fixture_{post} \times Quantity_{post}) \times Hours\ of\ Operation \right]_{t,u}$$

Where:

kWh Savings =	kilowatt-hour savings realized during the post-installation time period *t*
$kW/fixture_{baseline}$ =	lighting baseline demand per fixture for usage group *u*
$kW/fixture_{post}$ =	lighting demand per fixture during post-installation period for usage group *u*
$Quantity_{baseline}$ =	quantity of affected fixtures before the lighting retrofit for usage group *u*, adjusted for inoperative and non-operative lighting fixtures.
$Quantity_{post}$ =	quantity of affected fixtures after the lighting retrofit for usage group *u*

Hours of Operation = number of operating hours during the time period t for the usage group u, assumes operating hours are the same before and after measure installation

5.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g. utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

5.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems. However, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings (or losses) associated with the interactive effects of lighting efficiency projects:

1. Ignore interactive effects;

2. Use agreed-to, "default" interactive values such as a 5% addition to lighting kWh savings to account for additional air conditioning saving; or

3. Calculate interactive affects on a site-specific basis.

Refer to Section 2.10 for more details on the various options.

5.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Site specific M&V plan and schedule.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes much of the same components as in the Project Pre-Installation Report, except it contains information on **actual** rather than expected measure installations.

5.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Identification of corresponding variables and specification of assumptions;
- Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling, site inspection and monitoring plan), if required; and
- Identification and resolution of any other M&V issues.

Specific M&V issues related to lighting efficiency that need to be addressed include:

- Decision whether to establish baseline fixture wattages at current efficiency standards;
- Designation of usage groups for defining stipulated lighting operating hours;

- Assessment of non-operating fixtures;
- Choice of methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of interactive impact approach.

In addition, Project Pre- and Post-Installation Reports should identify specific steps required to implement the M&V plan.

SECTION II

Chapter 6

Measurement and Verification Plan (Option A)
Lighting Controls:
No Metering and Metering of Fixture Wattages Only
Methods LC-A-01 and LC-A-02

6.1 ECM Definition

The lighting projects covered by this verification plan are:

- Installation of occupancy sensors or daylighting controls **without** any changes to fixtures, lamps, or ballasts; and

- Installation of occupancy sensors or daylighting controls **with** changes to fixtures, lamps, and/or ballasts.

These lighting controls projects cause a reduction in fixture operating hours.

6.2 Overview of Verification Methods

Two methods are covered in this chapter. For both methods, the baseline and post-installation fixture hours of operation are stipulated. The methods differ in how the fixture wattages are determined for lighting controls projects.

Surveys are required of existing (baseline) and new (post-installation) fixtures and lighting controls. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

M&V Method LC-A-01 requires no metering of fixtures. Fixture wattages will be from a standard table unless other documentation, such as manufacturer data, is provided.

M&V Method LC-A-02 requires spot or short-term wattage measurements of a representative sample of baseline and post-installation fixtures or fixture circuits to establish demand. This method is more time consuming and expensive but may result in more accurate savings estimates if fixture wattage measurements are done carefully.

6.3 Calculation of Demand and Energy Savings

6.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the existing lighting equipment and the controls (and lighting equipment to be changed, if an efficiency retrofit is to be done concurrently) are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp and ballast types; lighting control types; usage area designations; counts of operating and non-operating fixtures; and whether the room is air conditioned and/or heated.

Method LC-A-01 - No Metering. Fixture wattages will be from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. In the event that a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) conduct instantaneous wattage measurements for a representative sample of fixtures (i.e., Method LE-A-02) or (b) provide an approved, documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures, and documented manufacturers' data should be used for post-installation fixtures.

Method LC-A-02 - Fixture Wattage Metering. Fixture wattages will be measured. An example of a metering protocol is:

- The ESCO will take 15-minute, true RMS wattage measurements from at least six[13] fixtures representative of the baseline and post-

[13] Actual values may vary by application.

installation fixtures. Readings will be averaged to determine per fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of +/- 2% of reading or better.

6.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** and have broken lamps, ballasts, and/or switches that are **intended for repair.**

A delamped fixture is not a non-operating fixture, and thus delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or which are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility; e.g., 10%.** If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a fixture wattage of zero.

6.3.3 Post-Installation Demand

For projects that involve only lighting controls, the post-installation demand is assumed to equal the baseline demand.

For projects with lighting efficiency and control measures, however, the measurement or definition of connected load will occur after all energy-efficiency retrofits have been installed to avoid double-counting the savings. For these projects, the post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency.

Savings for combined energy efficiency and lighting control projects are defined within the equation presented in subsection 6.4 below.

6.3.4 Operating Hours

Baseline and post-installation operating hours will be stipulated; i.e., agreed to by the federal agency and the ESCO. Sources of stipulated hours can be:

- Building occupancy hours multiplied by a lighting load factor; and/or
- Pre-metering of representative areas by the ESCO or federal agency.
- Results from other projects in similar facilities;
- Studies of lighting operating hours;

Operating hours should be defined for each unique usage group within a building or facility that is being retrofitted.

Usage groups are areas with similar operating hours (either annual operating hours, seasonal operating hours, or operating hours per the electric utility's time of use periods). Examples of usage groups are private offices, open offices, conference rooms, classrooms, and hallways. Within each group the range of operating hours should be narrow. Each usage group should have similar use patterns and comparable average operating hours.

6.4 Equations for Calculation of Energy and Demand Savings

6.4.1 Energy

To avoid double counting of lighting efficiency and control projects, the savings equation for combined projects is defined as follows:

$$kWh\ Savings_t = \sum_u [\ (kW/fixture \times Quantity \times Hours\ of\ Operation)_{baseline} - (kW/fixture \times Quantity \times Hours\ of\ Operation)_{post}\ ]_{t,u}$$

Where:

kWh Savings$_t$ =	the kilowatt-hour savings realized during the post-installation time period *t*
kW/fixture$_{baseline}$ =	the lighting baseline demand per fixture for usage group *u*
kW/fixture$_{post}$ =	the lighting demand per fixture during post-installation period for usage group *u*
Quantity$_{baseline}$ =	the quantity of affected fixtures before the lighting retrofit adjusted for inoperative and non-operative lighting fixtures for usage group *u*
Quantity$_{post}$ =	the quantity of affected fixtures after the lighting retrofit adjusted for inoperative and non-operative lighting fixtures for usage group u
Hours of Operation $_{baseline}$ =	the total number of operating hours during the pre-installation period for usage group *u*
Hours of Operation $_{post}$ =	the total number of operating hours during the post-installation period for usage group *u*

The equation above is based on two separate equations for lighting efficiency and lighting control projects given below:

Savings for **energy efficiency lighting projects** are defined with the following equation:

$$kWh\ Savings_t = \sum_u \left([(kW/fixture \times Quantity)_{baseline} - (kW/fixture \times Quantity)_{post}] \times Hours\ of\ Operation_{post} \right)_{t,u}$$

Savings for **lighting control projects** are defined with the following equation:

$$kWh\ Savings_t = \sum_u [(Hours\ of\ Operation_{baseline} - Hours\ of\ Operation_{post}) \times (kW/fixture \times Quantity_{baseline})]_{t,u}$$

6.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g. utility summer peak period) divided by the hours in the time period.

Maximum demand reduction. with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

6.5 Interactive Effects

Lighting efficiency and controls projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems. The reduction in lighting load, however, may also increase space heating requirements. Three options exist for estimating savings associated with the interactive effects of lighting efficiency projects:

1. Ignore interactive effects;
2. Use agreed-to, "default" interactive values such as a 5% addition to lighting kWh savings to account for additional air conditioning saving; or
3. Calculate interactive affects on a site-specific basis. For more details on the various options refer to Section 2.10.

6.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes much of the same components as in the Project Pre-Installation Report, except it contains information on *actual* rather than expected measure installations.

6.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Identification of corresponding variables and specification of assumptions; Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required; and
- Identification and resolution of any other M&V issues.

Specific M&V issues related to lighting efficiency and controls projects that need to be addressed include:

- Decision whether to establish baseline fixture wattages at current efficiency standards;
- Avoidance of double-counting the savings from energy-efficiency projects that are controlled;

- Designation of usage groups for defining stipulated lighting operating hours;
- Assessment of non-operating fixtures;
- Choice of methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of interactive impact approach.

In addition, Project Pre- and Post-Installation Reports should identify specific steps required to implement the M&V plan.

SECTION II

Chapter 7

Measurement and Verification Plan (Option A)
Constant Speed Motor Efficiency:
Metering of Motor kW
Method CLM-A-01

7.1 ECM Definition

Constant speed motor efficiency projects involve the replacement of existing (baseline) motors with high efficiency motors that serve constant load systems. These ECMs are called constant load motor efficiency projects because the power draw of the motors does not vary over time. These projects cause a reduction in demand and energy use.

This M&V method is appropriate only for projects where constant load motors are replaced with similar capacity constant speed motors, with two exceptions:

- Baseline motors may be replaced with smaller high efficiency motors where the original motor was oversized for the load; and
- Constant speed motor drives may be adjusted to account for the difference in slip between the baseline motor and the high efficiency motor.

If motor changes are accompanied by a change in operating schedule, a change in flow rate, or the installation of variable speed drives, other M&V methods will be more appropriate.

7.2 Overview of Verification Method

Under Option A, Method CLM-A-01 is the only specified technique for verifying constant load motor efficiency projects. **This method assumes that the federal agency and ESCO are confident that the motors operate at a consistent load with a definable operating schedule that can be stipulated.**

Surveys are required to document existing (baseline) and new (post-installation) motors. The surveys should include (in a set format) for each motor:

- Nameplate data;
- Operating schedule
- Spot metering data;

- Motor application; and
- Location.

Metering is required on at least a sample of motors to determine average power draw for baseline and new motors. Demand savings are based on the average kW measured before minus the average kW measured after new motors are installed. Allowances for differences in motor slip between existing and new motors may be allowed. Baseline and post-installation hours of operation, used for calculating energy savings, will be stipulated.

7.3 Calculation of Demand and Energy Savings

7.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey; and
- Spot metering of existing motors.

Pre-Installation Equipment Survey. In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Motor surveys with location information and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, nameplate data, motor horsepower, load served, operating schedule, spot metering data, motor application, and location.

Sample survey forms are included in Appendix B. Table M1 is the pre-installation survey form.

Spot-Metering of Existing Motors. Instantaneous measurements of 3-phase amps, volts, PF, kVA, kW and motor speed in rpm should be recorded based on spot metering of each motor to be replaced. These data should be entered into a form such as Table M2 (in Appendix B). Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 1% of reading.[14]

[14] Gordon et. al. (Gordon, F.M. et. al. Impacts of Performance Factors on Savings From Motors Replacement and New Motor Programs. ACEEE 1994 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy. 1994.) reported that on the

Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device, as long as such location is identical for the baseline and post-installation measurements.

7.3.2 Adjustments to Baseline Demand

Prior to installation of new motors, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required due to factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating equipment, the party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is equipment that is **typically operating** but which has broken parts and is **intended for repair**.

7.3.3 Post-Installation Demand

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. The ESCO should enter the information in Table M1. After high-efficiency motors are installed, spot-metering will be conducted for all motors using the same meter and procedures used for the baseline motors. Enter the results in Table M2. See Section 7.3.1.

7.3.4 Changes in Load Factor (Slip)

Standard efficiency motors and high efficiency motors may rotate at different rates when serving the same load. Such differences in rotational speed, characterized as "slip" may lead to smaller savings than expected. Considerable impacts on savings due to slip may be reflected in the difference in load factor between the existing motor and a new high efficiency motor. Large differences in load factor between the existing motor and the replacement high-efficiency motor may be symptomatic of other problems as well. As such, the ESCO will identify motors for which the difference in load factor between the high efficiency

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average, for all qualifying motors, the change in efficiency between a standard efficiency motor and a high-efficiency motor, including an adjustment for slip, was 4.4%. As such, the resolution of meters used to measure instantaneous kW should be much smaller than 4.0%.

motor and the baseline motor is greater than 10%. If the load factor is outside that range, the ESCO will provide an explanation, with supporting calculations and documentation.

An acceptable reason for changes in load factor greater than 10% may be that the high-efficiency motor is smaller than the original baseline motor:

7.3.5 Operating Hours

Operating hours will be stipulated; i.e., agreed to by the federal agency and the ESCO. Sources of stipulated hours can be:

- Operation logs or documentation schedules from energy management systems; and/or
- Pre-metering of representative areas by the ESCO or federal agency.
- Results from other projects in similar facilities;
- Studies of motor operating hours;

Operating hours can be estimated for each individual motor or for groups of motors with similar applications and schedules. Examples of such motor groupings are supply fan motors, exhaust fan motors, and boiler circulating pump motors. Each group type should have similar use patterns and comparable average operating hours.

Baseline and post-installation operating hours may be different.

7.4 Equations for Calculation of Energy and Demand Savings

Calculate the kWh savings using the following equations:

<u>If operating hours are the same before and after measure installation:</u>

$$kWh\ Savings\ (per\ each\ period) = [Period\ Hours]\ X\ [kW\ Savings]$$

$$kW\ Savings = kW_{baseline} - kW_{post}$$

If operating hours are different before and after measure installation:

$$kWh\ Savings\ (per\ each\ period) = [Baseline\ Period\ Hours \times kW_{baseline}] - [Post\text{-}Installation\ Period\ Hours \times kW_{post}]$$

Where:

$kW_{baseline}$ = the kilowatt demand of the baseline motors

kW_{post} = the kilowatt demand of the high-efficiency motors

Period Hours = measured hours for a defined time segment, e.g. operating hours per year or hours per utility peak period.

These values may be corrected for changes in motor speed (slip) per Section 7.3.4.

Demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_t$$

Average demand reduction:

$$kW\ Savings_{avg} = \frac{kWh\ Savings}{Period\ Hours}$$

7.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data; and
- Projected budget, and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes much of the same components as in the Project Pre-Installation Report, except that it contains information on **actual** rather than expected measure installations.

7.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC contract between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Source of stipulated motor operating hours;
- Specification of data collection methods, schedule, duration, equipment, and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to constant load motors efficiency projects include:

- Operating hours for motors;
- Assessment of non-operating motors; and
- Method(s) to account for changes in motor loading (slip) between baseline and new motors.

SECTION II

Chapter 8

Measurement And Verification Plan (Option A)
Variable Speed Drive Motor Efficiency:
Metering of Motor kW
Method VSD-A-01

8.1 ECM Definition

Variable speed drive efficiency projects involve the replacement of constant speed (baseline) motor controllers with variable speed drive (VSD) motor controllers. These projects cause a reduction in demand and energy use but not necessarily a reduction in utility demand charges. VSD retrofits also often include installation of new, high-efficiency motors. Typical VSD applications include HVAC fans and boiler and chiller circulating pumps.

This M&V method is only appropriate for VSD projects in which, for the baseline and post-installation motors,:

- Electrical demand 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 of motor power draw; and,

- Operating hours as a function of operating scenario can be stipulated.

If the affected motor has a complex variable load profile and/or a complicated operating schedule, other M&V methods will be more appropriate.

8.2 Overview of Verification Method

Under Option A, Method VSD-A-01 is the only specified technique for verifying VSD projects. **This method assumes that the federal agency and ESCO are confident that the affected motors operate with a definable operating schedule that can be stipulated.**

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include (in a set format) for each motor and control device:

- Nameplate data;
- Operating schedule;
- Spot metering data;
- Motor application;
- Applicable end-use definitions; and/or
- Location.

Commissioning of VSD operation is expected.

Spot-metering is required on at least a sample of the existing motors to determine baseline motor power draw under different operating scenarios. Constant load motors may require only one spot measurement as the power draw does not vary with time or operating scenario. Operating scenarios may include different control valve or damper positions (for baseline) or motor speeds (for VSDs).

Post-installation spot-metering is required on at least a sample of motors with VSDs. Post installation spot-metering is done while the motors' applicable systems are modulated over their normal operating range (or range of motor speeds).

Demand and energy savings are based on:

- Baseline motor kW (calculated, if required, as a function of different operating scenarios);

- Post-installation motor kW calculated as a function of different operating scenarios; and

- Stipulated hours per year for each operating scenario.

8.3 Calculation of Demand and Energy Savings

8.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined either by the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey; and
- Spot metering of existing motors.

Pre-Installation Equipment Survey. In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. Motor location and corresponding facility floor plans should be included with the survey submittal. The surveys will include, in a set format, motor and motor control nameplate data, motor horsepower, load served, operating schedule, spot metering data, motor application, and location.

Spot-Metering of Existing Motors. Instantaneous measurements of 3-phase amps, volts, PF, kVA, kW and motor speed in rpm, should be recorded with spot-metering for each motor to be replaced. These data should be entered into a standard form. Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 2% of reading. Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device, as long as such location is identical for the baseline and post-installation measurements.

Multiple spot measurements are made while the affected systems are in each operating scenario in the normal operating range. For example, if there are inlet damper vanes affecting a fan motor, motor measurements are made while the dampers are in each possible position.

8.3.2 Adjustments to Baseline Demand

Prior to installation of new motors, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required due to factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating equipment, the party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is equipment that is **typically operating** but which has broken parts and is **intended for repair**.

8.3.3 Post-Installation Demand

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. After VSDs are installed, spot-metering will be conducted for all motors using the same meter and procedures used for the baseline motors, and the results will be entered in a standard survey form. See Section 8.3.1.

When recording the motor kW, the motor speed is also recorded. Direct motor rpm measurements can be made or readings can be taken from the VSD control panel.

The power draw of the motors with VSDs will vary depending on the speed of the motor being controlled. In addition, other factors, such as downstream pressure controls, will affect the power draw. With this M&V method, it is assumed that:

- Motor power draw can be defined with spot metering for specific operating scenarios; and
- Operating hours can be assigned to each operating scenario.

Savings for variable speed drive retrofits are defined within the equation presented in subsection 8.4.

8.3.4 Operating Hours

Operating hours will be stipulated; i.e., agreed to by the federal agency and the ESCO. Sources of stipulated hours can be:

- Operator logs or documented schedules from energy management systems; and/or
- Pre-metering of representative areas by the ESCO or federal agency
- Results from other projects in similar facilities;
- Studies of motor operating hours (for example, using bin weather data);

Operating hours can be estimated for each individual motor or for groups of motors with similar applications and schedules. Examples of such motor groupings are supply fan motors, exhaust fan motors, and boiler circulating pump motors. Each group type should have similar use patterns and comparable average operating hours.

Operating hours will be defined for each operating scenario. For example, it may be assumed that a VSD operates at 25% speed or 3 kW for 2,500 hours per year and 80% speed or 30 kW for 6,260 hours per year. See Section 8.4 for a sample format of operating hour assumptions.

Baseline and post-installation total operating hours may be different.

8.4 Equations for Calculation of Energy and Demand Savings

Calculate the kWh savings using the following equations:

$$kWh\ Savings\ (per\ each\ operating\ scenario) = [Operating\ Scenario\ Hours] \times [kW\ Savings\ per\ each\ operating\ scenario]$$

Where:

kW Savings	=	$kW_{baseline} - kW_{post}$
$kW_{baseline}$	=	the kilowatt demand of the baseline motor in a particular operating scenario
kW_{post}	=	the kilowatt demand of the high-efficiency motor in a particular operating scenario
Operating Scenario	=	a particular mode of operation such as motor speed or valve position
Operating Hours	=	stipulated hours for each operating scenario

Demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_{per\ operating\ scenario}$$

Average demand reduction:

$$kW\ Savings_{avg} = \frac{Annual\ kWh\ Savings}{Annual\ Operating\ Hours}$$

Table 8.1 contains a summary of example baseline and post-installation power draw measurements and savings calculations made using the above equations.

