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ECO

Energy Conservation and Commercialization Project

A Program of USAID, Ministry of Power and ICICI

India Specific Performance Measurement & Verification Protocol

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Activity 3
Milestone 3A

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Preface

This report is part of the deliverable for Milestone 3A, draft model M&V protocols for verifying energy savings and benefits, of the ECO project. The report covers work done under this Milestone from September 2000 through December 2000. This milestone is part of Activity 3, support to Energy Efficiency Service Industry, to assist the ESCO industry to organize itself to offer attractive business solutions to industry.

The ECO project is being implemented by Bechtel National Inc (Nexant Inc) under a USAID contract, LAG-I-00-98-0000. This contract has been issued by the USAID Mission in New Delhi as a part of the IQC (Indefinite Quantity Contract) currently in place through USAID's Global Bureau. The project contract was signed on February 29, 2000, and continues through December 2003.

DISCLAIMER

This protocol serves as a guideline to measure and verify energy savings from an energy efficiency program. This protocol does not have any legal authority/ obligation to supervise, monitor or ensure compliance with provisions negotiated and included in contractual arrangements between third persons or third parties.

Purpose and Scope

The purpose of this protocol is to lay the framework and operational aspects of independently verifying energy savings and benefits from energy efficiency projects and ESCO contracts, applicable for industrial, commercial and residential sectors specific to India. The aim is to enable ESCOs, End-users, Financial Institutions and Consultants to speak in one voice. The protocol eventually will also help in funding of such projects by financial institutions by taking advantage of 'emission trading'.

Energy conservation measures covered herein include fuel and electricity saving measures, through installation or retrofit of equipment, and/or modification of operating procedures.

This protocol is intended to be fuel neutral and can be applied to a broad range of applications. Essentially, for an ESCO contract, this document can help in selecting an M&V (measurement and verification) approach that is most appropriate for the project taking into account the project costs, technology specific requirements and risk assessment.

This protocol is not intended to prescribe contractual terms between buyers and sellers of efficiency services, although it provides guidance on some of these issues. Once other contractual issues are decided, this document can help in the selection of the measurement & verification (M&V) approach that best matches: i) project costs and savings magnitude, ii) technology-specific requirements, and iii) risk allocation between buyer and seller, i.e., which party is responsible for installed equipment performance and which party is responsible for achieving long term energy savings.

The IPMVP 2000 approach is found to be applicable to M&V of savings for energy efficiency projects in Indian scenario too. However, we need to make base-line adjustments for factors such as capacity utilization, throughput, power cuts, interruptions. The option D's applicability in industry may not be widely applicable as software packages covering specific manufacturing processes may not be readily available.

Structure

This protocol is based on the IPMVP 2000. The IPMVP is quite generic in nature and an effort has been made to provide specific approaches in this protocol. The India specific Measurement and Verification Protocol is divided into three volumes:

Volume I : M&V Protocol - Industrial
Volume II : M&V Protocol - Commercial
Volume III : M&V Protocol - Residential

Voulme I addresses the typical ECMs (Energy Conservation Measures) in the Indian Industrial sector in addition to overview of the best practices available in the IPMVP. Future work which needs to be done and a suggested way forward is also provided.

Volume II and Vol III developed along the same lines address the commercial and residential sector respectively.

Move Forward & future Work

The future work is in terms of adding more specific and elaborate case examples for each of the options as in the case of IPMVP. A core group has been formed on the a *egroups url,* who have been constantly providing feedback on the discussions on need for a India specific protocol, technical and financial issues. This approach need to be extended wherein more members can get involved and share their experiences. This would enable constant improvement and updating the protocol periodically taking into account the developments that take place.

The end-users and financial institutions need to be constantly trained as they are the major stakeholders in such energy efficiency projects apart from the ESCOs. Systems need to be worked out for third-party M&V contractors and utilizing emission trading for funding energy efficiency projects.

The next version could be the development of a number of examples under Indian scenario the popular ECMs on the lines as presented in Appendix A of the IPMVP 2000. This would go a long way to have adequate comfort for funders (external) and internal (within the corporate) as well the end users.

Chapter 1 Introduction

1.1 Background

India is currently the world's sixth largest and second fastest growing source of global greenhouse gas (GHG) emissions. The single largest source (48 percent) of GHG emissions in India is coal-fired power plants, which constitutes the majority of electricity supply resources. Estimates indicate an enormous scope for implementing end-use improvements in various electricity-consuming sectors in a cost-effective manner.

The importance of energy conservation has been recognized in India but market distortions and policy barriers continue to plague the widespread commercialization and large-scale implementation of end-use energy efficiency improvements.

In this context, an important step has been USAID/India's ECO (Energy Conservation and Commercialization) activity, which has been designed to continue efforts to improve end-use efficiency of the Indian power sector in the context of emerging regulatory and institutional reforms. ECO was designed in 1998 on the basis of extensive inputs from partners, stakeholders and customers.

1.2 ECO Objectives

Energy Conservation and Commercialization (ECO) activity aims to promote wide-spread commercialization of energy efficiency technologies and services in India, thereby contributing to the reduction in growth of greenhouse gas emissions. It has two components:

(1) Energy Efficiency Market Development and Financing ("Markets" Component), and
(2) Energy Efficiency Policy and Institutional Reforms ("Policy" Component)

Activities of the Markets Component to lead to the development of strategies and implementation of programs that will address energy efficiency market barriers. Strengthen energy efficiency markets and develop innovative financial mechanisms.

Policy component will address policy development and reform issues at the central and state levels. To address constraints that cause market distortions, e.g. government-administered costs; irrational tariffs, taxes and subsidies; inadequate cost recovery; commercial (non-technical losses); weaker standards for energy efficiency performance, and ineffective billing/ collection mechanisms.

1.3 ECO Markets Component - M&V protocol

Immense opportunities exist for improving energy efficiency in every sector of the Indian economy. Potential investment exceeds Rs. 12,000 crores per year, nearly half of which exists in the industrial sector alone. Actual investments being made today are but a small fraction of the economically attractive investments available. One of the barriers to increased investment is the lack of consistent and objective procedures and guidelines for quantifying energy savings. Measurement and

Verification (M&V) Protocols establish a common framework and define acceptable procedures for determining savings from energy efficiency and energy conservation projects. Formally adopting a standard M&V protocol will result in more reliable energy saving estimates and improve lender confidence for securing lower cost financing for energy efficiency projects.

In this light, efforts were made to develop India specific M&V protocols for independently verifying energy savings in ESCO contracts.

1.4 ESCOs

Energy Service companies (ESCOs) develop and implement energy efficiency projects that support themselves financially based upon measured and verified savings, these projects generate. ESCOs often guarantee the savings to be realized and typically an agreed percentage of the savings is paid by the to the ESCO to cover the cost of the services while simultaneously leading to positive cash flows for the client. This service from ESCOs is often termed as performance contracting.

The concept of ESCOs is relatively new to India. Though, end-users of energy are overwhelmed by the ESCO concept, in the absence of any standards for measuring and verifying savings, they are not clear as to how to go about such projects. Surveys indicate energy efficiency projects, with good Measurement & Verification results in increased and consistent energy savings. The importance of M&V and a protocol therefore becomes imminent in this background.