Table 8.1
Example Reporting Format

Scenario	Operating Hours/Year	Baseline kW Measured	Percent VSD Speed	Control Valve Position	Post-Installation kW Measured	kWh Savings
1	1,000	30	50%	50%	15	15,000
2	3,000	35	50%	100% open	12	69,000
3	1,500	35	60%	100% open	20	22,500
4	2,000	35	70%	100% open	25	20,000
5	1,000	35	80%	100% open	30	5,000
Totals	8,500					131,500

Average kW Savings	15.5
Maximum kW Savings	23

8.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes much of the same components as in the Project Pre-Installation Report, except it contains information on **actual** rather than expected measure installations.

8.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Source of stipulated motor operating hours;
- Specification of data collection methods, schedule, duration, equipment, and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to VSD projects include:

- Definition of operating scenarios for motors;
- Motor operating hours for each operating scenario;
- Assessment of non-operating motors; and
- Meter specifications and spot metering methodology.

SECTION II

Chapter 9

Measurement and Verification Plan (Option A)
Chiller Replacement:
Method CH-A-01, No Metering
Method CH-A-02, Verification of Chiller kW/ton

9.1 ECM Definition

This ECM involves chillers used for space conditioning or process loads. Projects can include:

- Existing chillers replaced with more energy efficient chillers; or

- Changes in chiller controls that improve chiller efficiency.

There are two M&V methods described in this Section. For method CH-A-01, the chiller efficiency (e.g. kW/ton) and the chiller load (e.g. tons per year) are stipulated. For method CH-A-02, the chiller efficiency is measured and the chiller load is stipulated. **Thus, these methods are only appropriate for projects in which the baseline and post-installation chiller efficiency and/or the chiller load can be defined and stipulated by the ESCO and federal agency.**

9.2 Overview of Verification Methods

Surveys are required to document existing (baseline) and new (post-installation) chillers and chiller auxiliaries (e.g., chilled water pumps and cooling towers). The surveys should include (in a set format) for each chiller and control device:

- Nameplate data;
- Chiller application; and
- Operating schedules.

Commissioning of chiller operation is expected.

Method CH-A-01 - No Metering. Baseline and post-installation chiller ratings (e.g., kW/ton, IPLV) are stipulated based on manufacturers' or other data. Annual cooling loads (e.g., annual or monthly ton-hours) are also stipulated. Energy savings are based on the product of (a) the difference between average baseline kW/ton and post-installation kW/ton and (b) cooling load in ton-hours.

Method CH-A-02 - Performance Measured. Baseline and post-installation chiller ratings (e.g., kW/ton, IPLV) are based on short-term metering of chiller kW (and perhaps auxiliary pump and cooling tower fan kW) and chiller load. Annual cooling loads (e.g., annual or monthly ton-hours) are stipulated. Energy savings are based on the product of (a) the difference between baseline kW/ton and post-installation kW/ton (possibly at each load rating) and (b) cooling load in ton-hours.

Methods CH-A-01 and CH-A-02 can be "mixed and matched" for the baseline chiller(s) and new chiller(s). For example, baseline chiller efficiency may be measured, and manufacturer's data can be used to stipulate performance ratings for the new chiller.

Baseline and post-installation chiller load can be different to account for changes in load during the term of the contract.

9.3 Calculation of Demand and Energy Savings

9.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey; and

- Either defining chiller efficiency (Method CH-A-01) or metering of existing chillers (Method CH-A-02).

Pre-Installation Equipment Survey. In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Chiller location and corresponding facility floor plans should be included with the survey submittal. The surveys will include, in a set format:

- Chiller and chiller auxiliaries nameplate data;
- Chiller age, condition, and ratings;
- Load served;
- Operating schedule;
- Chiller application; and
- Equipment locations.

Method CH-A-01 - Stipulated Chiller Efficiencies. For this simple M&V method, the chiller performance is stipulated; i.e., agreed to by the federal agency and the ESCO. The most common source of chiller performance data is the manufacturer. For existing chillers, the "nameplate" performance ratings may be downgraded based on the chillers' age and/or condition (e.g., fouling). Chiller efficiency can be presented in several formats depending on the type of load data that will be stipulated. Possible options include annual average kW/ton expressed as Integrated Part Load Value (IPLV)[15] or kW/ton per incremental cooling loads for the chiller(s) affected by the ECM.

Method CH-A-02 - Metering of Existing Chillers. For this M&V method, the baseline chiller efficiency is measured. The following data should be collected:

- Chiller kW;
- Chilled water flow, entering and leaving temperatures for calculating cooling load;
- Chiller circulating and condenser pumps kW (kWh) if they are to be replaced or modified; and
- Cooling tower fan(s) kW (kWh) if they are to be replaced or modified[16].

These data should be entered into a standard form. Such measurements should be made using a meter with an accuracy at or approaching ± 2% of reading. Multiple measurements are made while the cooling systems are operating at different loads so that the complete range of chiller performance can be evaluated. Optimally, baseline metering is performed during a period where a range of cooling loads exist (i.e. summer).

ASHRAE is preparing chiller measurement protocols (e.g., RP-827) which may be specified by the federal agency.

9.3.2 Post-Installation Demand

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency.

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[15] For example, per the appropriate standards of the Air-Conditioning and Refrigeration Institute
[16] Condenser pumps and cooling tower measurements are not involved in air cooled systems. Circulating pump measurements are not involved in DX systems. Condenser flows and temperatures can also be measured to check system energy balances. For DX systems air flows and temperatures (although more difficult than water system measurements) are measured to determine cooling load.

9.3.3 Cooling Load

Cooling load will be stipulated; i.e., agreed to by the federal agency and the ESCO. Sources of stipulated data can be:

- Calculations of cooling load (for example, using bin weather data or computer simulation programs such as DOE-2); or
- Pre-installation metering of cooling loads by the ESCO or federal agency.
- Results from other projects in similar facilities;

Baseline and post-installation cooling loads may be different.

9.4 Equations for Calculation of Energy and Demand Savings

Calculate the kWh savings using the following equations:

$$\textit{kWh Savings} = (\textit{Cooling Load in Ton-Hours}) \times (\textit{Baseline kW/ton} - \textit{Post-Installation kW/ton})$$

Where:

Cooling Load in Ton-Hours is stipulated and can be different for baseline and post-installation

Baseline kW/ton is the stipulated or measured existing chiller performance

Post-installation kW/ton is the stipulated or measured new chiller performance

Demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_{per\ cooling\ load}$$

Average Demand Reduction:

$$kW\ Savings_{avg} = \frac{\text{Annual kWh Savings}}{\text{Annual Operating Hours}}$$

Table 9.1 contains a summary of example baseline and post-installation power draw measurements and savings calculations (using the above equations).

Table 9.1
Example Reporting Format

Scenario	Operating Hours/Year	Stipulated Cooling Load tons	Baseline Chiller kW/ton	Post-Installation Chiller kW/ton	kWh Savings
1	1,000	400	1.0	0.7	120,000
2	3,000	350	1.1	0.8	315,000
3	1,500	300	1.2	0.9	135,000
4	2,000	200	1.3	1.0	120,000
5	1,260	0	NA		0 000
Totals	8,760				690,000

Average kW Savings	79 kW
Maximum kW Savings	120 kW

9.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. Additionally, the report includes much of the same components as the Project Pre-Installation Report, except this report contains information on **actual** rather than expected ELM installations.

9.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Source of stipulated chiller performance and/or cooling loads;
- Specification of data collection methods, schedule, duration, equipment, and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed and are related to chiller replacement projects include:

- Definition of operating scenarios;
- Cooling loads of the chillers at each operating mode; and
- Duration of monitoring.

SECTION III

Descriptions of Selected Option B M&V Methods

The chapters in this section contain descriptions of technology-specific M&V methods associated with Option B. Option B is one of the three M&V options that are defined for implementation of federal ESPC projects. The methods described here are for the more typical ECMs; e.g., lighting retrofits, and are representative of the range of methods available.

The M&V Methods presented are summarized in the following table:

Table III
Option B, M&V Methods Presented In Section III

Section/ Chapter	ECM	Method Number
III/10	Lighting Efficiency	LE-B-01
III/11	Lighting Efficiency	LE-B-02
III/12	Lighting Controls	LC-B-01
III/13	Lighting Controls	LC-B-02
III/14	Constant Load Motors Efficiency	CLM-B-01
III/15	Variable Speed Drive Retrofit	VSD-B-01
III/16	Chiller Replacements	CH-B-01 CH-B-02
III/17	Generic Variable Load Project	GVL-B-01

SECTION III

Chapter 10

Measurement and Verification Plan (Option B)
Lighting Efficiency:
Monitoring of Operating Hours
Method LE-B-01

10.1 Project Definition

The lighting projects covered by this verification plan are:

- Retrofits of existing fixtures, lamps, and/or ballasts with an identical number of more energy efficient fixtures, lamps, and/or ballasts; and

- Delamping with or without the use of reflectors.

These lighting efficiency projects cause a reduction in demand. However, the fixtures have the same pre- and post-retrofit operating hours.

10.2 Overview of Verification Method

This method is similar to Option A methods LE-A-01 and LE-A-02 in that surveys will be made of all baseline and post-installation lighting fixtures and that fixture wattages will be based on a standard table or measurements. This method differs in that instead of stipulating operating hours, the operating hours are measured throughout the term of the agreement, either at regular intervals or continuously.

Surveys are required of existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

Fixture wattages will be determined from:

- A table of standard wattages;
- Documentation on each fixture/ballast/lamp combination; and/or
- Measurements of representative fixtures or lighting circuits.

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures/rooms. The monitoring time period must be reasonable and account for any seasonal variations.

This chapter addresses one of two M&V methods under Option B for lighting efficiency projects. Method LE-B-01 requires pre- and post-installation equipment surveys in combination with post-installation metering of hours of operation to estimate savings. Chapter 11 addresses Method LE-B-02, which involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

10.3 Calculation of Demand and Energy Savings

10.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp, and ballast types; usage area designations; counts of operating and non-operating fixtures; and whether the room is air conditioned and/or heated.

Fixture wattages will be based on a table of standard fixture wattages or spot/short-term metering.

Wattage Table. Fixture wattages will be from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. In the event that a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) take wattage measurements for a representative sample of fixtures or (b) provide a documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures, and documented manufacturers' data should be used for post-installation fixtures.

Fixture Wattage Metering. Fixture wattages will be measured. An **example** of a metering protocol is as follows:

> The ESCO will take 15-minute, true RMS wattage measurements from at least six[17] fixtures representative of the baseline and post-installation fixtures. Readings will be averaged to determine per fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of +/- 2% of reading or better.

10.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** but that have broken lamps, ballasts, and/or switches that are **intended for repair**.

A delamped fixture is **not** a non-operating fixture, and thus delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for non-operating fixtures will be limited to some percentage of the total fixture count per facility, e.g. 10%**. If for example, more than 10% of the total number of fixtures are non-operating, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

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[17] Actual values may vary by application.

10.3.3 Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency. The same techniques as discussed in Section 10.3.1 can be used to inventory the installed equipment.

10.3.4 Operating Hours

Three key issues must be defined for how post-installation operating hours will be measured:

- The appropriate usage groups and sample sizes for metering each facility or group of similar facilities;
- Whether lighting circuit measurements or lighting loggers will be used; and
- How long the metering of operating hours will be conducted to determine a representative operating profile.

Usage Groups. Building usage areas will be identified for those areas with comparable average operating hours as determined by the lights in operation during the year or each of the electric utility's costing periods. Usage areas must be defined in a way that groups together areas that have similar occupancies and lighting operating hour schedules.

For each unique usage area, the ESCO or federal agency will develop a sampling plan to monitor the average operating hours of either a sample of fixtures or a sample of circuits. Sampling guidelines are provided in Appendix C.

Meters. The ESCO will specify the meter to be used in the site-specific measurement and verification plan. Measurements of operating hours are typically done with either:

- "Light Loggers," devices that measure the operating hours of individual fixtures through the use of photocells. A wide variety of products are available that store information that can be translated into either elapsed run times for fixtures (run-time loggers) or actual load profiles of on and off times for fixtures (time of use loggers); or

- Current or power measurements of lighting circuits that, when calibrated to the total connected lighting load on the circuit, can be used to determine how many fixtures were operating in terms of elapsed time or actual time of use load profiles.

The meter and recording device may be required to measure and record data indicating operating hours for each all utility time-of-use costing period. The ESCO must use a data logger that records status at frequent intervals (i.e., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available.

If the ESCO chooses to monitor circuits to determine average operating hours, the ESCO will use run-time or power recording meters that record the circuit on/off pattern in each utility costing period. The ESCO will ***not*** monitor circuits when the circuit serving the lighting retrofit load also serves other non-lighting loads that cannot be distinguished from the lighting load. Thus, only when lighting and non-lighting loads are separable, circuits may be monitored.

Period of Monitoring. Monitoring is intended to provide an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating hours estimates. Monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the monitoring installation period, the duration should be extended for as many days as the usage aberration.

If less than continuous monitoring is used, the lighting operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of **three weeks** is recommended for almost all usage area groups. For situations in which lighting might vary seasonally or according to a scheduled activity, such as classrooms, it may be necessary to determine lighting operation hours during different times of the year.

The ESCO-supplied site-specific measurement and verification plan will detail the agreed-to sample plan and monitoring plan.

10.4 Equations for Calculation of Energy and Demand Savings

For the year of installation payments, the ESCO will provide operating hour estimates for each usage area. These estimates must be realistic and documented.

Either the federal agency or ESCO will extrapolate results from the monitored sample to the population to calculate the average operating hours of the lights for every unique usage area. Simple, unweighted averages will be used for each usage area. The assigned party will apply these average operating hours to the baseline and post-installation demand for each usage area to calculate the respective energy savings and peak period demand savings for each usage area.

The annual baseline energy usage is the sum of the baseline kWh for all of the usage areas. The post-retrofit energy usage is calculated similarly. The energy savings are calculated as the difference between baseline and post-installation energy usage. The operating hours determined each post-installation year will be used for both the baseline and post-installation energy calculations.

10.4.1 Energy

The following equation can be used to determine estimates of energy savings for lighting efficiency projects:

$$kWh\ Savings_t = \sum_u \left[(kW/fixture_{baseline} \times Quantity_{baseline} - kW/Fixture_{post} \times Quantity_{post}) \times Hours\ of\ Operation \right]_{t,u}$$

Where:

$kWh\ Savings_t$ =	kilowatt-hour savings realized during the post-installation time period *t*
$kW/fixture_{baseline}$ =	lighting baseline demand per fixture for usage group *u*
$kW/fixture_{post}$ =	lighting demand per fixture during post-installation period for usage group *u*
$Quantity_{baseline}$ =	quantity of affected fixtures before the lighting retrofit adjusted for inoperative lighting fixtures for usage group *u*
$Quantity_{post}$ =	quantity of affected fixtures after the lighting retrofit for usage group *u* and time period *t*
Hours of Operation =	total number of post-installation operating hours (assumes number is the same before and after the lighting retrofit) for usage group *u*

10.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate and is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

10.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems. However, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects;
- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air conditioning saving; and
- Calculate interactive effects on a site-specific basis.

For more details on the various options refer to Section 2.10.

10.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;

- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except that it contains information on **actual** rather than expected ELM installations.

10.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC contract between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Identification of corresponding variables and specification of assumptions;
- Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling, site inspection and monitoring plan), if required; and,
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed related to lighting efficiency projects include:

- Establishment of baseline fixture wattages at current efficiency standards;
- Designation of usage groups and lighting operating hours sampling plans, including accounting for lost data and unique situations at the site that can affect measurements; e.g., double-switched lighting fixtures;
- Assessment of non-operating fixtures;
  Methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of approach for determining interactive savings.

In addition, Project Pre- and Post-Installation Reports should identify specific steps required to implement the M&V plan.

Chapter 11

Measurement and Verification Plan (Option B)
Lighting Efficiency:
Metering of Lighting Circuits
Method LE-B-02

11.1 Project Definition

The lighting projects covered by this verification plan are:

- Retrofits of existing fixtures, lamps and/or ballasts with an identical number of more energy efficient fixtures, lamps and/or ballasts

- Delamping with or without the use of reflectors

Lighting efficiency projects cause a reduction in demand. However, the fixtures have the same pre- and post-retrofit operating hours.

11.2 Overview of Verification Method

This M&V method involves measuring all, or a representative number of, lighting circuits for determining:

- Baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and average demand savings, and/or

- Baseline and post-installation electrical demand (kW) profiles in order to determine demand savings.

Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The post-installation metering time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

This chapter addresses one of two M&V methods under Option B for lighting efficiency projects. Method LE-B-01 requires pre- and post-installation equipment surveys in combination with post-installation monitoring of hours of operation for establishing savings. Method LE-B-02 involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

11.3 Calculation of Demand and Energy Savings

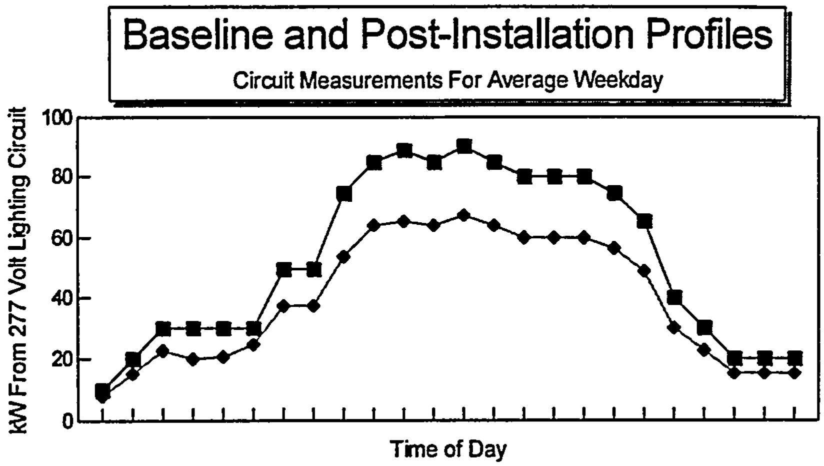
11.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, then the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

The basis for calculating energy and demand savings with this M&V method is circuit measurements. Equipment inventories, however, are strongly suggested for confirmation of proper equipment installation, as a check against circuit measurements, and as documentation for any changes that may be required in the definition of the baseline due to future retrofits or other changes. In addition, the survey is used to quantify non-operating fixtures for any required adjustments to the baseline and post-installation circuit measurements, as discussed below in Section 11.3.2.

Pre-Installation Equipment Survey. In a pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed for the facility or set of facilities under the project are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys should include, in a set format, fixture, lamp and ballast types; usage area designations, counts of operating and non-operating fixtures, and whether the room is air conditioned and/or heated.

Circuit Measurements. The concept of circuit measurements is to measure either power draw or current flow (as a proxy for power draw) on one or more circuits that have only (or primarily) lighting loads. The measurements are made before and after the lighting retrofit is completed. By comparing the power on the circuits before and after the retrofit, both energy and demand savings can be determined. The following figure is a comparison of average load profiles for a lighting circuit's energy draw before and after a retrofit. Such curves can be based on, for example, two weeks' worth of measurements that are averaged into a single daily baseline and post-installation profile.



The circuits must be carefully selected to ensure that:

- Only lighting loads that are affected by the retrofit are on the measured circuit(s) (typically 277 Volt circuits are used); or
- If other loads are on the circuit(s), the non-lighting loads should be minimal, well defined, and not vary from before to after the retrofit is complete.

If only a subset of affected lighting circuits are metered, the following issues must be addressed:

- Which lighting loads are on each lighting circuit;
- Which lighting circuits are representative of the entire facility, certain areas, or certain lighting usage groups; and
- The appropriate lighting circuit sample sizes.

Whether all or just a sample of circuits are metered it is important to specify how long the metering will be conducted in order to determine a representative baseline and post-installation operating profile.

For each facility, the ESCO or federal agency will develop a sampling plan for monitoring circuits. The sampling plan may concentrate measurements in areas with the greatest savings.

Meters. The ESCO will specify the meter to be used in the site-specific measurement and verification plan. Measurements of circuits are typically done with either:

- Current transducers connected to one or more legs of a lighting circuit. Current data measurements are taken over an extended period of time. Voltage and power factor data are taken as spot measurements and then assumed to be constant during the time period of the current metering. True RMS readings are preferred; or
- True RMS current and potential (voltage) transducers used to measure power continuously during the time period of circuit monitoring. This type of metering can be more accurate than just current measurement, but it is also more expensive.

The meter and recording device may be required to measure and record data for all utility time-of-use costing periods. The ESCO should use a data logger that records status at frequent intervals (i.e., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available to the federal agency.

Period of Monitoring. Metering is intended to provide an estimate of demand profiles and annual energy use. The duration and timing of the installation of circuit monitors have a strong influence on the accuracy of energy savings estimates. Metering should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the metering installation period, the duration of metering should be extended for as many days as the usage aberration.

If less than continuous metering is used, the energy use and demand profiles obtained during the metered period will be extrapolated to the full year. A minimum metering period of **three weeks** is recommended for almost all situations. For situations in which lighting might vary seasonally or according to a scheduled activity, such as class rooms, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific measurement and verification plan will detail the agreed-to sample plan and metering plan.

11.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** but have broken lamps, ballasts, and/or switches that are **intended for repair.**

A delamped fixture is **not** a non-operating fixture, and thus delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility; e.g., 10%.** If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

11.3.3 Post-Installation Demand

The post-installation conditions should be identified in the post-installation equipment survey, which is typically prepared by the ESCO and verified by the federal agency. The circuit measurements are then used to define post-installation demand and energy, as discussed above.

11.4 Equations for Calculation of Energy and Demand Savings

For the year of installation payments, the ESCO will provide energy and demand savings estimates. These estimates must be realistic and documented.

Either the federal agency or ESCO will extrapolate results from the metering data to determine demand and energy savings.

11.4.1 Energy

To determine estimates of energy savings for lighting efficiency projects use the following equation:

$$kWh\ Savings_t = (Average\ kWh_{baseline})_t - (Average\ kWh_{post})_t$$

Where:

$kWh\ Savings_t$ =	the kilowatt-hour savings realized during the time period *t,* where *t* can be a whole year, a week, weekdays, weekends, or a particular hour of the day
$(Average\ kWh_{baseline})_t$ =	the lighting baseline energy use averaged for all the time period *t* measurements
$(Average\ kWh_{post})_t$ =	the lighting post-installation energy use averaged for all the time period *t* measurements

Implicit in this equation is the assumption that baseline and post-installation lighting operating hours are the same.

11.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

11.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems; however, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects;

- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air conditioning saving; or

- Calculate interactive affects on a site-specific basis.

For more details on the various options refer to Section 2.10.

11.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except it contains information on **actual** rather than expected ECM installations.

11.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Identification of corresponding variables and specification of assumptions;
- Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed related to lighting efficiency projects include:

- Establishment of baseline fixture wattages at current efficiency standards;
- Selection of lighting circuits to be metered;
- Selection of metering equipment;
- Selection of time period for metering;
- Assessment of non-operating fixtures;
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of approach for determining interactive savings .

In addition, Project Pre- and Post-Installation Reports should identify specific steps required to implement the M&V plan.

SECTION III

Chapter 12

Measurement and Verification Plan (Option B)
Lighting Controls:
Monitoring of Operating Hours
Method LC-B-01

12.1 Project Definition

The lighting projects covered by this verification plan are installation of occupancy sensors of daylighting controls with or without changes to fixtures, lamps, or ballasts.

These lighting controls projects cause a reduction in fixture operating hours.

12.2 Overview of Verification Method

This method is similar to Option A methods LC-A-01 and LC-A-02 in that surveys will be made of all baseline and post-installation lighting fixtures and controls and that fixture wattages will be measured on a standard table of measurements. The difference is that instead of stipulating operating hours, the operating hours are measured throughout the term of the agreement either at regular intervals or continuously.

Surveys are required of existing (baseline) and new (post-installation) fixtures and controls. Corrections may be required for non-operating fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

Fixture wattages will be determined from :

- Measurements of representative fixtures or lighting circuits
- Documentation on each fixture/ballast/lamp combination; and/or
- A table of standard wattages;

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures/rooms. The monitoring time period must be reasonable and account for any seasonal variations.

This chapter addresses one of two M&V methods under Option B for lighting controls projects. Method LC-B-01 requires pre- and post-installation equipment surveys in combination with pre- and post-installation metering of hours of operation for establishing savings. Chapter 13 addresses Method LC-B-02, which involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

12.3 Calculation of Demand and Energy Savings

12.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed (if an efficiency retrofit is to be done concurrently) are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format, fixture, lamp, and ballast types; lighting controls; usage area designations; counts of operating and non-operating fixtures; and whether the room is air conditioned and/or heated.

Fixture wattages will be based on a table of standard fixture wattages or spot/short-term metering.

Wattage Table. Fixture wattages will be from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. In the event that a fixture is not in the table, the party conducting the pre-installation equipment survey should either (a) take wattage measurements for a representative sample of fixtures or (b) provide a documented source of the fixture wattages for approval by the other party.

In general, a standard table of fixture wattages should be used for the baseline fixtures, and documented manufacturers' data should be used for post-installation fixtures.

Fixture Wattage Metering. Fixture wattages will be measured. An **example** of a metering protocol is as follows:

> The ESCO will take 15-minute, true RMS wattage measurements from at least six[18] fixtures representative of the baseline and post-installation fixtures. Readings will be averaged to determine per fixture wattage values. For post-installation fixtures, readings should be taken only after the new fixtures have been operating for at least 100 hours. Meters used for this task will be calibrated and have an accuracy of +/- 2% of reading, or better.

12.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** but that have broken lamps, ballasts, and/or switches that are **intended for repair**.

A delamped fixture is **not** a non-operating fixture, and thus delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or that are broken and not intended for repair should not be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility, e.g. 10%**. If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

[18] Actual values may vary by application.

12.3.3 Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO and verified by the federal agency. The same techniques as discussed in Section 12.3.1 can be used to inventory the installed equipment.

12.3.4 Operating Hours

Three key issues must be defined for how operating hours will be measured (both before and after the control devices are installed):

- The appropriate usage groups and sample sizes for metering each facility or group of similar facilities;
- Whether lighting circuit measurements or lighting loggers will be used; and
- How long the metering of operating hours should be conducted to determine a representative operating profile.

Usage Groups. Building usage areas will be identified for those areas with comparable average operating hours as determined by the lights in operation during the year or each of the electric utility's costing periods. Usage areas must be defined in a way that groups together areas that have similar occupancies and lighting operating hour schedules.

For each unique usage area, the ESCO or federal agency will develop a sampling plan to monitor the average operating hours of either a sample of fixtures or a sample of circuits. Sampling guidelines are provided in Appendix C.

Meters. The ESCO will specify the meter to be used in the site-specific measurement and verification plan. Measurements of operating hours are typically done with either:

- "Light Loggers," devices that measure the operating hours of individual fixtures through the use of photocells. A wide variety of products are available that store information that can be translated into either elapsed run times for fixtures (run-time loggers) or actual load profiles of on and off times for fixtures (time-of-use loggers); or

- Current or power measurements of lighting circuits, which, when calibrated to the total connected lighting load on the circuit, can be used to determine how many fixtures were operating in terms elapsed time over a period of time or actual time of use load profiles.

The meter and recording device may be required to measure and record data for all utility time-of-use costing periods. The ESCO must use a data logger that records status at frequent intervals (i.e., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available to the federal agency.

If the ESCO chooses to monitor circuits to determine average operating hours, the ESCO will use run-time or power recording meters that record the circuit on/off pattern in each utility costing period. The ESCO will **not** monitor circuits when the circuit serving the lighting retrofit load also serves other non-lighting loads that cannot be distinguished from the lighting load. Thus, only when lighting and non-lighting loads are separable, circuits may be monitored.

Period of Monitoring. Monitoring is intended to provide an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the duration of monitoring should be extended for as many days as the usage aberration.

If less than continuous monitoring is used, the lighting operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of **three weeks** is recommended for almost all usage area groups. For situations in which lighting might vary seasonally or according to a scheduled activity, such as classrooms, it may be necessary to determine lighting operation hours during the different times of the year.

The ESCO supplied site-specific measurement and verification plan will detail the agreed-to sample plan and monitoring plan.

12.4 Equations for Calculation of Energy and Demand Savings

For the year of installation payments, the ESCO will provide operating hour estimates for each usage area. These estimates must be realistic and documented.

Either the federal agency or ESCO will extrapolate results from the monitored sample to the population to calculate the average operating hours of the lights for every unique usage area. Simple, unweighted, averages will be used for each usage area. The assigned party will apply these average operating hours to the baseline and post-installation demand for each usage area to calculate the respective energy savings and peak period demand savings for each usage area.

The annual baseline energy usage is the sum of the baseline kWh for all of the usage areas. The post-retrofit energy usage is calculated similarly. The energy savings are calculated as the difference between baseline and post-installation energy usage. The operating hours determined each post-installation year will be used for both the baseline and post-installation energy calculations.

To avoid double-counting the savings from energy-efficiency projects that also have lighting control projects applied, the ESCO will meter the pre-installation and post-installation controlled hours of operation as the basis for calculating lighting efficiency savings. See below for calculations.

12.4.1 Energy

To avoid double counting of lighting efficiency and control projects' savings, the savings equations for both types of projects are combined into a single equation:

$$kWh\ Savings_t = \sum_u [\ (kW/fixture \times Quantity \times Hours\ of\ Operation)_{baseline} - (kW/fixture \times Quantity \times Hours\ of\ Operation)_{post}\ ]_{t,u}$$

Where:

$kWh\ Savings_t$ =	kilowatt-hour savings realized during the post-installation time period *t*
$kW/fixture_{baseline}$ =	lighting baseline demand per fixture
$kW/fixture_{post}$ =	lighting demand per fixture during post-installation period for usage group u
$Quantity_{baseline}$ =	the quantity of affected fixtures before the lighting retrofit adjusted for inoperative and non-operative lighting fixtures for usage group *u*

Quantity$_{post}$ = quantity of affected fixtures after the lighting retrofit for usage group *u*

Hours of Operation $_{baseline}$ = total number of operating hours during the pre-installation period for usage group *u*

Hours of Operation $_{post}$ = total number of operating hours during the post-installation period for usage group *u*

This equation is based on:

Savings for **energy efficiency lighting projects** as defined in the following equation:

$$kWh\ Savings_t = \Sigma_u\ \left([(kW/fixture \times Quantity)_{baseline} - (kW/fixture \times Quantity)_{post}] \times Hours\ of\ Operation_{post} \right)_{t,u}$$

Savings for **lighting control projects** as defined in the following equation:

$$kWh\ Savings_t = \Sigma_u\ [(Hours\ of\ Operation_{baseline} - Hours\ of\ Operation_{post}) \times (kW/fixture \times Quantity_{baseline})]_{t,u}$$

12.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction with respect to cost savings, is typically the reduction in utility meter maximum demand under terms and conditions specified by the servicing utility. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define (a) how the reduction will affect the utility bill and (b) how the demand reduction will be calculated for purposes of payments to ESCOs.

12.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems; however, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects;

- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air conditioning saving; or

- Calculate interactive affects on a site-specific basis.

For more details on the various options refer to Section 2.10.

12.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as the Project Pre-Installation Report, except it contains information on **actual** rather than expected ECM installations.

12.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Identification of corresponding variables and specification of assumptions;
- Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling site inspection, and monitoring plan), if required; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed related to lighting efficiency projects include:

- Decision whether to establish baseline fixture wattages at current efficiency standards;
- Avoiding double-counting the savings from energy-efficiency projects that are controlled;
- Designation of usage groups and lighting operating hours sampling plans, including accounting for lost data and unique situations at the site that can affect measurements; e.g., double-switched lighting fixtures;
- Assessment of non-operating fixtures;
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of approach for determining interactive savings..

SECTION III

Chapter 13

Measurement and Verification Plan (Option B)
Lighting Controls:
Metering of Lighting Circuits
Method LC-B-02

13.1 Project Definition

The lighting projects covered by this verification plan are installation of occupancy sensors of daylighting controls with or without changes to fixtures, lamps, or ballasts.

These lighting controls projects cause a reduction in fixture operating hours.

13.2 Overview of Verification Method

This M&V method involves measuring all, or a representative number of, lighting circuits for determining:

- Baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and average demand savings; and/or

- Baseline and post-installation electrical demand (kW) profiles in order to determine demand savings.

Circuit measurements may be made of current flow (amperage) or power draw (wattage) per unit of time. The post-installation metering time period may be continuous or for a reasonable, limited period of time during each contract year.

Surveys are suggested for existing (baseline) and new (post-installation) fixtures. Corrections may be required for non-operating baseline fixtures. Light level requirements may be specified for projects that involve reducing lighting levels.

This chapter addresses one of two M&V methods under Option B for lighting controls projects. Method LC-B-02 involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings. The previous chapter addresses Method LC-B-01, which requires pre- and post-installation equipment surveys in combination with baseline and post-installation monitoring of hours of operation for establishing savings.

13.3 Calculation of Demand and Energy Savings

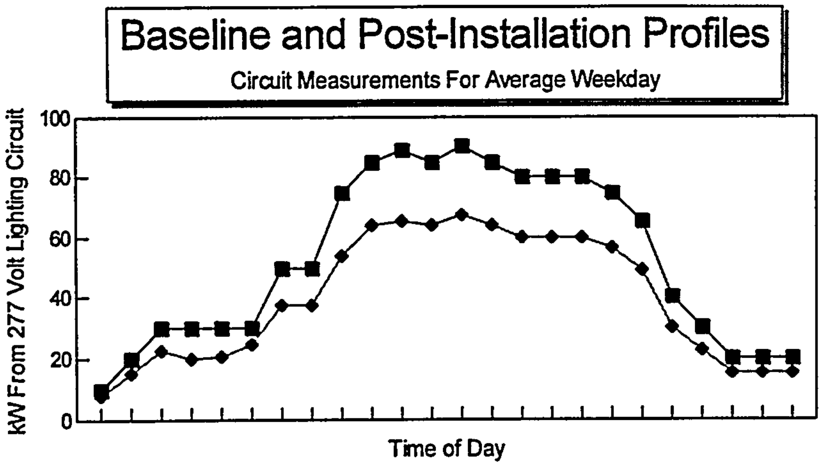
13.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey may be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

The basis for calculating energy and demand savings with this M&V method is circuit measurements. Equipment inventories, however, are strongly suggested for confirmation of proper equipment installation, a check against circuit measurements, and as documentation for any changes that may be required in the definition of the baseline due to future retrofits or other changes. In addition, the survey is used to quantify non-operating fixtures for any required adjustments to the baseline and post-installation circuit measurements, as discussed below in Section 13.3.2.

Pre-Installation Equipment Survey. In a pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed for the facility or set of facilities under the project are inventoried. Room location and corresponding building floor plans should be included with the survey submittal. The surveys should include, in a set format, fixture, lamp and ballast types, usage area designations, counts of operating and non-operating fixtures, and whether the room is air conditioned and/or heated.

Circuit Measurements. The concept of circuit measurements is to measure either power draw or current flow (as a proxy for power draw) on one or more circuits that have only (or primarily) lighting loads. Measurements are made before and after the lighting retrofit is completed. By comparing the power on the circuits before and after the retrofit, both energy and demand savings can be determined. The following figure is a comparison of average load profiles for the energy draw of a lighting circuit before and after a retrofit. Such curves can be based on, for example, two weeks' worth of measurements that are averaged into a single daily baseline and post-installation profile.



The circuits must be carefully selected to ensure that:

- Only lighting loads that are affected by the retrofit are on the measurement circuit(s) (typically 277 Volt circuits are used); or
- If other loads are on the circuit(s), the non-lighting loads should be minimal, well defined, and not vary from before to after the retrofit is complete.

If only a subset of affected lighting circuits are metered, the following issues must be addressed:

- Which lighting loads are on each lighting circuit;
- Which lighting circuits are representative of the entire facility, certain areas, or certain lighting usage groups;
- The appropriate lighting circuit sample sizes; and

Whether all or just a sample of circuits are metered it is important to specify how long the metering will be conducted in order to determine a representative baseline and post-installation operating profile.

For each facility, the ESCO or federal agency will develop a sampling plan for monitoring circuits. The sampling plan may concentrate measurements in areas with the greatest savings.

Meters. The ESCO will specify the meter to be used in the site-specific measurement and verification plan. Measurements of circuits are typically done with either:

- Current transducers connected to one or more legs of a lighting circuit. Current data measurements are taken over an extended period of time. Voltage and power factor data are taken as spot measurements and then assumed to be constant during the time period of the current metering. True RMS readings are preferred; or

- True RMS current and potential (voltage) transducers are used to measure power continuously during the time period of circuit monitoring. This type of metering can be more accurate than just current measurement, but it is also more expensive.

The meter and recording device may be required to measure and record data for all utility time of use costing periods. The ESCO should use a data logger that records status at frequent intervals (i.e., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available.

Period of Metering. Metering is intended to provide an estimate of demand profiles and annual energy use. The duration and timing of the installation of circuit metering have a strong influence on the accuracy of energy savings estimates. Metering should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the metering installation period, the duration of metering should be extended for as many days as the usage aberration.

If less than continuous metering is used, the energy use and demand profiles obtained during the monitored period will be extrapolated to the full year. A minimum metering period of **three weeks** is recommended for almost all situations. For situations in which lighting might vary seasonally or according to a scheduled activity, such as class rooms, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific measurement and verification plan will detail the agreed-to sample plan and metering plan.

13.3.2 Adjustments to Baseline Demand

Prior to installation of new lighting fixtures, adjustments to the baseline demand may be required for non-operating fixtures. In addition, after ECM installation, adjustments to baseline demand may be required because of remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating fixtures, the party responsible for defining the baseline will also identify any non-operating fixtures. Non-operating fixtures are those that are **typically operating** but that have broken lamps, ballasts, and/or switches that are **intended for repair**.

A delamped fixture is **not** a non-operating fixture, and thus delamped fixtures should have their own unique wattage designations. Fixtures that have been disabled or delamped or that are broken and not intended for repair should **not** be included in the calculation of baseline demand or energy. They should, however, be noted in the lighting survey to avoid confusion.

For non-operating fixtures, the baseline demand may be adjusted by using values from the standard table of fixture wattages or from fixture wattage measurements. **The adjustment for inoperative fixtures will be limited to some percentage of the total fixture count per facility; e.g., 10%.** If, for example, more than 10% of the total number of fixtures are inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero.

13.3.3 Post-Installation Demand

The post-installation conditions should be identified in the post-installation equipment survey, which is typically prepared by the ESCO and verified by the federal agency. The circuit measurements are then used to define post-installation demand and energy, as discussed above.