1.5 Role of Protocol

Essentially for laying the framework and operational aspects of independently verifying energy savings and benefits for ESCO contracts in India, applicable for industrial, commercial and residential sectors. This Protocol:

- Is based on the IPMVP (International Performance Measurement and Verification Protocol) and is modeled along the lines of the FEMP (Federal Energy Management Program) document
- Provides all stakeholders a common set of terms to discuss key M&V project-related issues and establishes methods, which can be used in energy performance contracts.
- Defines broad techniques for determining savings from both a "whole facility" and an individual technology
- Applies to a variety of facilities including residential, commercial, institutional and industrial buildings, and industrial processes.
- Provides outline procedures which i) can be applied to similar projects throughout all geographical regions, and ii) are internationally accepted, impartial and reliable.
- Presents procedures, with varying levels of accuracy and cost, for measuring and/or verifying: i)baseline and project installation conditions, and ii)long-term energy savings.
- Provides a comprehensive approach to ensuring that quality issues are addressed in all phases of ECM design, implementation and maintenance.

- Creates a living document that includes a set of methodologies and procedures that enable the document to evolve over time.
- Is Fuel neutral - the goal is to verify **cost** savings
- Does not dictate approach -this Protocol is intended as a guideline for measurement and verification in energy efficiency projects and is essentially a tool to help ESCOs prepare an M&V plan which adheres to International standards.
- Is intended for a broad range of applications across all the sectors of the economy viz. Industrial, commercial and residential i.e. it is neither process nor technology specific.

1.6 Audience for protocol

The target audience for this protocol includes:

- ESCOs (Energy Service Companies)
- Financial Institutions
- Consultants
- Project developers
- Researchers
- Energy managers
- Industry and other relevant associations
- Government agencies
- Contractors like CPWD

1.7 Uses of protocol

This protocol will enable all stakeholders i.e. ESCOs, end-users, financial institutions and consultants to speak in one voice and thereby minimize disputes in the measurement & verification of savings. Eventually, it will render funding by financial institutions much faster and easier. Financial institutions will be able to make use of 'emission-trading' for funding such energy saving projects.

Chapter 2 Overview of IPMVP M&V guidelines

2.1 Basic Concept

Facility energy savings are determined by comparing the energy use before and after the installation of energy conservation measures. The "before" case is called the baseline; the "after" case is referred to as the post-installation or performance period. Proper determination of savings includes adjusting for changes that affect energy use but that are not caused by the conservation measures. Such adjustments may account for differences in weather, addition of loads, throughput, product-mix, raw material changes, number of shift operation changes and occupancy conditions between the baseline and performance periods. In general,

Equation (1)

$$\text{Savings} = \text{Baseline Energy Use}_{(\text{adjusted})} - \text{Post-Installation Energy Use} \pm \text{Adjustments}$$

Baseline and post-installation energy use can be determined using the methods associated with several different M&V approaches. These approaches are termed M&V Options A, B, C, and D. A range of options is available to provide suitable techniques for a variety of applications. How one chooses and tailors a specific option is based on the level of M&V rigor required to obtain the desired accuracy level in the savings determination and is dependent on the complexity of the ECM, the potential for changes in performance, and the measure savings value.

The energy savings are guaranteed and, therefore, savings verification. The function of verification is to reduce project risk. The challenge of M&V is to balance M&V costs and savings certainty with the value of the conservation measures.

2.2 M&V Overview

This chapter is an overview of the M&V concepts and issues associated with performance contracting projects. Also included are summaries of M&V Options A, B, C, and D. The last portion of this chapter discusses the degree of rigor required in the M&V effort.

When planning a savings measurement process, it is helpful to consider the nature of the facility's energy use pattern, and the ECM's impacts thereon. Consideration of the amount of variation in energy patterns and the change needing to be assessed will help to establish the amount of effort needed to determine savings. The following three examples show the range of scenarios that may arise.

ECM reduces a constant load without changing its operating hours. Example: Lighting project where lamps and ballasts in an office building are changed, but the operating hours of the lights do not change.
ECM reduces operating hours while load is unchanged. Example: Automatic controls shut down air handling equipment or lighting during unoccupied periods.
ECM reduces both equipment load and operating hours. Example: Resetting of temperature on hot water radiation system reduces overheating, thereby reducing boiler load and operating periods.

Generally, conditions of variable load or variable operating hours require more rigorous measurement and computation procedures. It is important to realistically anticipate costs and effort associated with completing metering and data analysis activities. Time and budget requirements are often underestimated leading to incomplete data collection. It is better to complete a less accurate and less expensive savings determination than to have an incomplete or poorly done, yet theoretically more accurate determination that requires substantially more resources, experience and/or budget than available.

2.3 Methods

The Energy use quantities can be "measured" by one or more of the following techniques:

- Utility or fuel supplier invoices or meter readings.
- Special meters isolating a retrofit or portion of a facility from the rest of the facility. Measurements may be periodic for short intervals, or continuous throughout the post-retrofit period.
- Separate measurements of parameters used in computing energy use. For example, equipment operating parameters of electrical load and operating hours can be measured separately and factored together to compute the equipment's energy use.
- Computer simulation which is calibrated to some actual performance data for the system or facility being modeled
- Agreed assumptions or stipulations of ECM parameters that are well known. The boundaries of the savings determination, the responsibilities of the parties involved in project implementation, and the significance of possible assumption error will determine where assumptions can reasonably replace actual measurement. For example, in an ECM involving the installation of more efficient light fixtures without changing lighting periods, savings can be determined by simply metering the lighting circuit power draw before and after retrofit while assuming the circuit operates for an agreed period of time. This example involves stipulation of operating periods, while equipment performance is measured.

The Adjustments term in equation (1) can be of two different types:

- **Routine** Adjustments for changes in parameters that can be expected to happen throughout the post-retrofit period and for which a relationship with energy use/ demand can be identified. These changes are often seasonal or cyclical, such as weather or occupancy variations. This protocol defines four basic Options for deriving routine adjustments.
- **Non-routine** Adjustments for changes in parameters which cannot be predicted and for which a significant impact on energy use/demand is expected. Non-routine adjustments should be based on known and agreed changes to the facility.

The different M&V approaches are primarily differentiated by where the energy use 'boundary line' is drawn. If only the measure being implemented is being evaluated independent of other energy using systems, the approach is considered *retrofit isolation*. If the performance of a measure or a number of measures affects an entire facility and the total energy consumption is evaluated, the approach is considered *whole facility*. These two approaches are further divided according to the level of rigor and type of analysis used. These various approaches are given letter names as follows:

Retrofit Isolation Methods

Option A — Partially measured or one time measurement

Option B — Longer or continuous measurement

Whole Facility Methods

Option C — Whole facility energy analysis

Option D — Computer Simulation.