13.4 Equations for Calculation of Energy and Demand Savings

For the year of installation payments, the ESCO will provide energy and demand savings estimates. These estimates must be realistic and documented.

Either the federal agency or ESCO will extrapolate results from the metering data to determine demand and energy savings.

13.4.1 Energy

To determine estimates of energy savings for lighting controls projects use the following equation:

$$kWh\ Savings_t = (Average\ kWh_{baseline})_t - (Average\ kWh_{post})_t$$

Where:

kWh Savings $_t$ =	the kilowatt-hour savings realized during the time period *t*, where *t* can be a whole year, a week, weekdays, weekends, or a particular hour of the day
(Average kWh $_{baseline}$ *)* $_t$ =	the lighting baseline energy use averaged for all the time period *t* measurements
(Average kWh $_{post}$ *)* $_t$ =	the lighting post-installation energy use averaged for all the time period *t* measurements

Implicit in this equation is the assumption that baseline and post-installation lighting operating hours are the same.

13.4.2 Demand

Demand savings can be calculated as either an average reduction in demand or as a maximum reduction in demand.

Average reduction in demand is generally easier to calculate. It is defined as kWh savings during the time period in question (e.g., utility summer peak period) divided by the hours in the time period.

Maximum demand reduction is the largest reduction in demand that occurs from the retrofit during a specified period of time. For peak load reduction, for example, the maximum demand reduction may be defined as the maximum kW reduction averaged over 30-minute intervals during the utility's summer peak period. The maximum demand reduction is usually calculated to determine savings in utility peak demand charges. Thus, if utility demand savings are to be determined, each site must define how the reduction will affect the utility bill and how the demand reduction will be calculated for purposes of payments to ESCOs.

13.5 Interactive Effects

Lighting efficiency projects may have the added advantage of saving more electricity by reducing loads associated with space conditioning systems; however, the reduction in lighting load may also increase space heating requirements. Three options exist for estimating savings or losses associated with the interactive effects of lighting efficiency projects:

- Ignore interactive effects;

- Use agreed-to, "default" interactive values such as a 5% adder to lighting kWh savings to account for additional air conditioning savings; or

- Calculate interactive affects on a site-specific basis.

For more details on the various options refer to Section 2.10.

13.6 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except it contains information on **actual** rather than expected ECM installations.

13.7 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
  Identification of corresponding variables and specification of assumptions;
- Identification of data sources and/or collection techniques;
- Specification of data collection (i.e., sampling, site inspection, and monitoring plan), if required; and,
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed related to lighting efficiency projects include:

- Establishment of baseline fixture wattages at current efficiency standards;
- Avoiding double counting the savings from energy-efficiency projects that are controlled;
- Selection of lighting circuits to be metered:
- Selection of metering equipment;
- Selection of time period for metering;
- Assessment of non-operating fixtures;
- Methods to account for changes to baseline and post-installation fixture counts and types due to remodels; and
- Identification of approach for determining interactive savings.

In addition, Project Pre- and Post-Installation Reports should identify specific steps required to implement the M&V plan.

SECTION III

Chapter 14

Measurement and Verification Plan (Option B)
Constant Load Motors Efficiency[19]:
Metering of Operating Hours
Method CLM-B-01

14.1 ECM Definition

Constant load motor efficiency projects involve the replacement of existing (baseline) motors with high efficiency motors that serve constant load systems. These ECMs are called constant load motor efficiency projects because the power draw of the motors does not vary over time. These projects cause a reduction in demand and energy use.

This M&V method is appropriate only for projects in which constant load motors are replaced with similar capacity constant speed motors, with two exceptions:

1. Baseline motors may be replaced with smaller high efficiency motors when the original motor was oversized for the load; and
2. Constant speed motor drives may be adjusted to account for the difference in slip between the baseline motor and the high efficiency motor.

If motor changes are accompanied by a change in operating schedule, a change in flow rate, or the installation of variable speed control, other M&V methods are more appropriate.

14.2 Overview of Verification Method

Under Option B, Method CLM-B-01 is the only specified technique for verifying constant load motors efficiency projects. Surveys are required to document existing (baseline) and new (post-installation) motors. The surveys should include (in a set format) for each motor:

- Nameplate data;
- Operating schedule;
- Spot and short-term metering data;

[19] This chapter was prepared with methods developed by Jay Stein and Jack Wolpert of E-Cube, Inc., Boulder, CO

- Motor application definitions; and
- Location.

Metering is required on at least a sample of motors to determine average power draw for baseline and new motors. Demand savings are based on the average kW measured before, minus the average kW measured after, new motors are installed. Allowances for differences in motor slip between existing and new motors may be allowed.

Operating hours for the baseline and/or post-installation periods will be determined with short-term or long-term metering on at least a sample of motors. In addition, the metering can be used to (a) confirm constant loading and (b) determine average motor power draw (if normalization is required).

14.3 Calculation of Demand and Energy Savings

14.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey;
- Spot metering of existing motors; and
- Short-term metering of existing motors.

The equipment survey is described in this sub-section. The spot and short-term metering discussion is located separately in Section 14.5, as these types of metering activities are also required during the post-installation period.

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Motor location and corresponding building floor plans should be included with the survey submittal. The surveys will include, in a set format:

- Nameplate data;
- Motor horsepower;

- Load served;
- Operating schedule;
- Spot and short-term metering data (3-phase amps, volts, PF, kVA, kW and motor speed in rpm);
- Motor application; and
- Location.

Sample survey forms are included in Appendix B. Table M1 is the pre-installation survey form.

The spot metering is for measuring instantaneous power draw of the motors. The short-term metering is used for establishing that the motor load is constant, to determine "normalizing factors" for motor power draw, and possibly for determining operating hours.

14.3.2 Adjustments to Baseline Demand

Prior to installation of new motors, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required due to factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating equipment, the party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is equipment that is **typically operating** but that has broken parts and is **intended for repair**.

14.3.3 Baseline Operating Hours

Baseline motor operating hours can either be:

- Determined **prior** to ECM installation if the hours are assumed to be different than post-installation operating hours; or
- Determined **after** ECM installation if the hours are assumed to be the same as post-installation operating hours.

Short-term or long-term metering will be used to determine operating hours as discussed in Section 14.6.

14.3.4 Post-Installation Demand

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. After high-efficiency motors are installed:

- All the motors will be surveyed using the same reporting format as used for the baseline motors; and
- All motors should be spot metered using the same meter and procedures used for the baseline motors.

See Section 14.3.1 for details.

Where existing motors were short-term metered, their replacement, high-efficiency motors will also be subject to short-term metering. The data need only be processed for the purpose of normalizing the spot-metering results (as discussed in Section 14.5). There is no need to verify that the motor load is constant for the high efficiency motors.

14.3.6 Post-Installation Operating Hours

Post-installation operating hours either can be assumed to be the same as or different than the pre-installation operating hours. If the hours are assumed to be the same before and after the new motors are installed, either pre-installation or post-installation monitoring can be used. If the hours are assumed to be different, however, post-installation monitoring must also be done. Typically, where hours are the same before and after installation, post-installation monitoring will be used because motor installation can proceed without delay due to monitoring.

Operating hours monitoring is discussed in Sections 14.6.

14.4 Changes in Load Factor and Slip

Standard efficiency motors and high efficiency motors may rotate at different rates when serving the same load. Such differences in rotational speed, characterized as "slip," may lead to smaller savings than expected. Considerable impacts on savings due to slip may be reflected in the difference in load factor between the existing motor and a new high efficiency motor. Large differences in load factor between the existing motor and the replacement high-efficiency motor may also be symptomatic of other problems. As such, the ESCO will identify motors for which the difference in load factor between the high efficiency motor and the baseline motor is greater than 10%. If the load factor is outside that range, the ESCO will provide an explanation, with supporting calculations and documentation.

Acceptable reasons for changes in load factor greater than 10% may include these factors:

- The high-efficiency motor is smaller than the original baseline motor. The ESCO will provide documentation that demonstrates that the difference in load factor is due to differences in motor size.
- Because the high-efficiency motor exhibits less slip and it is operating at a higher operating speed than the baseline motor. The ESCO will provide calculations and documentation that demonstrate that the change in slip accounts for the difference in load factor. (On centrifugal loads, changes in RPM are governed by the "cube-law.") The ESCO is encouraged to account for slip when selecting motors and preparing initial savings calculations or modifying motor drive systems where appropriate.

14.5 Spot and Short-Term Metering

14.5.1 Spot-Metering

For each baseline and new motor spot-metering (i.e. instantaneous measurements) of volts, amperes, kVA, PF and kW should be recorded. These data should be entered into a form such as Table M2 (in Appendix B). Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 1% of reading.[20] Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device as long as the location is identical for the baseline and post-installation measurements.

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[20] Gordon et. al. (Gordon, F.M. et. al. Impacts of Performance Factors on Savings From Motors Replacement and New Motor Programs. ACEEE 1994 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy. 1994.) reported that on the average, for all qualifying motors, the change in efficiency between a standard efficiency motor and a high-efficiency motor, including an adjustment for slip, was 4.4%. As such, the resolution of meters used to measure instantaneous kW should be much smaller than 4.0%.

14.5.2 Short-Term Metering

The ESCO will conduct short-term monitoring to:

- Verify that motor loads are constant (baseline only);
- Normalize spot-metering kW measurement results; and
- Determine operating hours, as discussed in Section 14.6.

The ESCO will conduct short-term metering on all baseline and new motors or a randomly selected sample of motors with the same application and/or operating hours. Short-term metering should be summarized in a form such as Table M3 in Appendix B. Sample selection and results of metering for the entire sample are summarized in format such as shown in Table M4.

ESCOs may conduct short-term metering using current transducers and data loggers. The equipment for short-term metering need only be accurate within ±5% of full scale but must be calibrated against the spot-metering equipment specified above by taking spot-metering readings at the same time. Thus, short-term metering equipment must be installed at the same time spot-metering readings are being taken. Data loggers will record readings on intervals of 15 minutes or less.

The transducer installation and calibration report and data logger reports in Appendix A should be completed as part of this metering activity.

Verify Constant Load. The ESCO will verify that motor loads are constant by comparing the short-term metering period average amps to all hourly non-zero values. An application will be verified to be constant if 90% of all non-zero observations are within ±10% of the average amps determined above. The ESCO will record the number of non-zero observations, the number of observations within ±10% of the average amperes determined above, and the percent of observations within ±10% of the average amperes. If any application cannot be verified for constant load, the ESCO will examine the collected data to determine whether the load for the motor varies on a systematic and predictable basis, whether the constant load was changed during the test period, or whether there is some system anomaly.

If the load varies on a systematic basis, the motor will be treated as a variable load. If the load was changed during the short-term monitoring period, the spot-metering and short-term monitoring testing will be repeated. If a system anomaly is discovered, the ESCO will investigate the anomaly to determine whether there is a logical explanation. Once the anomaly is understood, the ESCO will either treat the load as a variable load or re-test as a constant load.

Normalize Spot-Metering kW Measurement Results. To determine the average power draw of the replaced or new motors, the spot kW measurements must be adjusted and normalized using short-term measurement data. To develop factors to normalize spot-metering wattage measurements, the ESCO will initiate short-term metering by taking measurements at the same moment as the spot metering. The ESCO will enter the spot values in Table M3, in the row titled "Instantaneous Amps." At the conclusion of the short-term metering period, the ESCO will determine the average ampere value during times of motor operation; i.e., the sum of all non-zero observations divided by the number of observations. The ESCO will also enter this value in Table M3. The ESCO will then calculate the "Normalizing Factor" with the following equation:

$$\textit{Normalizing Factor} = \frac{\textit{Average Amps measured during short-term metering}}{\textit{Instantaneous Amps measured with spot metering}}$$

During the short term metering, the ESCO will test each motor by modulating the applicable systems over their normal operating range (e.g., low cooling load to peak cooling load, economizer operation, low heating load to peak heating load, minimum output of process product to peak output of process product). Such testing will serve to verify (or not) that over the full range of normal system operation, motor load remains fairly constant.

For each motor replaced, the ESCO will then calculate average or normalized kW, using the following equation:

$$\textit{Normalized kW} = \textit{Instantaneous kW} \times \textit{Normalizing Factor}$$

For motors that were not subject to short-term metering, the Normalizing Factor is equivalent to the average Normalizing Factor developed for the motor sample of the same application (Table M4).

14.6 Monitoring For Determining Operating Hours

Operating hours may be the same before and after the new motors are installed, or the hours may be different. Operating hours for the baseline and/or post-installation periods will be determined with short-term or long-term monitoring on at least a sample of motors.

The ESCO will conduct short-term monitoring for a period of time to be specified in the site-specific measurement and verification plan. The period of time will be proposed by the ESCO and approved or modified by the federal agency.

Monitoring is intended to provide an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operation hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the duration should be extended for as many days as the usage aberration.

If less than continuous monitoring is used, the operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of **three weeks** is recommended for almost all usage area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to determine operating hours during different times of the year.

14.7 Sampling

The ESCO will spot meter all of the motors. However, the short- or long-term metering for determining (a) that the load is constant, (b) normalizing factors and (c) monitoring operating hours may only need to be done for a sample of motors.

ESCOs will begin their sampling analyses with a classification of existing motors by applications with identical operating characteristics and/or expected operating hours. Examples of applications include: HVAC constant volume supply fans, cooling water pumps, heating water pumps, condenser water pumps, HVAC constant volume return fans, and exhaust fans. Each application will be defined and supported with schematics of ductwork and/or piping, as well as control sequences to demonstrate that the application qualifies as a constant load.

For each application or usage group in the ESCO's program, there must be at least one motor subject to short-term metering.

14.8 Equations for Calculation of Energy and Demand Savings

Normalized kW can be calculated using the following equation:

$$kW_{normalized} = \textit{Instantaneous kW (from spot metering)} \times \textit{Normalizing Factor}$$

Calculate the kWh savings using the following equations:

If operating hours are the same before and after measure installation:

kWh Savings (per each period) = [Period Hours] X [kW baseline, normalized - kW post normalized]

If operating hours are different before and after measure installation:

$$kWh\ Savings\ (per\ each\ period) =$$

$$Baseline\ Period\ Hours \times kW_{baseline,\ normalized} -$$

$$Post\text{-}Installation\ Period\ Hours \times kW_{post,\ normalized}$$

Where:

$kW_{baseline,\ normalized}$ =	the normalized kilowatts for the baseline motors
$kW_{post,\ normalized}$ =	the normalized kilowatts for the high-efficiency motors
Period Hours =	measured hours for a defined time segment, e.g. operating hours per year or hours per utility peak period.

These values may be corrected for changes in motor speed (slip) per Section 14.4.

Demand savings may be calculated as:

Maximum demand reduction

$$kW\ Savings_{max} = (kW_{baseline,\ normalized} - kW_{post,\ normalized})_t$$

Average demand reduction

$$kW\ Savings_{avg} = \frac{kWh\ Savings\ Per\ Period}{Period\ Hours}$$

14.9 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as the Project Pre-Installation Report, except it contains information on **actual** rather than expected ECM installations.

14.10 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Source of stipulated motor operating hours;
- Specification of site survey plan;
- Specification of data collection methods, schedule, duration, equipment ,and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to constant load motors efficiency projects include:

- Method for determining operating hours;
- Short-term metering strategy, including usage groups, sampling plan, period of metering and type(s) of meters and data logger(s) to be used;
- Assessment of non-operating motors; and
- Method(s) to account for changes in motor loading (slip) between baseline and new motors.

SECTION III

Chapter 15

Measurement and Verification Plan (Option B)
Variable Speed Drive Retrofit:
Continuous Post-Installation Metering
Method VSD-B-01

15.1 ECM Definition

Variable speed drive efficiency projects involve the replacement of existing (baseline) motor controllers with variable speed drive (VSD) motor controllers. These projects cause a reduction in demand and energy use but not necessarily a reduction in utility demand charges. VSD retrofits also often include the installation of new, high-efficiency motors. Typical VSD applications include HVAC fans and boiler and chiller circulating pumps.

This M&V method is only appropriate for VSD projects in which, for the baseline and post-installation motors:

- Electrical demand as a function of operating scenarios, e.g. damper position for baseline or motor speed for post-installation, can be defined with spot measurements of motor power draw; and

- Operating hours as a function of different motor operating scenarios can be measured.

15.2 Overview of Verification Method

Under Option B, Method VSD-B-01 is the only specified technique for verifying VSD projects.

Surveys are required to document existing (baseline) and new (post-installation) motors and motor controls (e.g., motor starters, inlet vane dampers, and VSDs). The surveys should include (in a set format) for each motor and control device:

- Nameplate data;
- Operating schedule;
- Spot metering data;
- Motor application; and
- Location.

Commissioning of VSD operation is expected.

Metering is required on at least a sample of the existing motors to determine baseline motor power draw. Constant load motors may require only short term metering to confirm constant loading. For baseline motors with variable loading, the short term metering is done while the motors' applicable systems are modulated over their normal operating range. For variable load baseline motors, an average kW demand or a kW demand profile as a function of appropriate independent variables (e.g., outside air temperature) may be used for calculating baseline energy use. If baseline independent variable values are required for calculating the baseline, they will be monitored during the post-installation period.

Post-installation metering is required on at least a sample of motors with VSDs.

Baseline demand and energy use are based on:

- Motor operating hours which are measured before or after the VSDs are installed; and
- A constant motor kW value that is determined from pre-installation metering; or
- Motor kW calculated as a function of independent variables that are monitored during the post-installation period.

Post-installation demand and energy use are based on:

- Motor operating hours which are measured after the VSDs are installed; and
- Motor kW, which is continuously metered or metered at regular intervals during the term of the contract; or
- Motor kW calculated as a function of independent variables that are monitored during the post-installation period.

15.3 Calculation of Demand and Energy Savings

15.3.1 Baseline Demand and Energy

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Baseline motor demand will either be:

- A constant kW value;
- A value which varies per a set operating schedule; e.g., 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW; or
- A value that varies as a function of some independent variables, such as outdoor air temperature or system pressure for a variable air volume system.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey; and
- Spot and/or short-term metering of existing motors.

Pre-Installation Equipment Survey. In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. Motor location and corresponding facility floor plans should be included with the survey submittal. The surveys will include, in a set format :

- Motor and motor control nameplate data;
- Motor horsepower;
- Load served;
- Operating schedule;
- Spot metering data; and
- Motor application and location.

Spot-and Short-Term Metering of Existing Motors. For each motor to be replaced, spot metered 3-phase amps, volts, PF, kVA, kW and motor speed data should be recorded. These data should be entered into a standard form. Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 2% of reading. Other factors to measure include motor speed in rpm and the working fluid temperature if the motor serves a fan or pump. The temperature measurement may be taken at either the inlet or outlet of the device, as long as the location is identical for the baseline and post-installation measurements

The ESCO will conduct short-term monitoring for **constant load, baseline motors to**:

- Verify that motor loads are constant; and
- Normalize spot-metering kW measurement results.

The ESCO will conduct short-term monitoring for **variable load, baseline motors** to:

- Develop a schedule of motor kW; e.g., 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW (see Section 15.5); *or*
- Define the relationship between motor kW and the appropriate independent variables; e.g., such as outdoor air temperature or system pressure for a variable air volume system.

The ESCO will conduct short-term metering on all baseline and post-installation VSD-controlled motors or on a randomly selected sample of motors with the same application and/or operating hours. Short-term metering should be conducted and analyzed in the manner discussed in Method CLM-B-01 for constant load motor applications.