Table 1: Summary of M&V – Options, Savings Calculations & Applications

M&V Option	How Savings Are Calculated	Typical Applications
A. Partially Measured Retrofit Isolation Savings are determined by partial field measurement of the energy use of the system(s) to which an ECM was Applied, separate from the energy use of the rest of the facility. Measurements may be either short-term or continuous. Partial measurement means that some but not all parameter(s) may be stipulated, if the total impact of Possible stipulation error(s) is not significant to the resultant savings. Careful review of ECM design and Installation will ensure that stipulated values fairly represent the probable actual value. Stipulations should be shown in the M&V Plan along with analysis of the significance of the error they may introduce.	Engineering calculations using short term or continuous post-retrofit measurements and Stipulations.	Any end-use efficiency improvement which has savings less than 20% energy reduction on the total bill and that have no/ little impact on the other ECMs. Motor efficiency upgrades Lighting retrofit where power draw is measured periodically.
B. Retrofit Isolation Savings are determined by field measurement of the energy use of the systems to which the ECM was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.	Engineering calculations using short term or continuous measurements	Application of controls to vary the load on a constant speed pump using a variable speed drive. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor. In the baseyear this meter is in place for a week to verify constant loading. The meter is in place throughout the post-retrofit period to track variations in energy use.
C. Whole Facility Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken throughout the post-retrofit period.	Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression .	Multifaceted energy management program affecting many systems in a building. Energy use is measured by the gas and electric utility meters for a twelve month baseyear period and throughout the post-retrofit period.
D. Calibrated Simulation Savings are determined through simulation of the energy use of components or the whole facility. Simulation routines must be demonstrated to adequately model actual energy performance measured in the facility. This option usually requires considerable skill	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use Metering.	Multifaceted energy management program affecting many systems in a building but where no baseyear data are available. Post-retrofit period energy use is measured by the gas and electric utility meters. Baseyear energy

in calibrated simulation.		use is determined by simulation using a model calibrated by the post-retrofit period utility data.

2.3.1 Option A

2.3.1.1 Introduction

An Option A-based M&V method involves a retrofit or system-level M&V assessment. The approach is intended for retrofits where either performance factors (e.g., end-use capacity, demand, power) or operational factors (lighting operational hours, cooling ton-hours) can be spot or short-term measured during the baseline and post-installation periods. The factor not measured is stipulated based on assumptions, analysis of historical data, or manufacturer's data. Using a stipulated factor is appropriate only if supporting data demonstrates its value is not subject to fluctuation over the term of the contract.

All end-use technologies can be verified using Option A; however, the accuracy of this option is generally inversely proportional to the complexity of the measure. In addition, within Option A, various methods and levels of accuracy in verifying performance/ operation are available. The level of accuracy depends on the validity of assumptions, quality of the equipment inventory, and whether spot/short-term measurements are made. The penalty associated with low accuracy is not achieving the estimated measure savings and the associated utility bill cost reductions.

Option A can be applied when identifying the potential to generate savings is the most critical M&V issue, including situations in which:

- The magnitude of savings is low for the entire project or a portion of the project to which Option A can be applied.
- The risk of achieving savings is low or ESCO payments are not directly tied to actual savings.

2.3.1.2 Approach

Option A is an approach designed for projects in which the potential to generate savings must be verified, but the actual savings can be determined from stipulated factors, short term data collection, and engineering calculations. Post-installation energy use is not measured throughout the term of the contract. Post-installation and perhaps base-line energy use is predicted using an engineering or statistical analysis of information that does not involve long-term measurements.

With Option A, savings are determined by measuring the capacity, efficiency, or operation of a system before and after a retrofit and by multiplying the difference by a stipulated factor. Stipulation is the easiest and least expensive method of determining savings. It can also be the least accurate and is typically the method with the greatest uncertainty of savings. This level of verification may suffice for certain types of projects in which a single factor represents a significant portion of the savings uncertainty. Option A is appropriate for projects in which both parties agree to a payment stream that is not subject to fluctuation due to changes in the operation or performance of the equipment. Payments could be subject to change based on periodic measurements, however.

2.3.1.3 M&V Considerations

Option A includes procedures for verifying the following:

- Baseline conditions have been properly defined.
- The equipment and/or systems contracted to be installed were installed.
- The installed equipment/systems meet contract specifications in terms of quantity, quality, and rating.
- The installed equipment is operating and performing in accordance with con-tract specifications and is meeting all functional tests.
- The installed equipment/ systems continue, during the term of the contract, to meet contract specifications in terms of quantity, quality, rating, operation, and functional performance.

This level of verification is all that is contractually required for certain types of performance contracts. Baseline and post-installation conditions (e.g., equipment quantities and ratings such as lamp wattages, chiller kW/ton, or motor kW) represent a significant portion of the uncertainty associated with many projects.

All end-use technologies can be verified using Option A; however, the accuracy of this option is generally inversely proportional to the complexity of the measure. Thus, the savings from a simple lighting retrofit will typically be more accurately estimated with Option A than the savings from a chiller retrofit. If greater accuracy is required, Options B, C, or D may be more appropriate.

Within Option A, various methods and levels of accuracy in verifying performance are available. The level of accuracy depends on the quality of assumptions made, and it can also depend on whether an inventory method is used for ensuring nameplate data and quantity of installed equipment or whether short-term measurements are used for verifying equipment ratings, capacity, operating hours and/or efficiency.
The potential to generate savings may be verified through observation, inspections, and/or spot/short-term metering conducted immediately before and/or immediately after installation. Annual (or some other regular interval) inspections may also be conducted to verify an ECM's or system's continued potential to generate savings.

Savings potential can be quantified using any number of methods, depending on contract accuracy requirements. Equipment performance can be obtained either directly (through actual measurement) or indirectly (through the use of manufacturer data). There may be sizable differences between published information and actual operating data.

Where discrepancies exist or are believed to exist, field-operating data should be obtained. This could include 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. Baseline and post-installation equipment should be verified with the same level of detail. Either formally or informally, all equipment baselines should be verified for accuracy and for concurrence with stated operating conditions. Actual field audits are almost always required.

2.3.2 Option B

2.3.2.1 Introduction

Option B involves a retrofit or system-level M&V assessment. The approach is intended for retrofits with performance factors (e.g. end-use capacity, demand, power) and operational factors (lighting operational hours, cooling ton-hours) that can be measured at the component or system level. It is appropriate to use spot or short-term measurements to determine energy savings when variations in operations are not expected to change. When variations are expected, it is appropriate to measure factors continuously during the contract.

Option B is typically used when any or all of these conditions apply:

For simple equipment replacement projects with energy savings that are less than 20% of total facility energy use as recorded by the relevant utility meter or sub-meter.

- When energy savings values per individual measure are desired.
- When interactive effects are to be ignored or are stipulated using estimating methods that do not involve long-term measurements.
- When the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.
- When sub-meters already exist that record the energy use of subsystems under consideration

2.3.2.2 Approach

Option B verification procedures involve the same items as Option A but generally involve more end-use metering. Option B relies on the physical assessment of equipment change-outs to ensure the installation is to specification. The potential to generate savings is verified through observations, inspections, and spot/short-term/ continuous metering. The continuous metering of one or more variables may only occur after retrofit installation. Spot or short-term metering may be sufficient to characterize the baseline condition.

2.3.2.3 M&V Considerations

Option B is for projects in which (a) the potential to generate savings must be verified and (b) actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A, plus the determination of energy savings during the contract term through short-term or continuous end-use metering.

Option B:

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

- Determines an energy (and cost) savings value using short-term or continuous measurement of performance and operating factors.

All end-use technologies can be verified with Option B; however, the degree of difficulty and costs associated with verification increases as metering complexity increases. Energy savings accuracy is defined by the owner or is negotiated with the ESCO. The task of measuring or determining energy savings using Option B can be more difficult and costly than that of Option A. Results are typically more precise, however, than the use of stipulations as defined for Option A.

Methods involve the use of pre- and post-installation measurement of one or more variables. If operation does not vary between pre and post conditions, monitoring pre-installation operation is not necessary. Spot or short-term measurements of factors are appropriate when variations in loads and operation are not expected. When variations are expected, it is appropriate to measure factors continuously. Performing continuous measurements (i.e. periodic measurements taken over the term of the contract) account for operating variations and will result in closer approximations of actual energy savings. Continuous measurements provide long-term persistence data on the energy use of the equipment or system. These data can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit. In situations like constant-load retrofits there may be no inherent benefit of continuous over short-term measurements. Measurement of all affected pieces of equipment or systems may not be required if statistically valid sampling is used. For example, population samples may be measured to estimate operating hours for a selected group of lighting fixtures or the power draw of certain constant-load motors that have been determined to operate in a similar manner.

2.3.3 Option C

2.3.3.1 Introduction

Option C encompasses whole-facility or main-meter verification procedures that provide retrofit performance verification for those projects in which whole-facility baseline and post-installation data are available. Option C usually involves collecting historical whole-facility baseline energy use data and the continuous measuring of whole-facility energy use after ECM installation. Baseline and periodic inspections of the equipment are also warranted. Energy savings under Option C are estimated by developing statistically representative models of whole-facility energy consumption (i.e., kCal and/or kWh) or performing simple utility bill comparisons.

In general, Option C should be used with complex equipment replacement and controls projects for which predicted savings are relatively large (i.e., greater than about 10% to 20% of the site's energy use), on a monthly basis. Option C regression methods are valuable for measuring interactions between energy systems or determining the impact of projects that cannot be measured directly, such as insulation or other building envelope measures. Specific difficulties associated with Option C methods include meeting the following requirements:

Using at least 12, and preferably 24, months of pre-installation data to calculate a baseline model

Using at least 9, and preferably 12, months of post-installation data to calculate first-year savings

Collecting adequate data in order to generate accurate baseline and post-installation models, and, if required

Adjusting the analyses to have the baseline meet minimum operating conditions or energy standards (e.g., minimum ventilation rates that exceed current conditions).

2.3.3.2 Approach

With Option C, energy savings evaluations using facility-level metered data may be completed using techniques ranging from simple billing comparison to multivariate regression analysis. Utility bill comparison is the use of utility billing data (therms, fuel oil, kW, kWh) and simple mathematical techniques to calculate annual energy savings. Utility bill comparison is a very simple and, typically, an unreliable method. It is applicable only to very simple ECMs in which energy use changes are a direct result of ECM installation.

Option C regression modeling is a specific statistical technique appropriate for determining energy savings under a performance contract. Regression models can take into account the effects of weather and other independent variables on energy use; utility bill comparison techniques can not. Utility bill regression analysis involves developing a model to estimate baseline energy use. Energy savings are estimated by comparing energy use predicted by the baseline model (forecasted into the post-installation period) to post-installation utility billing data. The analysis requires an empirical evaluation of the behavior of the facility as it relates to one or more independent variables. The variables may include weather, occupancy, and production rate.

In general, the procedure for determining energy savings with a regression model is as follows:

1. Develop the appropriate baseline model for the baseline period that represents
2. normal operations.
3. Project the baseline energy use into the post-installation period by driving the baseline model with the post-installation weather and independent variable values.
4. Calculate savings by comparing the difference between predicted baseline energy use and the actual energy use of the post-installation period.

The best regression model is one that is simple and yet produces accurate and repeatable savings estimates. Finding the best model often requires the testing of several to find one that is easy enough to use and that meets statistical requirements for accuracy.

2.3.3.3 M&V Considerations

The following points should be considered when conducting Option C analyses for M&V:

- All explanatory variables that affect energy consumption as well as possible interactive terms (i.e., combination of variables) must be specified, whether or not they are accounted for in the model. Critical variables can include weather, occupancy patterns, set points, and operating schedules. Independent variable data will need to correspond to the time periods of the billing meter reading dates and intervals.

- If the energy savings model incorporates weather data, the following issues should be considered: Use of the building "temperature balance point" for defining degree-days versus an arbitrary temperature base.

- The relationship between temperature and energy use that tends to vary depending upon the time of year. For example, an ambient temperature of 55°F in January has a different implication for energy usage than the same temperature in August. Thus, seasons should be addressed in the model.

- The nonlinear 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.

- Matching degree-day data with billing start and end dates.

- The criteria used for identifying and eliminating outliers must 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 should be defined using common sense as well as common statistical practice.

Statistical validity of the final regression model must be demonstrated. Validation steps include checks to make sure that:

- The model makes intuitive sense; that is, the explanatory variables are reasonable and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- Modeled data are representative of the population.
- Model form conforms to standard statistical practice.
- The number of coefficients is appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations).
- All model data are thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.

Collecting data, validating the data, and ensuring that all start and end dates of the data are aligned are important elements of billing analysis. Data types and some data analysis protocols are discussed below.

Billing data provide the basis for calibrating models and post-installation energy use.

Other site data provide a means for controlling changes in energy use not associated with ECM installation. These data elements are discussed below. There are typically two types of monthly billing data: total usage for the month and usage aggregated by *time-of-use periods*. Although either type of data can be used with a regression model, time-of-use is preferable because it provides more insight into usage patterns. In many cases, the peak demand is also recorded.

This type of billing data records the average demand (or energy use) for a given interval (e.g., 30 minutes) associated with the billing period. Inventory readings or delivery information can be used to determine historical consumption for resources such as fuel oil. Site data provide the information necessary to account for changes in energy consumption that are not associated with the retrofit equipment. Typical site data that can be incorporated in regression models include weather parameters, occupancy, facility square footage, and operating hours. These data are typically used to help define the independent variables that explain energy consumption or changes associated with equipment other than the installed equipment.

2.3.4 Option D

2.3.4.1 Introduction

Option D involves the use of computer simulation software to predict facility energy use for Baseline or Post retrofit energy use. Such simulation models must be "calibrated" so that it predicts an energy use and demand pattern that reasonably matches actual utility consumption and demand data from either the baseyear or a post-retrofit period.

Option D may be used to assess the performance of all ECMs in a facility, akin to Option C. However, different from Option C, multiple runs of the simulation tool in Option D allow estimates of the savings attributable to each ECM within a multiple ECM project.

Option D may also be used to assess just the performance of individual systems within a facility, akin to Options A and B. In this case, the system's energy use must be isolated from that of the rest of the facility by appropriate meters.

2.3.4.2 Approach

The simulation model may involve elaborate models, spreadsheets, vendor estimating programs etc. Calibration is achieved by linking simulation inputs to actual operating conditions and comparing the simulation results with end-use or whole-facility data. The simulation may be of a whole facility or just the effected ECM end-use.

2.3.4.3 M&V Considerations

The following points should be considered when completing simulations for M&V:

- Simulation analysis needs to be conducted by trained and experienced personnel who are familiar with the software used.
- Input data should represent the best available information including, if possible, the same or similar data and precautions described above for billing analysis.
- The simulation needs to be calibrated by its ability to track with real utility billing data and/or sub-metering data with acceptable tolerances.
- Simulation analyses need to be well documented with hard copy and electronic copies of input and output "decks" as well as the survey and metering /monitoring data used to define and calibrate the model.