15.3.2 Baseline Operating Hours

Baseline motor operating hours can either be:

- Determined prior to ECM installation if the hours are assumed to be different than post-installation operating hours; or
- Determined after ECM installation if the hours are assumed to be the same as post-installation operating hours.

Short-term or long-term metering will be used to be determine operating hours as discussed in Section 15.5.

15.3.3 Adjustments to Baseline Demand and Energy

Prior to installation of new motors, adjustments to the baseline demand may be required for non-operating motors that are normally operating or intended for operation. In addition, after ECM installation, adjustments to baseline demand may be required because of factors such as remodeling or changes in occupancy. Methods for making adjustments should be specified in the site-specific M&V plan.

With respect to non-operating equipment, the party responsible for defining the baseline will also identify any non-operating motors. Non-operating equipment is **typically operating** but has broken parts and is **intended for repair**.

15.3.4 Post-Installation Demand and Energy

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency. After VSDs are installed, short-term metering will be conducted for all motors using the same meter and procedures used for the baseline motors, and the results will be entered in a standard survey form. See Section 15.3.1.

When recording the motor kW, the motor speed is also recorded. Direct motor rpm measurements can be made or readings can be taken from the VSD control panel.

The power draw of the motors with VSDs will vary depending on the speed of the motor being controlled. In addition, other factors such as downstream pressure controls will affect the power draw. With this M&V method it is assumed that:

- Motor power draw is continuously metered or metered for set intervals during the term of the contract; or

- Motor power draw can be defined as a function of appropriate independent variables, **and** the independent variables are continuously monitored or monitored for set intervals during the term of the contract.

If less than continuous monitoring is used, the monitored data during the monitoring period will be extrapolated to the full year. A minimum monitoring period of **one month** is recommended for almost all usage area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to collect data during different times of the year.

Examples of set monitoring or metering intervals are once a month for each season or one random month during each contract year.

15.3.5 Post-Installation Operating Hours

Post-installation operating hours either can be assumed to be the same as or different than the pre-installation operating hours. If the hours are assumed to be same before and after the new motors are installed then the post-installation monitoring of motors with VSDs can be used for determining operating hours. Typically, post-installation monitoring will be used because waiting for results of the baseline monitoring could delay VSD installation.

Operating hours can be established per a certain time period (e.g., weekday hours) or per operating different operating scenarios (e.g., at different VSD speeds). Operating hours monitoring is discussed in Sections 15.5.

15.4 Sampling

The ESCO will spot meter all of the motors; however, the short- or long-term metering may only need to be done for a sampling of motors.

ESCOs will begin their sampling analyses by classifying existing motors according to applications with identical operating characteristics and/or expected operating hours. Examples of applications include HVAC supply fans, cooling water pumps, heating water pumps, condenser water pumps, HVAC constant volume return fans, and exhaust fans. Each application will be defined and supported with schematics of ductwork and/or piping as well as control sequences.

For each application or usage group in the ESCO's project, there must be at least one motor subject to short-term metering.

15.5 Monitoring For Determining Operating Hours

Operating hours may be the same before and after the VSDs are installed, or the hours may be different. Operating hours for the baseline and/or post-installation periods will be determined with short-term or long-term monitoring on at least a sample of motors.

Operating hours will be established for different operating scenarios. Examples include:

- For a baseline motor: 4,000 hours per year at 50 kW (control valve open) and 4,760 hours per year at 40 kW (control valve closed).

- For a motor with a VSD: 2,000 hours per year at 15 kW (50% speed), 2,000 hours at 30 kW (75% speed) and 4,760 hours at 50 kW (100% speed).

The ESCO will conduct short-term monitoring for a period of time to be specified in the site-specific measurement and verification plan. The period of time will be proposed by the ESCO and approved or modified by the federal agency.

Monitoring is intended to provide an estimate of annual equipment operating hours and energy use. The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operation hours estimates. Run-time monitoring should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the run-time monitoring installation period, the duration should be extended for as many days as the usage aberration.

If less than continuous monitoring is used, the operating hours during the monitored period will be extrapolated to the full year. A minimum monitoring period of **three weeks** is recommended for almost all usage area groups. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to determine operation hours during different times of the year.

15.6 Equations for Calculation of Energy and Demand Savings

Calculate the kWh savings using the following equations:

kWh Savings (per each operating scenario) =
[Operating Scenario Hours] X [kW Savings per each operating scenario]

Where:

kW Savings =	$kW_{baseline}$ - kW_{post}
$kW_{baseline}$ =	the kilowatt demand of the baseline motor in a particular operating scenario
kW_{post} =	the kilowatt demand of the high-efficiency motor in a particular operating scenario

Operating Scenario = a particular mode of operation defined by an independent variable such as motor speed or valve position

Operating Hours = hours for each operating scenario

Demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_{operating\ scenario,\ t}$$

Average demand reduction:

$$kW\ Savings_{avg} = \frac{Annual\ kWh\ Savings}{Annual\ Operating\ Hours}$$

15.7 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except that it contains information on **actual** rather than expected ECM installations.

15.8 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Specification of site survey plan;
- Specification of data collection methods, schedule, duration, equipment , and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and which are related to VSD projects include:

- Definition of operating modes for motors;
- Sampling plan for motor power measurements;
- Post-installation metering strategy for motor kW or independent variables; and
- Assessment of non-operating motors.

SECTION III

Chapter 16

Measurement and Verification Plan (Option B)
Chiller Replacement:
Method CH-B-01, Metering of Chiller kW
Method CH-B-02, Metering of Chiller kW and Cooling Load

16.1 ECM Definition

This ECM involves chillers used for space conditioning or process loads. Projects can include:

- Existing chillers replaced with more energy efficient chillers; or

- Changes in chiller controls that improve chiller efficiency.

There are two M&V methods described in this section. For method CH-B-01, the post-installation chiller energy use is continuously metered or metered at regular intervals. With method CH-B-02, the post-installation chiller energy use and the cooling load are continuously metered or metered at regular intervals.

16.2 Overview of Verification Methods

Surveys are required to document existing (baseline) and new (post-installation) chillers and chiller auxiliaries (e.g., chilled water pumps, cooling towers). The surveys should include (in a set format) for each chiller and control device:

- Nameplate data;
- Chiller application; and
- Operating schedules.

Commissioning of chiller operation is expected.

Method CH-B-01 - Energy Use Metered. Post-installation chiller energy use is continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV); and

- Stipulated cooling loads or cooling loads calculated from the measurement of post-installation chiller energy use.

Method CH-B-02 - Energy Use and Cooling Load Metered. Post-installation chiller energy use and cooling loads are continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV); and

- Cooling loads measured during the post-installation period.

16.3 Calculation of Demand and Energy Savings

16.3.1 Baseline Demand

The baseline conditions identified in the pre-installation equipment survey will be defined by either the federal agency or the ESCO. If the baseline is defined by the federal agency, the ESCO will have the opportunity to verify the baseline. If the baseline is defined by the ESCO, the federal agency will verify the baseline.

Steps involved in establishing the baseline demand are:

- Pre-installation equipment survey; and

- Defining chiller efficiency (see Method CH-A-01) or metering of existing chillers (see Method CH-A-02).

Pre-Installation Equipment Survey. In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed will be inventoried. Chiller location and corresponding facility floor plans should be included with the survey submittal. The surveys will include, in a set format:

- Chiller and chiller auxiliaries nameplate data;
- Chiller age, condition, and ratings;
- Load served:
- Operating schedule;
- Chiller application; and
- Equipment locations.

Chiller performance can either be stipulated or measured.

Stipulated Chiller Efficiencies. The most common source of chiller performance data is the manufacturer. For existing chillers, the "nameplate" performance ratings may be downgraded based on the chiller's age and/or condition. Chiller efficiency can be presented in several formats depending on the type of load data that will be stipulated. Possible options include annual average kW/ton expressed as Integrated Part Load Value (IPLV)[21] or kW/ton per incremental cooling loads.

Metering of Existing Chillers. The following data should be collected:

- Chiller kW;
- Chilled water flow, entering and leaving temperatures for calculating cooling load;
- Chiller circulating and condenser pump(s) if they are to be replaced or modified; and
- Cooling tower fan(s) kW (kWh) if they are to be replaced or modified.[22]

These data are entered into a standard form. Such measurements should be made using a meter with an accuracy at or approaching ± 2% of reading for power measurements and +/- 5% for flow measurements.
Multiple measurements are made while the cooling systems are operating at different loads so that the complete range of chiller performance can be evaluated. Thus, the baseline metering typically requires a time period of at least several weeks, and often more time is required.

16.3.2 Post-Installation Demand and Energy

The new equipment will be defined and surveyed by the ESCO and verified by the federal agency.

Chiller energy use and demand profile will be measured either:

- Continuously throughout the term of the ESPC contract; or

[21] For example, per the appropriate standards of the Air-Conditioning and Refrigeration Institute
[22] This list includes condenser pumps and cooling tower measurements are not involved in air cooled systems and circulating pump measurements are not involved in DX systems. Condenser flows and temperatures can also be measured to check system energy balances. For DX systems, air flows and temperatures (although more difficult than water system measurements) are measured to determine cooling load.

- At set intervals during the term of the contract (e.g., one month during each of the four seasons). The intervals must adequately define the full range of chiller performance.

If data are not collected continuously, the data that are collected are extrapolated to represent the periods of time when metering is not done.

The following data should be collected:

- Chiller kW;
- Chiller circulating and condenser pump(s) kW (kWh) if they were replaced or modified; and
- Cooling tower fan(s) kW (kWh)if they were replaced or modified.[23]

16.3.3 Cooling Load

Cooling load does not have to be measured for determining post-installation energy use and demand since the post-installation chiller energy use is metered with these two M&V methods. The baseline cooling load, however, has to be determined for calculating baseline energy use and demand.

Method CH-B-01 - Energy Use Metered. With this method, cooling load is not measured; therefore, baseline cooling load is either:

- Stipulated; or

- Calculated from post-installation chiller energy use measurements.

Possible sources of stipulated baseline chiller loads are:

- Pre-installation metering of cooling loads by the ESCO or federal agency; and

- Studies of cooling load (for example, using bin weather data or computer simulation programs such as DOE-2); and

- Results from other projects in similar facilities.

Baseline and post-installation cooling loads may be different. Typical weather data or actual weather data can be used for determining cooling loads. The difficulty with stipulating cooling loads is that the savings may be inappropriately

[23] This list includes condenser pumps and cooling tower measurements not involved in air cooled systems and circulating pump measurements not involved in DX systems.

biased by comparison of baseline and post-installation energy use of different cooling loads.

Method CH-B-02 - Energy Use and Cooling Load Metered. With this method, cooling loads are measured; therefore, baseline cooling loads are based on the post-installation cooling load. Data that should be metered include:

- Chilled water flow;
- Chilled water entering and leaving temperatures,[24]
- Outside air temperature or weather data (for reference).

16.4 Equations for Calculation of Energy and Demand Savings

Calculate the kWh savings using the following equations:

$$kWh\ Savings = [(Baseline\ Cooling\ Load\ in\ Ton\text{-}Hours) \times (Baseline\ kW/Ton)] - Post\text{-}Installation\ kWh$$

where:

Cooling Load in Ton-Hours is stipulated, measured, or calculated;

Baseline kW/ton is the stipulated or measured existing chiller performance; and

Post-installation kWh is measured for the new chiller(s).

Demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_{at\ maximum\ cooling\ load,t}$$

Average demand reduction:

$$kW\ Savings_{avg} = \frac{Annual\ kWh\ Savings}{Annual\ Operating\ Hours}$$

[24] Air flow measurements are required for DX systems.

16.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except that this report contains information on **actual** rather than expected ECM installations.

16.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations;
- Source of baseline chiller performance and/or cooling loads;
- Specification of site survey plan;
- Specification of data collection methods, schedule, duration, equipment, and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that need to be addressed and are related to chiller replacement projects include:

- Determination of whether to meter cooling load; and
- Duration of the monitoring.

SECTION III

Chapter 17

Measurement And Verification Plan (Option B)
Generic Variable Load:
Continuous Post-Installation Metering
Method GVL-B-01

17.1 Project Definition

This measurement and verification method plan covers projects that improve the efficiency of end-uses that exhibit variable energy demand and/or variable operating hours. Examples of such projects include:

- Replacement of motors that serve variable loads with high efficiency motors;
- Upgrading of building automated systems;
- Installation of new air-conditioning equipment; and
- Installation of thermal insulation.

For this M&V method, it is assumed that the savings associated with the ECMs can be verified with end-use metering.

17.2 Overview of Method

The ESCO will audit existing systems to document relevant components; e.g., piping and ductwork diagrams, control sequences, and operating parameters. The ESCO will also document the proposed project and expected savings. All, or a representative sample, of the existing systems will be metered by the ESCO 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.

Once the ECM is installed, there are two general approaches for determining savings:

1. Continuously measuring post-installation energy use and the appropriate variables. The post-installation variable data are used with the baseline "equations" to calculate baseline energy use; and

2. Continuously measuring only the appropriate post-installation variables. The post-installation variable data are used with the baseline and post-installation "equations" to calculate baseline and post-installation energy use. With this approach, the ESCO will conduct metering to determine the post-installation relationship between input energy and the appropriate variables after the project is installed.

The ESCO will apply the results of the post-installation metering to determine the difference between pre-installation and post-installation input energy use (and demand). This difference represents the system savings.

17.3 Metering and Calculation of Baseline Demand and Energy Savings

17.3.1 Audit Baseline System

The ESCO will audit system(s) to be affected by projects to document all relevant components, such as motors, fans, pumps, and controls. For each piece of equipment, documented information will include manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, MBtu/hr), nominal efficiency, the load served, and a listing of independent variables that affect system energy consumption. Equipment location and corresponding facility floor plans should be included with the survey submittal.

17.3.2 Establishing Baseline Model

The ESCO will meter system input energy (e.g., kWh, Btu) and demand[25] (e.g., kW, Btu/hr) over a representative time period before any efficiency modifications are made. Such metering will be applied to those devices that will be directly affected by the ECM. Duration of input metering will be sufficient to document the full range of system operation. The ESCO will propose an appropriate duration in the site-specific measurement and verification plan, subject to approval by federal agency on a case-by-case basis. Typically, observations will be made of 15-minute intervals, unless the ESCO demonstrates that longer intervals are sufficient and such intervals are approved by the federal agency.

Energy Standards. If the project is subject to any energy standards, these standards may need to be accounted for in the baseline model.

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[25] Demand is measured if contract payments include a demand savings-based component.

If multiple, similar equipment components or systems are to be modified (e.g., ten supply fans), the ESCO may propose in the site-specific plan to meter only a sample.

Variable Measurements. Over the same time period that input energy use is monitored, the ESCO will meter:

- Independent variables that affect the energy and demand use. Examples of such data are ambient temperature, control set points, and building occupancy; and/or
- Dependent variables (system output) that indicate the energy and demand use. Such monitoring will clearly quantify output in units that directly correspond to system input. Examples of dependent variables are tons of cooling, MBtu of heating load, and gallons of liquid pumped.

Baseline Model(s). Most efficiency projects and systems may be directly influenced by highly variable independent variables such as weather conditions. For such projects, the ESCO may choose to develop a regression model that links independent variable data to energy input. Specific methodologies to do so may be presented by the ESCO in the site-specific measurement and verification plan and considered for approval by the federal agency.

The ESCO will combine results of energy input metering and variable(s) monitoring to establish the pre-installation relationship between the quantities. This relationship will be known as the "System Baseline Model" and will probably be presented in the form of an equation. The ESCO may use regression analysis to develop such an equation, although other mathematical methods may be approved. If regression analysis is used, the ESCO will demonstrate that it is statistically valid. Examples of criteria for establishing statistical validity 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 are representative of the population;
- The form of the model conforms to standard statistical practice;
- The number of coefficients are 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's R^2 is reasonable given the type of data being modeled; and

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

.The federal agency will make final determination on the validity of models and monitoring plans and may request additional documentation, analysis, and/or metering from the ESCO as necessary.

It must be stressed that it is incumbent on the ESCO to carefully investigate systems and select data input and output for monitoring that exhibit direct relationships to energy use. For example, some processes may use the same amount of energy regardless of the amount of units produced. In such cases, the ESCO will carefully analyze systems to identify a quantifiable output that exhibits a direct relationship to the input energy.

17.4 Post-Installation Metering and Calculation of Savings

There are two approaches defined in this section for calculating savings:

1. Continuously measuring post-installation energy use (and demand) and the appropriate variables. The post-installation variable data are used with the baseline "equations" to calculate baseline energy use (and demand); and

2. Continuously measuring the appropriate post-installation variables. The post-installation variable data are used with the baseline and post-installation "equations" to calculate baseline and post-installation energy use (and demand).

17.4.1 Savings Calculation - Metering Post-Installation Energy and Variables

After installation of the ECM, the ESCO will conduct continuous metering of the system energy input and monitoring of output (e.g., tons of cooling) or independent variables (e.g., weather) over the life of the claimed energy savings. Such metering and monitoring will be conducted in a manner identical to the monitoring performed to model the performance of the baseline system.

For this option, the post-installation **metered input** energy will be used directly in the savings calculation. The **monitored data** will be used in the System Baseline Model to calculate pre-installation energy input.

Energy savings over the course of a single observation interval will be calculated by the ESCO using the following equation (assuming an electric measure):

$$Energy\ savings_i = (kW_b - kW_m) * T_i$$

where:

kW_b = Baseline kW[26] calculated from System Baseline Model and corresponding to the same time interval, system output, weather, etc. conditions as kW_m.

kW_m = Measure kW obtained through continuous post-installation metering

T_i = Length of time interval

For a particular observation interval, the ESCO will apply the monitored data to the Baseline System Model in order to determine what the baseline system energy input would have been. From this amount, the ESCO will subtract the metered system post-installation input. Energy savings are determined by multiplying this difference by the length of the observation interval.

17.4.2 Savings Calculation - Metering Post-Installation Variables

The ESCO may conduct metering of post-installation system energy input and monitoring of post-installation conditions in order to develop a Post-Installation System Model. The ESCO would then monitor system output (and/or the other relevant variables) during a representative period on a regular basis. Such a representative period will be similar to the representative period over which the System Baseline Model monitoring occurred. If regression analysis is employed, the Post-Installation System Model will also be subject to the same validity criteria specified in Section 17.3.2.

When choosing this alternative, the ESCO will use two equations for calculating savings or one equation that calculates changes in energy use. The ESCO will apply monitored data to the Baseline System Model to obtain the baseline system energy input. The ESCO will then apply the same monitored data to the Post-Installation System Model to obtain the post-installation system energy input. The monitored data (e.g., ambient temperature) may be obtained continuously or for selected intervals (e.g., once a month for each season for weather dependent measures) during the term of the contract. The ESCO may

[26] kW is used in the equation but other factors such as Btu/hr may be appropriate.

then calculate the savings by taking the difference of the baseline and post-installation system data input and multiplying by the appropriate time interval.

17.4.3 Actual Or Typical Data

To determine savings using dependent or independent variables, either use (a) the actual measured values as they occur during the term of the agreement or (b) typical values for calculating savings. For example, with respect to weather data, it may be more appropriate to use typical year data versus actual weather data.

17.5 Pre- and Post-Installation Submittals

For each site, the ESCO submits a Project Pre-Installation Report that includes:

- A project description and schedule;
- A pre-installation equipment survey;
- Estimates of energy savings;
- Documentation on utility billing data;
- Projected budget; and
- Scheduled M&V activities.

In the event the federal agency defines the baseline condition, the ESCO will need to verify an agreed-to pre-installation equipment survey.

The ESCO submits a Project Post-Installation Report following project completion and defines projected energy savings for the first year. In addition, the report includes many of the same components as in the Project Pre-Installation Report, except that it contains information on **actual** rather than expected ECM installations.

17.6 Site-Specific Measurement and Verification Plan

The site-specific measurement and verification approach may be pre-specified in the ESPC between the federal agency and ESCO and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the site-specific nature of the following elements:

- Overview of approach;
- Specification of savings calculations method including what models will be used;
- Specification of site survey plan;
- Specification of what data will be collected and the data collection methods, schedule, duration, equipment, and reporting format; and
- Identification and resolution of any other M&V issues.

Specific M&V issues that may need to be addressed and that are related to these types of generic variable load projects include:

- Determination of metering approach -- i.e., monitoring of energy uses or post-installation variable;
- Identification of appropriate variables; and
- Duration of monitoring.

SECTION IV

Descriptions of Option C M&V Methods

Option C is one of three approaches used to obtain estimates of energy savings associated with ECMs. With Option C, total energy savings are predicated based on either:

- Statistical analysis of utility meter billing data; or
- Computer simulation modeling calibrated with hourly or monthly billing data.

With billing analysis, there are different statistical techniques that range from simple comparisons to multivariate regression. There is no single correct technique. The first chapter in this Section presents the most commonly used billing analysis techniques that are applicable to the measurement and verification of federal ESPC projects as well as the advantages and disadvantages of the various techniques.

For some situations, computer simulation modeling calibrated with billing data is an appropriate M&V approach. A discussion of calibrated computer simulation is discussed in the second chapter.

Chapter 18

Measurement and Verification Plan (Option C)
Billing Analysis
Measure GVL-C-01

Option C is applicable for projects in which:

- There is a high degree of interaction between multiple energy conservation measures at a single site;
- The measurement of individual component savings would be difficult; and/or
- Other approaches are more expensive. Typically billing analysis is less expensive than end-use metering.

There are two basic statistical approaches, billing analysis comparison and multivariate regression, that are discussed in this chapter.

18.1 Billing Analysis Comparison Approach

The comparison approach involves the differences between consumption and demand (a) before and after installation of ECMs, and/or (b) between a participating site and a control group/site. There are three basic types of simple comparisons—time-series comparison, cross-sectional comparison, and pre/post/cross-sectional comparison.

Usually, the time-series comparison is the only appropriate M&V method for evaluating federal ESPC projects. In the time-series approach, building energy use before and after the installation of ECMs are compared. The difference indicated from the comparison is the change in energy consumption and demand due to the ECMs *as well as other factors that affect energy use.*

The other two comparison approaches, which use control groups, are problematic. Implicit in these other two approaches is the assumption that the participating site is identical to the control group/site in all respects except for installation of the ECMs. In general, the ESPC projects will be implemented in facilities that are unique, and, thus, obtaining a similar control group/site is almost impossible.

A critical factor in a comparison approach is the specification of the analysis period. The analysis period should include at least one year's worth of utility meter billing data for the baseline period as well as the post-installation period. The smallest interval of billing data that is available for the site should be used in the analysis; i.e., billing data in the form of 15-minute, hourly, or monthly energy consumption. A typical analysis may include an hourly or monthly comparison of energy consumption and demand for a site.

In general, the time-series comparison approach for evaluating electric ECM projects is:

$$Average\ kWh\ Savings_t = \frac{\sum_t kWh_{baseline,t}}{(n_{baseline,t})} - \frac{\sum_t kWh_{post,t}}{(n_{post,t})}$$

$$Average\ Demand\ Reduction_t = \frac{\sum_t kW_{baseline,t}}{(n_{baseline,t})} - \frac{\sum_t kW_{post,t}}{(n_{post,t})}$$

$$Maximum\ Demand\ Reduction_t = Maximum\ (kW)_{baseline,t} - Maximum\ (kW)_{post,t}$$

Where,

kWh denotes the kilowatt-hour use during the billing/meter interval

kW denotes the kilowatt demand during the billing/meter interval

subscript *baseline* refers to the unaffected or baseline consumption

subscript *post* refers to the affected or post-installation consumption

subscript *n* refers to the number of observations or intervals

subscript *t* refers to the observation time period (e.g., 15-minute intervals, hours, month)

If, for example, the unit of analysis is monthly consumption, the formula generates the average change in energy consumption for each month in the post-installation period. The comparison is made between the post-installation months and the corresponding baseline months.

The results of the comparison should also include statistical indicators showing whether observed changes are statistically significant within specified confidence levels. There are numerous statistical tests and appropriate techniques that should be specified in the contract or site-specific M&V plan.[27]

The limitation of the comparison approach is that it cannot control for non-retrofit-related factors that affect energy consumption and change over time, such as weather, occupancy, and operating schedules. The savings estimates may be fairly reliable only if there are no changes (or minimal changes) in non-retrofit-related factors over the analysis period. Thus, some investigation of these factors will be required to make such a determination.

In the event that non-retrofit related factors do change, they can be controlled by normalizing consumption to typical or baseline conditions. Even with normalization, the saving estimates under these circumstances are highly suspect without a full examination of all the effects of non-retrofit-related factors. In addition, a possible issue with normalizing is that the resulting change in energy consumption is based on typical or baseline conditions rather than actual conditions in the post-installation year. Another issue is that normalizations are not always linear. For example, a building's gas consumption for space heating would not vary with heating degree days above or below a certain number of degree days. These types of problems can be dealt with more easily in a multivariate regression analysis.

Nonetheless, the comparison approach is simple and easily applied where non-retrofit-related factors remain relatively constant over the analysis period. The approach requires a minimal amount of data collection since the information is available in utility meter billing data. Where the value of a project is relatively low and the level of certainty in the estimates of savings is not critical, the comparison approach is appropriate for evaluating the energy savings of ESPC projects. For these types of projects, it would probably not be worth conducting a more complex analysis such as multivariate regression.

18.2 Multivariate Regression Billing Analysis

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

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[27] For example, the average consumption at a site for a typical day in April is 15 kWh in the pre-installation period and 10 kWh in the post-installation period (with a variance of 6.5 kWh and 6.8 kWh, respectively). One statistical test (using statistic Z) that examines the difference between those two means yields a value of 2.96. Thus, the observed difference of 5 kWh is significant at a level of significance of 0.01 (where the null hypothesis is rejected when $Z > 2.58$).

The use of the multivariate regression approach is dependent on and limited by the availability of data. The decision to use a regression analysis technique must be based on the availability of appropriate information. Thus, on a site-specific basis, it is critical to investigate the systems that affect and are affected by the project and select all independent variables that exhibit direct relationships to energy use. Data need to be collected for dependent and explanatory variables in a suitable format over a significant amount of time.

When the information is not available and/or unobtainable, regression analysis cannot be used to estimate energy savings. If a valid model cannot be developed, an alternative method needs to be used. As previously discussed, a simple comparison approach may be appropriate for projects in which the value of the savings is small and reliability of savings estimates is not very critical. If the reliability of the savings estimates is critical, then perhaps computer simulation modeling calibrated with billing data is an appropriate M&V approach.

18.2.1 Overview of the Regression Approach

A regression model(s) should be developed that describes changes between pre-installation and post-installation energy use for the affected facility (or facilities), taking into account all explanatory variables. The savings are calculated by using the actual values of explanatory variables from the post-installation period in the final regression model(s). The exception to this "actual values" rule is that, for weather data, long term, average, weather data are often used in the models.

For affected utility electric billing meters with time-of-use data, the regression model(s) will yield savings by hour or critical time-of-use period, taking into account seasonal variations where appropriate. For meters with only monthly consumption data, the models will be used to predict monthly savings.

The analysis period will typically require at least 12 months' worth of pre-installation data and at least 12 months' worth of post-installation data in the regression model(s) to determine savings estimates for the first year after installation of ECMs. If energy consumption for the building is fairly sensitive to weather, then at least 24 months of data may be required for both the pre-installation period and post-installation period.

The models will no longer have to be updated once enough months of pre-installation and post-installation data have been used and the models are shown to be statistically valid. However, the savings estimates based on the "final models" will vary depending on actual data inputs to the model; e.g., due to changes in building occupancy.

18.2.2 Standard Equation for Regression Analysis

In the regression analysis, utility meter billing data (monthly or hourly) on a site-specific basis is used to prepare models for comparing the energy use before the installation of ECMs to energy use after the installation of ECMs. Any differences, after adjusting for non-retrofit-related factors, are then defined as the gross load impacts of the project at the site.

The following discussion covers the steps involved in developing a regression model. The steps include specification of the equation, identification of independent variables, data analysis, and tests for statistical validity of the model.

Specification of Standard Format for Equations. The regression equations should be specified so as to yield as much information as possible about savings impacts. For example, with 15-minute load data that are converted to 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.

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.

The model may be described by a multivariate equation of the form:

$$y_{i,t} = B_1 + B_2 PART + B_3 x_{3,i,t} + \ldots + B_k x_{k,i,t} + e_i$$

where:

y denotes the dependent variable minus changes in energy use during comparable time periods

x denotes a vector of explanatory or independent variable

$PART$ denotes a binary variable that equals 0 for baseline consumption and 1 for post-installation consumption

.... denotes a vector of coefficients that relate changes in the independent variables to changes in the dependent variable

subscript i refers to the relevant consumption reading

subscript k refers to the particular explanatory variable subscript t refers to the observation time period (e.g., 15 minutes, hours, month)

B_k is the coefficient(s) of explanatory variable k based on the regression analysis

e_i is an error term

Identification of Independent Variables. A list of explanatory variables that affect energy consumption as well as possible interactive terms (i.e., combination of variables) need to be specified. Critical variables can include weather, occupancy patterns, and operating schedules. It should be noted that the independent variable data will need to correspond to the time period of the billing data.

If the energy savings model discussed above incorporates weather in the form of heating degree days (HDD) and cooling degree days (CDD), the following issues should be considered:

- 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;
- The non-linear response to weather. For example, a 10°F change in temperature results in a very different energy use impact if that change is from 75°F to 85°F rather than 35°F to 45°F; and
- Matching degree days and billing start and end dates.

Data Analysis Protocols. The following are examples of data analysis protocols:

Baseline energy consumption. The regression analysis requires at least 12 months' worth of data prior to the date of installation except if energy consumption is sensitive to weather (then at least 24 months);

First-year post-installation energy consumption. The regression analysis requires at least 9 months' worth of data after the date of installation to determine impacts for the first year.

Subsequent energy consumption. The billing analysis models should be updated each year until 12 months' worth of post-installation data (or 24 months if energy consumption is sensitive to weather) have been used to determine the independent variables' coefficients. Thereafter, the model would be considered constant for the remaining program years unless a change in project or facility characteristics affects the independent variables or their coefficients.

Outliers. The criteria used for identifying and eliminating outliers needs to be documented. Outliers are data beyond the expected range of values (or two to three standard deviations away from the average of the data). Outliers will 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.

With respect to outliers, the following meter data issues should be considered when completing billing analysis:

⇒ Occupancy type may change over the analysis period. A decision will have to be made about how to account for such a change in the regression model.

⇒ There is the possibility of multiple meters at a site. The analyses should include pre-processing all billing and tracking system data to identify problems of this type. Any site for which the estimate of savings is an extremely small percentage of annual usage or an extremely large percentage of annual usage is suspect.

Testing Statistical Validity of Model(s). The statistical validity of the final regression model will need to be demonstrated:

- 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 are representative of the population;
- The form of the model conforms to standard statistical practice;
- The number of coefficients are 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's R^2 is reasonable given the type of data being modeled;
- The model is tested for multicollinearity, autocorrelation, or heteroscedasticity. If these are present, appropriate statistical techniques are used to correct for them; and
- All data input to the model are thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.

18.2.3 Calculation of Savings

Saving and demand estimates can be calculated using the final regression model with actual post-installation values for explanatory variables rather than the typical or average values. For example, actual building occupancy rates should be used versus typical building occupancies. The one exception to this rule is weather data where impacts can be based on long-run, normal weather conditions.

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; and,
- Whether current energy standards need to be accounted for in the baseline.

18.2.4 Accounting for Energy Standards.

When a certain level of efficiency is required by law or federal agency standard practice, savings **may** be based on the difference between the energy usage of the new equipment and equipment which complies with the minimum standards. In these situations, the baseline energy and demand consumption must be equal to or less than any applicable minimum energy standards. If this situation requirement exists, it will be adjusted in the baseline.

Under a regression analysis approach, two regression models would need to be specified—one for pre-installation energy use and one for post-installation energy use model rather than a single "savings" model. This specification would allow for an easy adjustment to the baseline in the pre-installation model, and, thus, the savings calculation would be the difference between the adjusted, pre-installation and post-installation energy use models. It should be noted that all equipment components and systems installed under the federal ESPC program are expected to meet or exceed the minimum standards indicated in any applicable energy codes or agency requirements that are in effect at the time of project installation.

SECTION IV

Chapter 19

Measurement and Verification Plan (Option C)
Computer Simulation Analysis

19.1 Project Definition

Computer simulations for measurement and verification are used when the energy impacts of the ECMs are too complex to cost-effectively analyze with M&V Option B or when billing analysis cannot provide the level of detail or accuracy required. Situations where computer simulations can be used include:

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

19.2. Overview of Method

Computer simulations of building energy performance and cost have been cited by many experienced building modellers as more of an art form than an exact science. The reason for this view is that the nature of energy use in a building depends on a large number of factors. These factors include the physical layout of a building, its physical properties, intended use and installed equipment. Thus, numerous and varied input data are required to correctly simulate the buildings energy performance; while few program outputs can be used to verify the accuracy of the simulation.

A key element of this method is calibrating the simulation model with actual utility metering data and/or short term metering of individual systems. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, the software is evolving and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics and occupancy schedules, etc. enable the discovery and rectification of discrepancies much more rapidly. A brief discussion of the most useful software is in section 19.3.

Computer simulation measurement and verification of ECM installations involves the following steps:

- Selection of appropriate simulation software;
- Conduct extensive and detailed site surveys of building and equipment data;
- Select appropriate program inputs such as weather, occupancy schedules, load schedules etc.;
- Select appropriate calibration data such as equipment spot or short term metering and periodic (i.e. hourly, weekly, monthly etc.) electric and gas usage (usually from utility bill data);
- Input baseline data into model, simulate the baseline;
- Calibrate the baseline simulation model;
- Input ECM performance specifications and simulate the building with the installed ECM (post-installation model);
- Estimate savings by comparing energy use predicted by the baseline and post-installation models; and
- If savings are to be based on the actual value of parameters, such as weather and building occupancy, then the savings will be updated on a regular basis (e.g., annually) using current input values for the baseline and post-installation models.

19.3 Available Simulation Software

Computer based building energy simulation tools can allow much needed flexibility in analyzing a buildings energy performance while preserving accuracy.

The most comprehensive building energy simulation programs in use today are based on the same modeling strategy. They first determine the loads in each room, considering all heat entering the room as positive (loads module), then the required system heat extraction (or addition) rates necessary to maintain the indoor temperature (system module) and finally the physical plant size and performance requirements (plant module). An economics module is often included to calculate monthly operating costs and determine simple paybacks from capital costs. Each step is performed individually, meaning for example that the output of the load module cannot be changed by the procedures of the systems module, even though in reality systems operation may affect the building loads. Future versions of the programs may address this issue.

Calculating building loads, then system and plant requirements, then economics in this order has advantages. For example, once the building loads are calculated, if there are no modifications that affect the building load, the load module may not need to be run again to compare different chillers or boilers. The agency and ESCO may wish to use the calculated loads as a basis for agreements.

The system simulation module predicts the performance of the chosen HVAC system. Many versions of the available simulation programs have libraries of different HVAC systems. The user must choose the HVAC system and the various components and control features for each type of system used. The plant simulation module determines the part-load operating conditions under which the plant will operate. The plant libraries contain polynomial equations to approximate the part-load behavior of the selected plant. Most plant information is general, however specific plant performance data can be used, but this information must be supplied by the manufacturer.

Many simulation programs have features that make the process of calibrating the simulation much easier. In addition to extensive libraries of common building parts, there are powerful graphical user interfaces and computer aided design (CAD) interfaces. The libraries contain common building construction shapes and materials, lighting and window characteristics, HVAC equipment performance characteristics, and building-type equipment and occupancy schedules. These are often sorted by building era, as defined by introduction of new equipment or energy standards. Other libraries may contain typical weather data for different climate zones.

Graphical user and CAD interfaces allow for the viewing of the building as it is modeled. They can show front and side elevations of the building as well as window shading. Other tools allow for viewing the simulation input data, as well as simulation results. Table 19.1 contains a short selection and description of some building energy simulation software which is currently available.

Table 19.1
Non-Comprehensive List of Whole Building Simulation Tools[28]

Program	Description[29]	Users[30]	CAD	Developer
AXCESS	LSP	ERC	no	AXCESS Consulting and Training, Roswell GA
BLAST	LSPEU	ACEPR	some versions	US Army Construction Engineering Research Laboratory, University of Illinois
Builder Guide	LSEU	ACEPR	no	National Renewable Energy Laboratory, Golden, CO
DOE-2	LSPEU	ACEPR	some versions	Lawrence Berkeley National Laboratory, Berkeley, CA
HAP	LSP	ACEP	some versions	Carrier Corporation
TRACE	LSP	ACEP	some versions	The Trane Company
TRYNSYS	LSP	ACER	no	Solar Energy Laboratory, University of Wisconsin

The selection of building simulation software depends in part on the level of verification desired. Both DOE-2 and BLAST can output hourly electrical and gas consumption and demand. For some projects, such as new HVAC equipment, controls, or when extra hourly-based metering data are provided, hourly simulation output may be desired for comparison and calibration. For other projects, it may be enough to know the monthly values.

In general, DOE-2 and BLAST are recommended as the preferred simulation engines. These programs allow the most flexibility in accurately modeling the building physical layout, construction materials, HVAC systems, control systems, occupancy schedules etc. Many package programs using DOE-2 as the simulation engine with graphical user interfaces are available. With this software, simulation and calibration efforts that once took 2 weeks can now be performed in days, if accurate site information is available.

[28] A more comprehensive list can be found in "The CRC Handbook of Conservation and Renewable Energy," Chapter 9, Thermal Conservation in Buildings, M. Sherman and D. Jump, F Kreith and R. West, eds., CRC Press, Inc., Boca Raton, FL, 33431, in press, 1996
[29] L = loads analysis, S = systems analysis, P = plant analysis, E = economics analysis, U = residential solar analysis
[30] A = architects, C = energy consultants, E = design engineers, P = HVAC professionals, R = building energy researchers

19.4 Procedure

19.4.1 Site Survey

A detailed site survey is required for generating the necessary input data for the simulation model. It is important that all collected data are as accurate as possible. An example list of items to be collected is[31]:

- Building orientation, floor plans, fenestration and construction. Much of this information can be collected from a set of as-built architectural drawings.

- Descriptions of as-built building mechanical systems including all HVAC equipment (primary and secondary). As-built building mechanical drawings can be of use. Information on zoning of HVAC systems can be provided by these drawings

- Descriptions of all electrical systems in the building. As-built electrical drawings can provide this information. These drawings can also provide lighting load information and control system specifications.

- Determine directions major facades of building face, estimate distance from surrounding buildings and height of surrounding buildings for shading calculations. Photograph the building exterior and surroundings.

- HVAC system: record nameplate data, type and locations of all primary and secondary HVAC systems. Obtain an air balance report including supply and return measurements of air temperature. From manufacturer, obtain part-load performance characteristics of equipment.