2.4 M&V Plan

The M&V plan is a document that defines project-specific measurement and verification methods for determining the savings resulting from performance contracting projects. The plan may include a single option that addresses all the measures installed at a single facility or it may include several M&V options to address multiple measures installed at the facility. The ESCO prepares the project-specific M&V plan and presents it to the client for review.

The following material defines the general requirements for submitting a project-specific M&V plan. Issues and requirements associated with measure-specific M&V. An overview of M&V plan content requirements. The steps, which can be iterative, for defining a project-specific M&V plan include the following:

- Identify goals and objectives.
- Specify the characteristics of the facility and the ECM or system to be installed.
- Specify by measure the M&V option, methods, and techniques to be used.
- Specify data analysis procedures, algorithms, assumptions, data requirements, and data products.
- Specify the metering points, period of metering, and analysis and metering protocols.
- Specify accuracy and quality assurance procedures.
- Specify the annual M&V report format and how results will be documented.
- Define budget and resource requirements.

2.5 M&V Program components

It is important to realistically anticipate the costs and level of effort associated with completing metering and data analysis activities. Time and budget requirements are often underestimated. Note that metering is just one part of a successful M&V program. Other key components include:

- Properly defining the project and critical factors that affect energy consumption in order to prepare an appropriate M&V plan.
- Completely defining baseline conditions such as comfort conditions, lighting intensities, and hours of operation.
- Defining analysis equations and confidence required in the savings calculations in order to determine (1) the data that must be collected, (2) the

period of time for data collection, and (3) the required accuracy of the data collection and analysis technique(s).
- Calculating the value of the project in order to define a cost-effective level (accuracy) of M&V and addressing the relative value of the M&V information.
- Using qualified staff and/or contractors to collect and analyze data.
- Defining the data reporting and archiving requirements.

A project-specific M&V plan should demonstrate that any metering and analysis will be done in a consistent and logical manner and with a level of accuracy acceptable to all parties. The potential for the installed ECM to generate savings should be verified at regular intervals during the performance contract period. Verifying the potential to generate savings can also be stated as confirming that:

- The baseline conditions were accurately defined,
- The proper equipment/systems were installed,
- The equipment/systems are performing to specification, and
- The equipment/systems have the potential to generate the predicted savings.

Either the client or the ESCO may define baseline conditions. Baseline physical conditions (such as equipment inventory and conditions, occupancy, name-plate data, energy consumption rate, control strategies, and so on) are typically determined through surveys, inspections, investment-grade audits, and spot or short-term metering activities. Baseline conditions are established for the purpose of calculating savings and in case operational changes that occur after measure installation mandate baseline energy use adjustments.

In almost all cases after the measure has been installed, one cannot go back and reevaluate the baseline. It no longer exists! Therefore, it is very important to properly define and document the baseline conditions. Deciding what needs to be monitored, and for how long, depends on factors such as the stability of the baseline, the variability of equipment loads, and the number of variables that affect the load.

2.6 Selection of M&V method

Since the primary purpose of M&V is to validate payments or performance guarantees, the cost of M&V should be less than the payment amount or guarantee that is at risk. Consequently, the objective of M&V should not necessarily be to derive a precise energy savings number, but rather to ensure that ESCOs properly complete their projects and that the resulting energy savings are reasonably close to the savings claimed. The appropriate level of M&V rigor and accuracy is a level that protects the project investment and fulfills the intent of the federal legislative requirements. In summary, the selection of an M&V method is based on:

- Project costs
- Expected savings
- Uncertainty or risk of savings being achieved
- Risk allocation between the parties (i.e., which party is responsible for the performance of the installed equipment and which party is responsible for achieving long-term energy savings).

- Whether the contract is based on guaranteed performance (fixed payments) or shared savings (variable payments)
- Duration and accuracy of metering activities
- Number and complexity of dependent and independent variables that are
- metered or accounted for in analyses
- Availability of existing data collecting systems (e.g., energy management systems)
- Contract term.

As noted, the level of certainty and thus effort required to verify both a project's potential to perform and its actual performance will vary from project to project. The actual contract, and/or the project-specific M&V plan should be prepared with serious consideration of what M&V requirements, reviews, and costs will be specified. These are some factors that affect the decision of which M&V option, Method, and technique to use for each ESCO project.

2.6.1 Risk Assessment

A key factor in the selection of an appropriate M&V plan is proper Risk Assessment. The major risks associated with an ESCO project can be classified as:

- Uncertainty Risk
- Performance Risk
- Usage Risk
- Financial Risk

2.6.1.1 Uncertainty Risk

Uncertainty risk is simply the inability to exactly and consistently quantify the savings. As savings are estimated by comparing a system to the way it operated before and the way it operated after a measure was installed - claimed savings are always an estimate.
Uncertainty is introduced through:

- Measurement error
- Sampling error
- Random variations
- Simplifying assumptions

Even though a large number of parameters can be measured, there are still errors associated with measuring equipment. Since not every piece of equipment can be measured, sampling techniques are often used which can introduce additional uncertainty. Random variations occur in energy use or equipment that may be related to human behaviour, weather conditions, or other random factors. Simplifying assumptions are sometimes used when it is too difficult to measure or estimate a parameter, introducing additional uncertainty.

All of these factors prevent obtaining a 'true' estimate of the savings. In measurement and verification, the goal is to minimize these uncertainties to acceptable levels, understanding that they can never be completely eliminated.

2.6.1.2 Performance Risk

Performance risk is related to actual equipment performance. Replacing old, inefficient equipment with new will usually generate savings. But new equipment will also become old and worn out with time, reducing its inefficiency. A poor Operations and Maintenance (O&M) regimen can hasten degradation.

Occasionally, poor performance is due to wrong design or selecting the wrong piece of equipment for the job. These are factors that the ESCO controls since typically, it is the ESCO that is responsible for both proper design and performance of equipment. Because the ESCO usually assumes the responsibility of maintaining adequate performance, they usually assume the savings risk.

2.6.1.3 Usage Risk

Usage risk is related to how or how often a piece of equipment is used. Usage can be defined as:

- Operating hours (lighting, equipment)
- Occupancy or schedules
- Heating/cooling loads
- Production

The client usually has control over the operating hours, the schedules and whether it is kept hotter or colder than originally intended. Although these factors significantly affect savings, the ESCO has little control over these and hence ESCOs are reluctant to assume the risks that arise from usage changes.

2.6.1.4 Financial Risk

Financial risk relates to factors such as interest rates and energy costs. Many of these are functions of market conditions. Neither the ESCO nor the customer has significant control over actual energy prices. For calculating savings, the value of saved energy may either be a constant, change at a fixed inflation rate, or float with market conditions. Depending on the market, either the ESCO or the client may be placed at a risk, if the value fluctuates.

Falling energy prices place the ESCO at risk of failing to meet the guaranteed cost savings. On the other hand, in the event of an energy price rise, there is a small risk to the client that energy saving goals might not be met but the financial goals are. If the value of saved energy is fixed (either constant or escalated), the customer risks making payments in excess of actual energy cost savings.

Neither the ESCO nor the client has significant control over the prevailing interest rate. Higher interest rates will increase project cost, finance term or both.