- Obtain hourly HVAC schedules, thermostat settings including day/night setback. Obtain a printout of EMCS program settings where possible.

- Verify lighting loads estimated from electrical diagram by counting fixtures and measuring lamp and ballast wattages. Obtain indoor and outdoor lighting schedules.

- Measure the wattage of internal plug loads (appliances, computers etc.). Obtain usage schedules.

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[31] This list was based in part on the site survey list found in T. E. Bou-Saada and J. S. Haberl, "An Improved Procedure for Developing Calibrated Hourly Simulation Models," International Building Performance Simulation Association, report no. ESL-PA-95/08-01, 1995

- Determine if local weather data are available. Weather data such as air temperature, humidity, wind speed and wind direction and solar insolation (vertical and south-facing horizontal) should be available for the general climate region, either measured at the nearest airport, or may be measured on-site. TRY or TMY[32] weather files for a typical year of data may also be substituted where necessary.

- Utility electric and gas rate schedules.

19.4.2 Calibrate Baseline Model

The data collected during the initial site survey are used as input data to the simulation program to build the baseline model. The process of simulation calibration then follows. This often takes a number of iterations and requires an experienced building modeller to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is considered to be calibrated when the output electric (i.e. kWh and kW) and gas (i.e. therms and therms/hr.) use closely match that of the measured data. Methods for determining this "closeness of match" are described below[33].

For programs that output hourly kWh and therm consumption, and with availability of actual hourly kWh and therm consumption, the mean bias error (MBE), and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model. These statistical concepts are defined below.

The mean (A) of the measured consumption is determined by:

$$A = \frac{\sum_{month} M_{hr}}{N_{hr}}$$

[32] These are standard formats for average or typical hourly weather data

[33] This method is based on methods described in "An Improved Procedure for Developing Calibrated Hourly Simulation Models," by T. E. Bou-Saada and J. S. Haberl , International Building Performance Simulation Association, report no. ESL-PA-95/08-01, 1995

The mean bias error of the simulated results, per month, is:

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

where M indicates the measured kWh or therm consumption and S the simulated kWh or therm consumption.

The root mean square error for the month is:

$$RMSE = \sqrt{\frac{\sum_{month}(M-S)^2_{hr}}{N_{hr}}},$$

where N_{hr} are the number of hours in the month. The coefficient of variation of the root mean squared error is:

$$CV(RMSE) = \frac{RMSE}{A} \times 100$$

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption, and by what percentage. A small value of the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because of the possibility of the cancellation of under- and over prediction errors from one hour to the next.

The CV(RMSE) is an indication of the variability in the data. The larger the CV(RMSE), the higher degree of variability. Comparing monthly measured and simulated data with a low MBE and a low CV(RMSE) means that the simulated results match with the measured results very well. In general, the absolute value of the MBE should be less than 7%, and the absolute value of the CV(MBSE) should be less than 25%. These specifications are guidelines only, the agency and ESCO may agree to tighter or looser calibration criteria.

Tabulated values of the measured and simulated values, the MBE and CV(RMSE) for each month over the year will yield a more comprehensive basis for simulation calibration. For the months where either the MBE or the CV(RMSE) or both are large, an indication of model adjustments can be obtained. The agency and ESCO should both agree to acceptable levels of the MBE and CV(RMSE).

19.4.3 Post-Installation Verification

As with other M&V methods described in this document, installation of the ECMs should be verified and the equipment/systems commissioned. As part of this activity performance data of the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.

19.4.4 Post-Installation Simulation

Once the baseline model is considered calibrated, the baseline input file is saved and the new ECM's description replaces data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may or may not require calibration; primarily depending on the amount of changes required to model the new ECMs.

19.4.5 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit shall consist of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.

Successive annually recalibrated models can be used to calculate savings using either:

- Typical meteorological year (TMY) weather and/or average building occupancies, etc. - this is the most common option; or
- Actual, post-installation values for the weather and/or building occupancies, etc.

19.5 ASHRAE GPC-14P Committee on Measurement of Demand and Energy Savings

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has convened a committee to create a guideline that covers the measurement of demand and energy savings. Measurement and verification methods using computer simulation are expected to be included in this document. The FEMP M&V guidelines will refer to the ASHRAE guidelines when they become available.

SECTION V

APPENDICES

APPENDIX A

Sample Metering Forms (Short Term and Long Term)

form date: 2/96

Transducer Installation and Calibration Report Example

Report Date:

I. Site/Customer Information

Site Name:
Site Contact/Phone #:
Contractor Company Name:
Contractor Name/Contact:
Installer Company Name:
Installer Name/Phone Number:

Date Installed/Calibrated:

II. Transducer:

Flow Meter [ ]
Pulse Generator [ ]

Temperature Sensor [ ]
Status Indicator [ ]
Current Transducer [ ]

Device ID #:

Other [ ] Describe:
Device Type:

Variable being measured
Expected range of variable (w/units): –

III. Device Specifications:

Make:
Model:
Serial #:

Location at site:

Location in system:

Output:
Multiplier:
Precision:
Accuracy:
Range (w/units): –

[ ] Include copy of calibration tag
[ ] Include specification sheet
[ ] Include invoice for device
[ ] Attach copy of manual

IV. Calibration Results

Method:
Standard used:
Units of readings:
Data logger:
Notes:

Adjustment Iteration	Date	Time	Transducer Reading T	Standard Reading S	T - S	Percent, (T - S)/S	Comments

Data Logger Report Example

Report Date:

I. Site/Installer Information

Site Name:
Site Contact/Phone #:
Contractor Company Name:
Contractor Name/Contact:
Installer Company Name:
Installer Name/Phone Number:

Date Installed/Programmed:

II. Data Collection Information

Data Output Format:

Data Reporting Period:
Storage Capacity of Data Logger:

Downloading Procedure:

Person/Company Responsible
For Delivering Data to Federal Agency:

III. Data Format

Channel	Output	Units	Expected Range	Sampling Rate

IV. Transducers

Channel	Transducer/Location	Transducer Output	Transducer Vendor/Model	Transducer Install Date	Transducer Calibrated

APPENDIX B

Sample Lighting and Motor Forms

Table LE1
Pre-Installation
Lighting Equipment Expected To Be Installed

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

			EXISTING LIGHTING EQUIPMENT						PROPOSED LIGHTING EQUIPMENT						
Space ID	Circuit ID	Usage Area Type	Equipment Type	Number of Fixtures	Number of Non-Operating Fixtures	kW Per Fixture	kW Per Space or Usage	Control Device	Equipment Type	Number of Fixtures	kW Per Fixture	kW Per Space	Control Device	Space Heated and/or Cooled	Notes
TOTALS FOR PAGE OR USAGE TYPE															

one set of tables by space location and one set by usage type

Table LE2
Post-Installation
Actual Lighting Equipment Replaced and Installed

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

Space ID	Circuit ID	Usage Area Type	EXISTING LIGHTING EQUIPMENT						NEW LIGHTING EQUIPMENT					Notes
			Equipment Type	Number of Fixtures	Number of on-Operati Fixtures	kW Per Fixture	kW Per Space or Usage	Control Device	Equipment Type	Number of Fixtures	kW Per Fixture	kW Per Space	Control Device	
TOTALS FOR PAGE OR USAGE TYPE														

one set of tables by space location and one set by usage type

Table LE3
Post-Installation

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

Results of Operating Hours Survey and Savings Result

Provide Documentation On Survey Results

Usage Area Type	Total Number Sampled	Dates Of Survey From - To	Total kW Saved	Average Operating Hours						Annual kWh Saved	Peak Demand Savings, kW
				Summer Peak	Summer Part Peak	Summer Off Peak	Winter Part Peak	Winter Off Peak	Total		

Table LE4
Annual Report

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

Results of Annual Operating Hours Survey and Savings Result

Provide Documentation On Survey Results

Usage Area Type	Total Number Sampled	Dates Of Survey From - To	Total kW Saved	Average Operating Hours						Annual kWh Saved	Peak Demand Savings, kW
				Summer Peak	Summer Part Peak	Summer Off Peak	Winter Part Peak	Winter Off Peak	Total		

Table LC1
Pre-Installation
Lighting Equipment Expected To Be Installed

Site Name:
Bidder Name:
Date of Table:
Table Completed By:

			EXISTING LIGHTING EQUIPMENT						PROPOSED LIGHTING EQUIPMENT		
Space ID	Circuit ID	Usage Area Type	Equipment Type	Number of Fixtures	Number of Non-Operating Fixtures	kW Per Fixture	kW Per Space or Usage	Exisitng Control Device?	New Control Device?	Control Device Type	Notes
TOTALS FOR PAGE											
OR USAGE TYPE											

one set of tables by space location and one set by usage type

provide operating hours estimates (annual andf peak-period) by usage area in separate table

Table LC2
Post-Installation
Actual Lighting Equipment Replaced and Installed

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

			EXISTING LIGHTING EQUIPMENT						NEW LIGHTING EQUIPMENT		
Space ID	Circuit ID	Usage Area Type	Equipment Type	Number of Fixtures	Number of Non-Operating Fixtures	kW Per Fixture	kW Per Space or Usage	Exisitng Control Device?	New Control Device?	Control Device Type	Notes
TOTALS FOR PAGE											
OR USAGE TYPE											

Table LC3
Pre-Installation
Results of Operating Hours Survey

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

Provide Documentation On Survey Results

Usage Area Type	Total Number Sampled	Dates of Survey From	- To	Total Connected kW	Average Operating Hours: Pre-Installation					
					Summer Peak	Summer Part Peak	Summer Off Peak	Winter Part Peak	Winter Off Peak	Total Annual

Table LC4
Post-Installation
Results of Operating Hours Survey and Savings Results

Site Name:
Bidder Name:
Date of Table:
Table Completed By:

Provide Documentation On Survey Results

Savings Based on Difference In Operating Hours From Table LC3

Usage Area Type	Total Number Sampled	Dates of Survey From	- To	Total Connected kW	Average Operating Hours: Post-Installation						Annual kWh Saved	Peak Demand Savings, kW
					Summer Peak	Summer Part Peak	Summer Off Peak	Winter Part Peak	Winter Off Peak	Total Annual		

Table LC5
Annual Report
Results of Operating Hours Survey and Savings Results

Site Name:

Bidder Name:

Date of Table:

Table Completed By:

Provide Documentation On Survey Results

Savings Based on Difference In Operating Hours From Table LC3

Usage Area Type	Total Number Sampled	Dates of Survey		Total Connected kW	Average Operating Hours: Post-Installation						Annual kWh Saved	Peak Demand Savings, kW
		From	- To		Summer Peak	Summer Part Peak	Summer Off Peak	Winter Part Peak	Winter Off Peak	Total Annual		

Table M1: Motor Survey
Pre- and Post-Installation Data

Complete for all motors.

Contractor Name: ______________________

Site Name: ______________________

Motor Location: ______________________

Motor Application ______________________

Item	Baseline (complete during pre-installation)	High-Efficiency (complete during post-installation)
Motor ID No.		
Table Completed By		
Date of Table		
Nameplate Available (yes/no)		
Manufacturer		
Model No.		
Serial No.		
Service Factor		
Enclosure Type		
Full Load HP		
Volts		
Phase and Hz		
Full Load Amperes		
Full Load Speed (RPM)		
Synchronous Speed (RPM)		
Nominal Efficiency		
Load Served by Motor		
Summer Weekday Operating Hours		
Summer Weekend Operating Hours		
Winter Weekend Operating Hours		
Winter Weekend Operating Hours		
Annual Operating Hours		
Other		

Table M2: Spot Metered Values
Pre- and Post-Installation Data

Complete for all motors.

Contractor Name:
Site Name:
Motor Location:
Motor Application

	pre-installation	post-installation
Item	**Baseline**	**High-Efficiency**
Motor ID No.		
Table Completed By		
Date and Time of Readings		
Instantaneous Volts		
Instantaneous Amps		
Instantaneous kW		
Power Factor		
Temp. of Working Fluid		
Location of Temp. Sensor		
Meter Model No.		
Meter Serial No.		

Table M3: Short Term Metering Results
Pre- and Post-Installation Data

Complete for each motor in approved sample

Contractor Name: ____________________
Site Name: ____________________
Date of Table: ____________________
Table Completed By: ____________________

Motor Location: ____________________
Motor Application: ____________________

Item	Baseline (pre-installation results)		High-Efficiency (post-installation results)
Motor ID No.			
Date and Time Initiated			
Date and Time Completed			
Data-Logger Model No.			
Data-Logger Serial No.			
Instantaneous Amps (spot meter) Table M-2			
Average Amps (short-term meter)			
Normalizing Factor			
No. of Non-Zero Observations			
No. of Obs. Within +/- 10%			
% of Obs. Within +/- 10%			
	Average Operating Hours	Maximum Hours	Average Operating Hours
Summer Peak Hours		774	
Summer Partial Hours		903	
Summer Off Hours		2739	
Winter Partial Hours		1612	
Winter Off Hours		2732	
Total Annual Hours		8760	

Table M4: First Year Sample Selection and Results

To be completed for each unique application.

Contractor Name: ____________________
Site Name: ____________________
Date of Table: ____________________
Table Completed By: ____________________

Application Name:

Item	Value
ID Nos. of Motors Serving Application	
Required Sample Size	
ID Nos. of Motors in Sample	
Average Normalizing Factor	
Average Summer Peak Operating Hours	
Average Summer Partial Peak Oper. Hours	
Average Summer Off Peak Oper Hours	
Average Winter Partial Peak Oper. Hours	
Average Winter Off Peak Oper Hours	
Average Total Annual Operating Hours	

APPENDIX C

Sampling Guidelines For Monitoring Lighting and Motor Efficiency Projects

C.1 Introduction

This section was prepared to provide sampling guidelines for monitoring. The guidelines are applicable to ECMs such as lighting retrofits and energy efficient motor replacements consisting of a large quantity of equipment operated in a similar manner. The sampling guidelines are designed to assist in determining the sample points that should be monitored in order to provide a convincing demonstration of key parameters such as energy consumption or hours of operation.

Information in this section can be used for preparation of site-specific M&V plans. Section C.2 presents an overview of the sampling guidelines. Sections C.3 and C.4 discuss definitions and statistical concepts that underlie sampling. Section C.5 discusses aspects of the sampling method such as designation of usage groups, calculation of sample size, and sample selection. Section C.6 discusses the effects of "outliers" or data points beyond the expected range of values. Section C.7 presents a lighting retrofit example using the sampling guidelines.

C.2 Overview of Sampling Guidelines

The sampling guidelines describe procedures for the selection of a properly sized random sample of representative equipment for monitoring such factors as energy consumption or operating hours. The measurements can then be used to estimate energy use for the population, from which the sample was drawn. Sampling techniques should be used when it is unrealistic to monitor every piece of affected equipment.

Sampling involves the selection of a subgroup of areas or equipment. A successful sample will be sufficiently representative of the population to draw inferences about the population as a whole. The accuracy with which the sample estimate reflects the true population is determined with the specification of statistical criteria such as the degree of confidence and precision level.

The sample size, however, is highly dependent upon the amount of variation in projected use (i.e., equipment energy consumption or hours of operating) for the "population" of affected equipment or systems. For example, if the operating hours of all lighting circuits are very close to each other, only a small sample is required to demonstrate this. If the operating hours vary widely from very high to very low, a large sample size would be needed to estimate the average number of operating hours. However, the sample sizes can be reduced through designation of "usage groups" from which samples are drawn. Usage groups are subsets of the entire population that have similar equipment and operating characteristics. Thus, the proper designation of usage groups is critical for maintaining small sample sizes while still obtaining statistically valid results within specified confidence bounds.

Usage groups are defined based on the equipment's operating characteristics. Indicators used in defining usage groups include: (a) operating schedules that provide information on energy consumption or hours of operation; and (b) type of application or location that provides information on how and when equipment (e.g., fixtures or motors) are operated.

A site-specific sampling plan will indicate how many points need to be monitored, for each usage group, in order to estimate the energy use (i.e., consumption or operating hours) for the population with a specified confidence and precision level. Imposing the same confidence and precision level on each usage group is not necessary in order to ensure desired accuracy requirements for the project as a whole, which is the primary goal. The purpose, however, of imposing the same accuracy requirements is to simplify the sampling plan (from a field implementation perspective) rather than uphold the statistical efficiency of the sample design.

The sampling plan should also include a method for dealing with issues associated with sample points identified as "outliers." Specifically, the elimination of these types of sample points may cause the confidence level of the resulting estimate (average energy consumption or operating hours) to fall below the desired accuracy requirements.

Based on the results of data gathered for a selected period of time (e.g., the first year of an agreement versus the second year), the sample size required may be reduced or increased. It may be advantageous to use the best information available up-front to determine the required sample size so that subsequent determinations of sample size will vary as little as possible. That is, the use of any data that suggests an appropriate sample size will likely result in a properly determined sample size which will not require much modification in later sampling cycles.

C.3 Statistical Definitions

The guideline described in this Appendix for determining sample size is based on several key assumptions: (a) that the parameter in question (i.e., energy consumption or hours of operation) within a correctly defined usage group are predictable and conform to a normal distribution, and (b) accuracy requirements are defined in terms of percentage confidence and precision levels. The federal agency and ESCO will be responsible for specifying accuracy requirements for each project depending on the project's value and the importance associated with obtaining accurate savings estimates.

The following define the above mentioned key terms:

Usage Group. Usage groups are designated for similar types of equipment in areas or with applications that have similar operating characteristics. The designation of usage groups is based on equipment application and operating characteristics. This grouping technique subdivides a large group into smaller groups that are more homogeneous and thus reduce the variance of the projected energy use (i.e., consumption or operating hours), and therefore the overall sample size requirement.

Normal Distribution. Statistical techniques, discussed in this Appendix, are based on the assumption that the projected energy use (or operating hours or whatever parameter is measured) of similar types of equipment, that are classified in the same usage group, are normally distributed. A normal distribution is a frequency distribution of actual data that follows a bell shaped pattern. The validity of the methods require that observations be independent and taken in similar ways so that their averages, and not necessarily the individual observations, approach a normal distribution.

Coefficient of Variation. A parameter that is important in determining the proper sample size is the coefficient of variation or cv(y). This is a measure of the 'spread' of the data or how wide is the bell shape of the normal distribution curve that is assumed to represent the usage group's projected energy use (i.e., consumption or operating hours). Cv(y) is calculated by dividing the standard deviation of the data by the average values of the data. Values for cv(y) between 0.2 and 1.0 are typically observed, although any positive number is possible.

Degree of Confidence and Precision Level. Two other key parameters that affect sample size are degree of confidence and precision level. The degree of confidence is the probability that the estimate is true and falls within some interval. However, increasing the degree of confidence only widens this interval and creates uncertainty as to the true value, thus, a precision level must be specified in conjunction with the degree of confidence. The precision level limits the interval within which the true value falls. The federal agency and ESCO will specify these accuracy requirements. Typical values for the degree of confidence and precision level are 80% and 20%, respectively. These accuracy requirements are intended to allow one to make the statement, for example, that the estimates based on this sampling are within ±20% of the true value and that the federal agency and ESCO are 80% sure of the truth of such a statement.