2.6.2 Risk Mitigation

All the factors discussed in 2.6.1 above contribute to uncertainty in the savings estimates. If simple M&V methods with large amounts of uncertainty are used, then there is very little confidence in the savings estimates. This may mask savings shortfalls and presents a risk to the client. More rigorous (and more costly) M&V methods may reveal savings shortfalls that simpler methods do not. This is how M&V reduces risk - by identifying savings shortfalls.

2.7 M&V Rigor

The scale of a project, energy rates, term of the contract, comprehensiveness of ECMs, the benefit-sharing arrangement, and the magnitude of savings can all affect the value of the ESCO 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 vnalue of the project itself. "Rule of thumb" estimates put M&V costs at 1% to 10% of typical project cost savings.

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

2.8 Reporting Requirements

Documentation is an integral part of M&V. This plays a key role in reporting to Financial Institutions. The fact that a company is willing to subject itself to protocol procedure could convey an important message to the financier about the sincerity and openness of the management to incorporate the energy efficiency solutions.

As has already been brought out in this document, M&V is essentially a self-monitoring activity. As a rough guideline, the checklist provided as Appendix B may be taken as a starting point to ensure proper documentation.

Chapter 3 Incorporating M&V into ESCO contracts

3.1 Introduction

This chapter is an overview of general M&V activities associated with implementing ESCO projects. The information is useful for preparing performance contracts, and for documenting baseline conditions. The data and analyses performed during M&V development and baseline characterization can be updated and used later in the project.

3.2 Project Categories

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).

3.3 M&V activities

M&V activities fall into the following five areas:

1) Define M&V requirements for inclusion in the contract between the client and the ESCO based on the M&V options and methods defined in other sections of this document.
2) As soon as the project has been fully defined, either before or after the contract is signed, prepare a site-specific M&V plan for the project.
3) Define the pre-installation baseline, including (a) equipment and systems, (b) base-line 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.
4) Define the post-installation situation, including (a) equipment and 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.
5) Conduct periodic M&V activities as per Option to (a) verify the operation of the installed equipment/ systems, (b) determine current year savings, and (c) estimate savings for subsequent years.

3.4 ESCO Project Procedures

As a contract is implemented, both the client and the ESCO take certain steps with respect to the measurement and verification of each project. The overall project procedures are:

- Specify M&V Approach
- Prepare M&V Plan
- Review and make changes if required
- Initial M&V Activities (if necessary)
- Measure Installation
- M&V Activities (if necessary)
- Periodic M&V Report
- Review and Approval Required
- Payments Begin

The roles of each party in these steps are described in the contract, depending on the type of specific business agreements, risk allocation, and accuracy of desired verification. In general, however, the ESCO provides documentation on equipment and demonstrated savings.

The documents include the project pre-installation report, project post-installation report, and regular interval reports. These steps should apply to most projects; however, some M&V activities (see below) might not be necessary if certain variables, used in estimating savings, are stipulated in the contract. The steps identified above are briefly described in the following paragraphs.

A site-specific M&V plan that is based on these M&V Guidelines should be defined. This M&V plan will consider the type of ECM or system selected, the desired level of confidence, and the level of accuracy of verification needed. The ESCO will propose a site-specific plan to be finalized either before or after execution of a contract or delivery order.

The M&V plan should include a project description, facility equipment inventories, descriptions of the proposed measures, energy and cost savings estimates, budget documentation (construction and M&V budgets), and proposed construction and M&V schedules. After the M&V plan is firmed up, baseline documentation and analysis is conducted, as needed, and then project installation may proceed. Pre-installation metering is conducted in accordance with the approved, site-specific M&V plan. As soon as the pre-installation metering and analysis, the project can be installed. The major tasks associated with M&V work before the ECM installation are as follows:

- Pre-installation metering is conducted for a period of time required to capture all operating conditions of affected systems and/or processes. As specified in the M&V plan, documentation on the results of the pre-installation metering is discussed with the client for review.
- Once the client and the ESCO agree on the pre-installation M&V, the project installation may start.

When the measures are installed, the project post-installation report is made and calculations with energy and cost savings estimates. Post installation, M&V work may be conducted before or after submitting a project post-installation report.

Chapter 4 M&V Protocol: Industrial

4.1 M&V Methods

As mentioned earlier the ECMs can be grouped as:

- Variable load, Constant hours
- Constant load, Variable hours
- Variable load, Variable hours

Most of these ECMs can be grouped under Option A & B, whereas for situations such as multiple ECMs for a single manufacturing facility, a major process change or cogeneration project is proposed where the power & fuel bills are going to alter, Option C is preferred.

For a new construction, computer simulation option could be the choice. However, in all the cases, the increase in M&V costs (if any) needs to be justified by the reduction in uncertainty costs.

4.1.1 Option A- Retrofit Isolation - Partial measurement

Once the boundary is defined, base-year consumption can be arrived at using energy meter readings from sub-meters if available, or through one time spot measurements for the existing conditions. The same measurement is repeated for the post-retrofit conditions and the difference is computed as the energy savings. The hours of use is stipulated and the savings is quantified. This option is suitable when there are no interactive effects of one ECM over the other.

Typical ECMs which come under Option A include Motor/ Drive improvements, lighting efficiency / controls. The base-line and post-retrofit kW figures once established due to efficiency improvements

4.1.2 *Option B – Retrofit Isolation Continuous measurement*

In this option measurements are made for not just one time. Periodic monitoring is performed at different conditions as for example upgradation with an efficient boiler. The efficiency is assessed with metering of steam, fuel as per certain standards.

4.1.3 Option C – Whole facility

This invariably involves collection of historical data and arriving at a base-line consumption model using regression techniques. The variables usually are: product throughput, product-mix, number of shift operations, raw material quality changes, weather changes etc. As generally this may involve multiple ECMs a combination of option A and B could be selected. If there are interactive ECMs, then comparing the whole facility's bill to production would be a preferable method.

4.1.4 Option D – Computer Simulation

The process can be simulated where it is difficult to monitor all the parameters and the M&V procedures for other options A,B or option C would become too complex and expensive. The computer simulation packages that are available for a specific industry are limited and can be expensive. The M&V cost versus the reduction in uncertainty risks/ costs and the acceptability of such simulation tool to Indian end-users have to be weighed prior to use of this approach.

4.2 Relevant inferences

4.2.1 Factors Affecting Savings Performance

Many factors affect the performance of equipment and achievement of savings. Depending upon the scope of the savings determination (its boundaries), the range of parameters of concern can be very focused (specific ECMs) or as wide as the whole facility.

In the savings equation (Energy Savings = Baseline – post-retrofit ± adjustments), parameters that are predictable and measurable can be used for routine adjustments. Such adjustments reduce the variability in reported savings, or provide a greater degree of certainty in reported savings.