C.4 Statistical Concepts

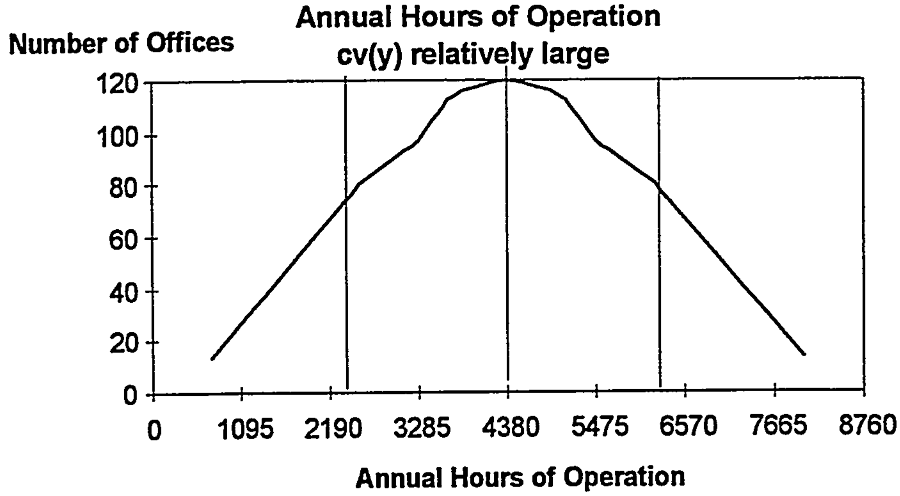
The sampling guidelines emphasize the definition of usage groups so that the population within each group has very similar projected energy consumption, hours of operation, etc. This is extremely important for determining sample size. If the federal agency and the ESCO define a usage group with a wide range of projected energy use within it, then a large sample will need to be metered in order to determine the actual average value. On the other hand, if a usage group has the same equipment with a narrow range of projected use, it will only take a small metered sample to demonstrate energy consumption or operating hours for the population.

Figure C.1 graphs a hypothetical situation where the mean (average) annual hours of operation for the lamps in a usage group (e.g., private offices) is 4,380. The horizontal ("X") axis shows hours of operation (from 0 to 8,760 per year), and the vertical ("Y") axis shows the number of offices with each number of lighting operating hours. There are more offices with about 4,380 hours than any other number of hours, but the offices are quite spread out over the range of hours, requiring a larger sample size (cv(y) is large).

Figure C.2 graphs another hypothetical building where the common area offices also show a mean daily lighting operating hours value of 4,380. However, most of the offices' lighting operating hours are very close to the mean of 4,380. The difference between the distribution that is seen in Figure C.1 versus the one in Figure C.2 is the difference between the need for a large sample and a small one.

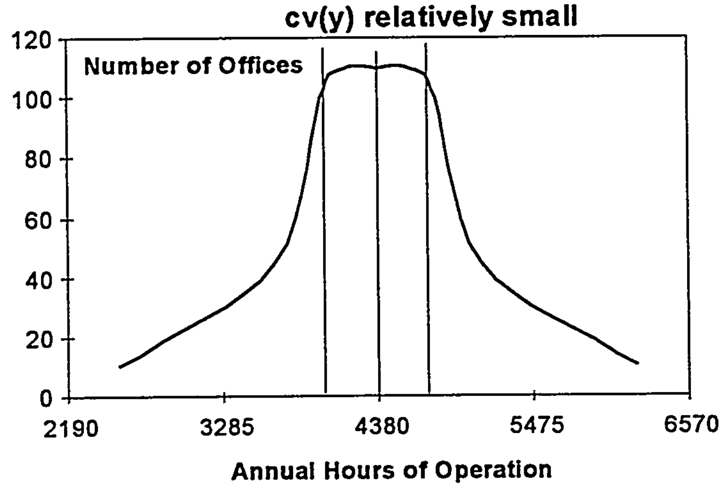
If a small sample was applied to only a few of the private offices represented by Figure C.1, the measured hours of operation would probably be very different from each other. Those few, very disparate cases do not instill confidence that the estimated hours of operation would be close to the real average for the usage group. Based on a few cases, the average annual hours of operation for

Figure C.1
Distribution of Private Offices' Annual Hours of Operation
cv(y) relatively large



the office usage group may appear to range anywhere from 1,500 to 6,000 and there would be little basis for choosing between them. On the other hand, a small sample from the usage group represented in Figure C.2 would very likely contain little variation in measured hours, giving the federal agencies and the ESCO confidence that the average hours are close to those sampled offices, and somewhere around 4,380.

Figure C.2
Distribution of Common Area Offices' Annual Hours of Operation
cv(y) relatively small



The standard deviation is a statistic that helps quantify the width of the distribution curve. The standard deviation would be large for the distribution in Figure C.1 and small for that in Figure C.2 (the vertical lines in Figure C.1 and Figure C.2 show approximately where ±1 standard deviations for these two examples are). A large standard deviation requires a large sample to achieve some confidence that the average of the sample is the average of the population from which it was drawn. On the other hand, a small standard deviation means that a very small sample will provide accurate estimates with a fair amount of confidence.

The size of the standard deviation has meaning only in relation to the size of the mean. In lighting, for example, if the mean hours of operation is 10, a standard deviation of 7 is quite large. However, with a mean of 2,500 (using *annual* hours of operation), a standard deviation of 7 would be extremely small. So, it is the magnitude of the mean in relation to the standard deviation that determines the sample size needed for a desired confidence and precision level.

One way to express this relationship is to divide the standard deviation by the mean, thus expressing the standard deviation as a fraction of the mean. This number is referred to as the coefficient of variation, or cv(y). This value is commonly used in equations that determine a required sample size, and the required sample size goes up rapidly as the cv(y) increases in magnitude.

The desired confidence and precision level also affects the sample size. The specification of these accuracy requirements allows for making statements about the reliability of the estimate or the mean of the sample measurements, i.e. energy consumption or operating hours. As defined earlier in this section, the degree of confidence is the probability that the estimate is true and falls within some interval. However, increasing the degree of confidence only widens this interval and creates uncertainty as to the true value, thus, a precision level must be specified in conjunction with the degree of confidence. The precision level limits the interval within which the true value falls. Typically values for the confidence and precision levels are 80% and 20%, respectively. For example, these accuracy requirements are intended to allow one to make the statement that the estimates based on this sampling are within ±20% of the true value and that the federal agency and ESCO are 80% sure of the truth of such a statement.

C.5 Sample Design

The sampling approach involves dividing the population of equipment into usage groups and drawing random samples from each usage group based on a specified level of confidence and precision. This approach minimizes the total sample size while controlling the sampling error by reducing the variability in equipment use within each usage group.

The following sub-sections discuss topics related to sample design such as usage group designation, sample size calculation, and sample selection.

C.5.1 Designation of Usage Groups

The federal agency or ESCO will need to firmly establish specific criteria for designating usage groups so that the other party can easily identify in which usage group that equipment belongs. The designation of usage groups will be based on similarities in equipment and operating characteristics, specifically:

1. Average operating hours,
2. Variability of operating hours, and
3. Timing of the operating hours.

Indicators of operating characteristics other than monitoring data, if unavailable, include: (a) operating schedules that provide information on hours of operation; and (b) area type designations and equipment applications that provide information on how and when equipment might be operated.

Usage groups should be defined on a per site basis. Examples of standard usage groups for fan motors with similar operating characteristics are HVAC ventilation supply fans, return fans, and exhaust fans. Examples of standard usage groups for lighting projects are fixtures with similar operating characteristics in offices, laboratories, hallways, stairwells, common areas, perimeters, storage areas, etc.

In some instances, area type alone may be insufficient to designate usage groups. Usage groups may need to be further subdivided if an area type is inherently variable in nature due to different characteristics of their human occupants. For example, some laboratories may have longer operating hours than others and should be subdivided, if information is available that predicts the operating hours (e.g., computer laboratory hours are always 8 hours per day while agriculture laboratory hours are always 4 hours per day).

When a sample is taken within a well-defined usage group, the range of the projected energy consumption or operating hours will be narrow; and, thus requires a small sample. At a site level, the overall sample that is aggregated across all usage groups is smaller than without specifying usage groups. Thus, the first step in determining sample size is to define the usage groups within a project. Then sample sizes must be calculated separately for each usage group.

Usage groups will typically be defined for the population on a building-by-building basis. However, for some projects it may be reasonable to determine sample sizes across a number of buildings with similar usage areas. For example, if an ESCO is conducting lighting retrofits in barracks then the usage groups of common sleeping areas, private sleeping areas, washrooms, etc. may be totaled for all the barracks in order to determine total population size for each usage group. Samples would be selected from all the barracks. This would result in fewer monitoring points than if each building was considered separately.

C.5.2 Calculation of Sample Sizes

To determine the necessary sample size of equipment or circuits to monitor ***for each of the usage groups,*** the following equation should be used:

$$n = \frac{z^2 cv(y)^2}{p^2}$$

where,

n	=	required sample size (in number of circuits or pieces of equipment). Values of *n* should be rounded up to the next higher integer. For example, calculated sample sizes of 7.129 and 7.657 would both indicate a sample size of 8.
z	=	degree of confidence. The degree of confidence is the probability that the value (mean of the unit of measurement *y*) is true and falls within the confidence interval. A commonly specified degree of confidence is 80% where z=1.282 (from a table of normal distribution).
cv(y)	=	coefficient of variation of unit of measurement *y*. The cv(y) is the ratio of the standard deviation to the mean for the variable in question. Typically for the first year of measurement, a default cv(y) of 0.5 for a homogeneous usage group is assumed as the nominal value. In subsequent years, cv(y) from actual sample calculations could be used when available in order to reduce the sample size.
p	=	precision level. The precision level limits the interval within which the true value (mean of the unit of measurement *y*) falls. A commonly specified precision level is 20% where $p = 0.20$.

When the population under study is relatively small compared to the sample size estimated, a finite population correction factor may be employed. The finite population adjustment equation is:

$$n^* = \frac{n}{1 + n/N}$$

Where n^* is the adjusted sample size, n is the sample size estimated above and N is the total population size. Note, however, that when n is much smaller than N (about 10% of N or smaller) this correction has little effect.

For the first year of metering, a default cv(y) of 0.5 for a homogeneous usage group may be used, as no prior knowledge of distribution may exist. If information is available, cv(y) is obtained by dividing the standard deviation by the mean of the measurements. Cv(y) may be different for different usage groups. For example, when there is prior information available for a lighting project, (e.g. after the first monitoring period's worth of data are available) the mean (or average) of the unit of measurement is calculated as follows:

$$\text{Average Hours of Operation} = \frac{\sum \text{Metered Hours}}{\text{Number of Data Points}}$$

The standard deviation is computed as:

$$\text{Standard Deviation} = \sqrt{\frac{\sum(\text{hours} - \text{average hours})^2}{\text{Number of Data Points} - 1}}$$

Cv(y) is computed as:

$$cv(y) = \frac{\text{Standard Deviation}}{\text{average hours}}$$

Therefore, for the monitoring required after the year of installation cv(y) may not be 0.5 for each usage group, and thus, the sample size may be different than in the first monitoring period. The key to being able to reduce the cv(y) in subsequent monitoring periods, and therefore sample size requirements, is to define usage groups with very similar equipment and operation characteristics. In the event that monitoring data demonstrates that usage groups were poorly designated, then usage groups may need to be split, joined, or reallocated. The federal agency and ESCO will need to agree on the criteria for redesignating usage groups.

Table C.1 presents an example of required sample sizes for various populations of equipment assuming a default cv(y) of 0.5, confidence level of 80%, precision level of 20%, and the use of the finite population adjustment.

Table C.1
Sample Size Table

Population	Sample Size
4	3
8	4
12	6
16	7
20	7
25	8
30	8
35	8
40	9
45	9
50	9
60	9
70	9
80	10
90	10
100	10
125	10
150	10
175	10
200	10
300	10
400	11
500	11

This table is valid for 80% confidence level, 20% precision, cv(y) of 0.5 and using a finite population correction factor.

C.5.3 Sample Selection - Specific Points of Control for Monitoring

Once the sample size is determined the specific circuits, points of control or pieces of equipment are selected for actual monitoring. In order for the sampling to be valid, the points must be selected randomly. The sample should be random across all areas and/or equipment applications where measures are installed. Clustering of samples in a single part of a building should be avoided. For each performance period of the contract, a new random sample should be selected.

The federal agency will use the information and electronic equipment surveys submitted by an ESCO to determine or review the random locations and/or equipment applications of the sample that will be monitored. The federal agency or the ESCO will use a random number generator in order to specify the monitoring locations or equipment applications. Alternate locations may be included in the sample selection in order to replace rooms and/or equipment applications which are not accessible.

In the case of monitoring operating hours, lighting loggers are an acceptable metering device. If a logger is assigned to a fixture it will only meter operating hours for the control point, e.g. a light switch, associated with that fixture. Special caution should be used in rooms with multiple switches, particularly for instances where each switch controls a portion of the fixtures' lamps.

Alternatively, circuits can be metered using status indicating devices such as current transducers. Circuit selection to accommodate multiple switches for a single, specific usage group is possible but unlikely. Circuit selection and metering will be carefully reviewed by the federal agency to confirm what electrical equipment is on each circuit and how indicators such as current will be used to indicate lighting use.

C.6 Outliers in Data Analysis

Monitored data will be checked for reasonableness and completeness by the federal agency. An analysis of the monitored data may result in the identification of *outliers* - i.e., data beyond the expected range of values (or two to three standard deviations away from the average of the data). These sample points will be investigated. Common statistical practice includes eliminating a sample point if in fact it is in error but not because it differs from other sampling points. Some outliers may result due to mis-specification of usage groups. In this case, the elimination of a sampling point identified as an outlier could potentially cause the remaining sample to be unrepresentative of the population and thus skew the results. Procedures for eliminating data points should follow standard statistical techniques. Elimination and redesignation of usage groups should be well documented for approval by the federal agency.

It is important to remember that the goal of the sampling is to obtain statistically valid results within specified confidence bounds (e.g., 80% confidence and 20% precision level). The elimination of sample points may cause the confidence level of the estimate to fall below specified requirements. To safeguard against this possibility, one option is to over sample by 10%. However when over-sampling is employed, the federal agency should require that the ESCO submit *all* metered data. Over-sampling should be reported and documented in the site-specific M&V plans and savings reports.

C.7 Application of the Sampling Method

This section describes the application of the sampling approach in the measurement and verification of a hypothetical lighting project. The example project consists of a lighting retrofit where fixtures receive energy-efficient lamps and ballasts. The retrofit affects a variety of fixtures in the following areas of an office building: hallways, conference rooms, private offices, common areas, lobbies, restrooms, and exterior lighting areas. The M&V method chosen is Method LE-B-01 (for more details refer to Chapter 10). M&V activities include conducting equipment surveys to document baseline and post-installation fixture wattages and post-installation monitoring of operating hours for a statistically valid sample of fixtures. For purposes of this example, it is assumed that measurement and verification is at the beginning stages of the post-installation monitoring of operating hours.

The following discussion of sampling for post-installation monitoring of lighting operating hours covers the designation of usage groups, the calculation of sample sizes and the selection of monitoring points. The steps include:

1. Generate a list of usage groups based on similar operating characteristics. Indicators used in defining usage groups when no monitoring data are available include: (a) operating schedules that provide information on hours of operation; and (b) area type designations that provide information on how and when fixtures are operated. From the post-installation equipment survey, summarize operating characteristics by fixture location and projected daily hours of operation. Tables C.2 and C.3 presents projected seasonal-daily hours of operation by usage group and annual time-of-use hours of lighting operation by usage group for the example, respectively. These tables are useful in summarizing operating characteristics of fixtures for purposes of defining usage groups.

2. Assign each line item in the lighting post-installation equipment survey to a usage group. It should be noted that each line in the equipment survey should contain the number and type of fixtures operated by a single circuit or switch as well as a description of the location.

Table C.2*

Example: Lighting Retrofit in an Office Building

Projected Daily Hours of Lighting Operation For Each Usage Group**

Usage group	Summer Weekday	Summer Weekend	Winter Weekday	Winter Weekend
Hallways	24	24	24	24
Conference Rooms	5.75	0	5.75	0
Private Offices	13.5	0	13.5	0
Common Area Offices	12.5	12.5	12.5	12.5
Lobbies	16.5	16.5	16.5	16.5
Restrooms	24	24	24	24
Exterior Lights	10	10	14	14

* The projected hours of operation listed in these tables are only examples for a hypothetical project. ESCOs must report hours of operation and usage areas that are specific to each project.
** Hours of operation are projected based on operating schedules and fixture location when no monitoring data is available.

Table C.3

Example: Lighting Retrofit in an Office Building

Annual TOU Hours of Lighting Operation For Each Usage Group*

Usage group	Summer On-Peak	Summer Mid-Peak	Summer Off-Peak	Winter Mid-Peak	Winter Off-Peak
Hallways	498	747	1,611	2,210	3,694
Conf. Rooms	477	0	0	978	0
Private Offices	415	706	0	1,700	595
Common Offices	498	498	492	2,125	950
Lobbies	498	747	719	2,210	1,849
Restrooms	498	747	1,611	2,210	3,694
Exterior Lights	0	83	1,107	510	2,934

* For this example, the hours by time-of-use periods are based on the projected daily hours of operation specified in Table C.2.

3. For each usage group, tabulate: a) the population of survey lines; and, b) coefficient of variation of the projected operating hours, if possible. Since this is the first post-installation period of measurements, cv(y) of 0.5 for a homogeneous usage group is assumed as the nominal value. In subsequent years, cv(y) calculated from actual monitored data will be used.

4. For the project, specify accuracy requirements - i.e., degree of confidence and precision level. For this example, it is assumed that federal agency pays on measured performance and there is some concern that the ESCO's projected hours of operation are somewhat high; thus, the federal agency might specify the sample size meet accuracy requirements where the degree of confidence is 80% and the precision level is 20%.

5. Calculate the sample size per usage group using the equation specified in sub-section C.5.2 (using the finite population correction factor) and the assumptions stated in steps 3 and 4.

6. Summarize sample calculations in a table that presents for each usage group the population of survey lines, projected kWh savings, and sample size. For the example, Table C.4 presents a summary of this information where the sample sizes range from 6 to 11 across the seven usage groups.

7. Select a random sample of monitoring points based on the calculated sample size by usage group. A random sample of locations for monitoring can be selected using a random number generator in order to specify the monitoring locations, i.e. which locations in each usage group should be monitored in order to determine operating hours for each usage group. Select alternate locations in case certain locations are not accessible. One technique that can be used to select a random sample for each usage group for a given project includes the following steps:

   a) For the project, group lines from the post-installation equipment survey into the usage groups and then number the lines in each usage group.
   b) Generate a list of 20 random numbers between 1 and the population of the usage group for the project.
   c) Starting at the beginning of the random number list, use the random number to select a matching line number in the post-installation equipment survey.
   d) Move to the next line on the random number list, use the random number to select a matching line number in the post-installation equipment survey.
   e) Repeat step d until the number of selected lines reaches the desired sample size by usage group for the project.
   f) Repeat steps b through e for each usage group in the project.

g) Place a logger on any fixture in an area identified by the selected line number. Special caution will be used with these loggers in rooms that have multiple fixtures on multiple switches.

Table C.4
Example: Lighting Retrofit in an Office Building
Sample Size for Each Usage Group

Usage group	Population of Survey Lines	Projected Operating Hours Per Year*	Estimated Annual kWh Savings By Usage Group	Sample Size**
Hallways	70	8,760	245,520	9
Conference Rooms	60	1,455	7,200	9
Private Offices	350	3,416	147,000	11
Common Area Offices	120	4,563	216,000	10
Lobbies	22	6,023	66,000	8
Restrooms	80	8,760	17,520	10
Exterior Lights	10	4,634	2,000	6
Totals	703	NA	701,240	63

* Projected operating hours based on Table C.3.
** The sample size is based on a 80% confidence level and 20% precision, a default cv(y) of 0.5, and the finite population correction factor.

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