Unpredictable parameters within the boundaries of a savings determination may require future non-routine Baseline Adjustments (*e.g. load creep or addition of loads, power cuts, power interruptions, power quality such as variations in voltage, frequency*). Unmeasured parameters give rise to savings fluctuations for which no adjustment can be computed, only guessed (e.g. raw material quality, air infiltration rate). Therefore, when planning an M&V process, consideration should be given to

1) predictability
2) measurability and
3) likely impact of all plausible factors in each category below:

- Product-mix
- Plant throughput
- Power cuts & interruptions
- Power quality variations voltage, frequency
- Humidity, Temperature (Weather)
- Schedule
- Number of shifts of operation
- Installed equipment intensity, schedule
- Ability of the ECM as designed to achieve the intended savings
- ECM implementation effectiveness in meeting the design intent
- Operator cooperation in using ECM related equipment in accordance with direction
- Equipment deterioration, both ECM related equipment and non-ECM related
- Equipment life, both ECM and non-ECM related

4.2.2 Evaluating Savings Uncertainty

The effort undertaken in determining savings should focus on managing the uncertainty created in the determination process. ECMs with which the facility staff are familiar may require less effort than other, uncommon ECMs. The savings determination process itself introduces uncertainties through

- Instrumentation Error
- Modeling Error
- Sampling Error
- Planned and Unplanned Changes

Methods of quantifying the first three errors are discussed in detail in IPMVP-2000. The last category of error above, encompasses all the unquantifiable errors associated with stipulations, and the assumptions necessary for measurement and savings determination. It is feasible to quantify many but not all dimensions of the uncertainty in savings determination. Therefore when planning an M&V process, consideration should be given to quantifying the quantifiable uncertainty factors and qualitatively assessing the unquantifiable. The objective is to consider all factors creating uncertainty, either qualitatively or quantitatively.

The accuracy of a savings estimate can be improved in two general ways. One is by reducing biases, by using better information or by using measured values in place of assumed or stipulated values. The second way is by reducing random errors, either by increasing the sample sizes, using a more efficient sample design or applying better measurement techniques. In most cases, improving accuracy by any of these means increases M&V cost. Such extra cost should be justified by the value of the improved information.

Quantified uncertainty should be expressed in a statistically meaningful way, namely declaring both accuracy and confidence levels. For example, "The quantifiable error is found, with 90% confidence, to be +20%." A statistical precision statement without a confidence level is meaningless since accuracy can sound very good if the confidence level is low.

The appropriate level of accuracy for any savings determination is established by the concerned parties. Some issues in establishing a level of uncertainty are addressed in IPMVP 2000.

If the energy consumption of the metered equipment or systems varies by more than ten percent from month to month, additional measurements must be taken at sufficient detail and over a long enough period of time to identify and document the source of the variances. Any major energy consumption variances due to seasonal production increases must also be tracked and recorded.

4.2.3 Minimum Energy Standards

When a certain level of efficiency is required either by law or the owner's standard practice, savings may be based on the difference between the post-retrofit energy use and the minimum standard. In these situations, baseyear energy use may be set equal to or less than the applicable minimum energy standards.

4.2.4 Minimum Operating Conditions

An energy efficiency program should not compromise the operations of the facility to which it is applied without the agreement of the facility users, industrial process managers. Therefore the M&V Plan should record the agreed conditions that will be maintained

4.2.5 Energy Prices

Energy cost savings may be calculated by applying the price of each energy or demand unit to the determined savings. The price of energy should be the energy provider's rate schedule or an appropriate simplification thereof. Appropriate simplifications use marginal prices which consider all aspects of billing affected by metered amounts, such as consumption charges, demand charges, power factor

4.2.6 Baseline Adjustments (Non-Routine)

Conditions which vary in a predictable fashion are normally included within the basic mathematical model used for routine adjustments Where unexpected or one-time changes occur they may require non-routine adjustments, normally called simply *Baseline Adjustments.*

Examples of situations often needing Baseline Adjustments are:

i) changes in the end-use loads
ii) changes in the amount or use of equipment
iii) changes in set-point temperatures,
iv) changes in schedule or throughput.

Baseline Adjustments are not needed where:

- the variable is included in the mathematical model developed for the project changes affect a variable that was stipulated in the M&V Plan. For example, if the number of hours of compressed air used were stipulated for an air compressor upgrade ECM, an increase in the running hours of the compressor will not affect the savings determined by the agreed simplified method, though actual savings will change.

- changes occur to equipment beyond the boundary of the savings determination. For example if the boundary includes only the lighting system, for a lighting retrofit, addition of personal computers to the space will not affect the savings determination.

Baseyear conditions need to be well documented in the M&V Plan so that proper adjustments can be made. It is also important to have a method of tracking and reporting changes to these conditions. This tracking of conditions may be performed by one or more of the facility owner, the agent determining savings, or a third party verifier. It should be established in the M&V Plan who will track and report each condition recorded for the baseyear and what, if any other aspects of facility operation will be monitored. Where the nature of future changes can be anticipated, methods for making the relevant non-routine Baseline Adjustments should be included in the M&V Plan.

Non-routine Baseline Adjustments are determined from actual or assumed physical changes in equipment or operations. Sometimes it may be difficult to identify the impact of changes. If the facility's energy consumption record is used to identify such changes, the impact of the ECMs on the metered energy consumption must first be removed by Option B techniques.

4.2.7 Cost

The cost of determining savings depend on many factors such as:

- IPMVP Option selected
- ECM *number, complexity and amount of interaction amongst them*
- number of energy flows across the boundary drawn around the ECM to isolate
- it from the rest of the facility in Options A, B or D when applied to a system only
- level of detail and effort associated with establishing baseyear conditions
- *needed for the Option selected amount and complexity of the measurement* equipment (design, installation, maintenance, calibration, reading, removal)
- sample sizes used for metering representative equipment
- amount of engineering required to make and support the stipulations used in Option A *or the calibrated simulations of* Option D
- number and complexity of independent variables which are accounted for in mathematical models
- duration of metering and reporting activities accuracy requirements
- *savings report requirements*
- process of reviewing or verifying reported savings
- experience and professional qualifications of the people conducting the savings determination

Often these costs can be shared with other objectives such as real time control, operational feedback, or tenant sub-billing. It is difficult to generalize about costs for the different IPMVP Options since each project will have its own unique set of constraints. However it should bean objective of M&V Planning to design the process to incur no more cost than needed to provide adequate certainty and verifiability in the reported savings, consistent with the overall budget for the ECMs. Typically however it would not be expected that average annual savings determination costs exceed more than about 10% of the average annual savings being assessed. Table below on unique elements of M&V costs highlights key cost governing factors unique to each Option.

Unique Elements of M&V Costs

Option A	Number of measurement points Complexity of stipulation Frequency of post-retrofit inspection
Option B	Number of measurement points
Option C	Number of meters Number of independent variables needed to account for most of the variability in energy data.
Option D	Number and complexity of systems simulated. Number of field measurements needed to provide input data. Skill of professional simulator in achieving calibration

4.2.8 Weather Data

Where monthly energy measurements are used, weather data should be recorded daily and matched to the actual energy metering period. For monthly or daily analysis, government published weather data should be treated as the most accurate and verifiable. However weather data from such source may not be available as quickly as site monitored weather data.

When analyzing the response of energy use to weather in mathematical modeling, daily mean temperature data or degree days may be used.

4.2.9 Balancing Uncertainty and Cost

Commonly, since Option A involves stipulation, it will involve fewer measurement points and lower cost, providing stipulation and inspection costs do not dominate.

Since new measurement equipment is often involved in Options A or B, the cost of maintaining this equipment may make Option C a less costly endeavor for long monitoring periods. However, as mentioned above, the costs of extra meters for Options A or B may be shared with other objectives.

When multiple ECMs are installed at one site, it may be less costly to use the whole building methods of Options C or D than to isolate and measure multiple ECMs with Options A or B.

Though development and calibration of an Option D simulation model is often a time consuming process, it may have other uses such as for designing the ECMs themselves or designing a new facility.

Where a contractor (ESCO) is responsible for only certain aspects of project performance, other aspects may not have to be measured for contractual purposes, though the owner may still wish to measure all aspects for its own sake. In this situation, the costs of measurement may be shared between owner and contractor.

The acceptable level of uncertainty required in a savings calculation is a function of the level of savings and the cost-effectiveness of decreasing uncertainty. For example, suppose a project has an expected savings of Rs 1000,000 per year and that a basic M&V approach had an accuracy no better than ±25% with 90% confidence, or Rs 250,000 per year. To improve the accuracy to within Rs 100,000 it may be seen as reasonable to spend an extra Rs 50,000 per year on M&V but not Rs 300,000 per year. The quantity of savings at stake therefore places limits on the target expenditure for M&V.

Further benefits of activities to reduce uncertainty may be the availability of better feedback to operations, enabling an enhancement of savings or other operational variables. The information may also be useful in assessing equipment sizing for planning plant expansions or replacement of equipment. It may also allow higher payments to be made under an energy performance contract based on measured vs. conservative stipulated values. Additional investments for improved accuracy should not exceed the expected increase in value.

Discussions 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 ECM savings. However it should be recognized that not all uncertainties can be quantified . Therefore both quantitative and qualitative uncertainty statements must be considered when considering M&V cost options for each project.

For a given savings determination model at a specific site, there will be an optimal savings determination plan. The method to identify that Plan includes iterative consideration of sensitivity of the savings uncertainty to each variable estimating the cost of metering specified variables in the model and a criteria for valuing reduced uncertainty (e.g. risk-adjusting saving per a given formula).

4.2.10 Measurement Issues

4.2.10.1 Instrumentation and Measurement Techniques

Special meters may be used to measure physical quantities or to submeter an energy flow. Example quantities which may have to be measured without the use of energy supplier meters are temperature, humidity, flow, pressure, equipment runtime, electricity and thermal energy. To determine energy savings with reasonable accuracy and repeatability, good measurement practices should be followed for these quantities. Such practices are continually evolving as metering equipment improves. It is recommended that the latest measurement practices be followed to support any savings determination. IPMVP 2000 provides a review of some common measurement techniques.

4.2.10.2 Calibration of Instrumentation

It is highly recommended that instrumentation be calibrated periodically. Sensors and metering equipment should be selected based in part on the ease of calibration and the ability to hold calibration. An attractive solution is the selection of equipment that is self-calibrating.

4.2.10.3 Data Collection Errors and Lost Data

Methodologies for data collection differ in degree of difficulty, and consequently in the amount of erroneous or missing data. No data collection is without error. The M&V Plan should consider two aspects of data collection problems:

- establish a maximum acceptable rate of data loss and how it will be measured. This level should be part of the overall accuracy consideration. The level of data loss may dramatically affect cost.
- establish a methodology by which missing or erroneous data will be interpolated for final analysis. In such cases, baseyear and post-retrofit models may be used to calculate savings.

Use of Energy Management Systems for Data Collection

The facility energy management system (EMS) can provide much of the monitoring necessary for data collection. However, the system and software must be fully specified to provide this extra service as well as its primary real-time control function. For example, significant use of trending functions may impair the basic functions of the EMS. Some parameters to be monitored may not be required for control. These extra points must be specified in the design documents. Electric power metering is an example. Trending of small power, lighting and main feed power consumption may be very useful for high quality savings determination and operational feedback, but useless for real time control.

Other functions that can easily be incorporated into the software are automatic recording of changes in set-points. It is not unusual for many of the trending capabilities required for verification to be incorporated in an EMS. However adequate hardware and software capability must be provided since data trending can tie up computer processing, communication bandwidth and storage.

Facility staff should be properly trained in this use of the EMS so they too can develop their own trending information for diagnosing system problems, providing the system has the capacity for extra trending. However where a contractor is responsible for some operations controlled by the system, EMS security arrangements should ensure that persons can only access functions for which they are competent and authorized.

Chapter 5 Typical ECMs & Applications

5.1 Common M&V approaches for the Industrial Sector

	1. Lighting Improvements	2. Process Modifications	3. Electric Motors & Drives	4. Controls / Recommissioning	5. Boiler Improvements	6. Chiller Improvements	7. Chilled/Hot /Steam Piping & Distribution Systems, Compressed Air	8. Heat (& Cold) Recovery-Thermal Energy	9. Cogeneration	10. Renewable Energy Systems
Option A: One-time metering	•		•				•	•		
Option B: Continuous metering	•	•	•	•	•	•	•	•	•	•
Option C: Utility Bill Analysis		•		•	•	•			•	•
Option D: Computer Simulation				•				•		•
	1	2	3	4	5	6	7	8	9	10

5.2 Selected M&V Methods —Option A

The chapters in this section describe technology-specific M&V methods associated with Option A. Option A is one of the M&V options that can be used in implementing energy efficiency projects. The methods described here are for the most typical ECMs, such as technology upgrades for energy efficiency gains, heat recovery, control system retrofits, motors, variable speed drives and lighting. Chapter 2 introduces Option A.

An Option A based M&V method involves a retrofit or system level M&V assessment. The approach is intended for retrofits where either performance factors (e.g. end-use capacity, demand, power, thermal energy use) or operational factors (operational hours, production-rate) can be spot or short-term measured during the baseline and post-installation periods. The factor not measured is stipulated based on assumptions, analysis of historical data, or manufacturer's data. *Using a stipulated factor is appropriate only if supporting data demonstrates its value is not subject to fluctuation over the term of the contract.*

All end-use technologies can be verified using Option A. However, the applicability of this option is generally inversely proportional to the complexity of the measure. In addition within Option A, various methods and levels of accuracy in verifying performance/operation are available. The level of accuracy depends on the validity of assumptions, quality of the equipment inventory, and what kinds of spot/short-term measurements are made. The risk associated with the resulting uncertainty is not achieving the estimated measure savings and the associated fuel or power bill cost reductions.

Option A can be applied when identifying the potential to generate savings is the most critical M&V issue, including situations in which:

- The magnitude of savings is low for the entire project or a portion of the project to which Option A can be applied.
- The risk of achieving savings is low or ESCO payments are not directly tied to actual savings.

APPROACH

Option A is an approach designed for projects in which the *potential* to generate savings must be verified, but the actual savings can be determined from stipulated factors, short-term data collection, and engineering calculations. Post-installation energy use is not measured throughout the term of the contract. Post-installation and perhaps baseline energy use is predicted using an engineering or statistical analysis of information that does not involve long-term measurements.

With Option A, savings are determined by measuring the capacity, efficiency, or operation of a system before and after a retrofit and by multiplying the difference by a usage factor. Stipulating the usage factor(s) is the easiest and least expensive method of determining savings. It can also be the least accurate and is typically the method with the greatest uncertainty of savings. This level of verification may suffice for certain types of projects where a single factor represents a significant portion of the savings uncertainty. Option A is appropriate for projects in which both parties agree to a payment stream that is not subject to fluctuation due to changes in the operation or performance of the equipment.

M&V CONSIDERATIONS

Option A includes procedures for verifying that:

- Baseline conditions have been properly defined.
- The equipment and/or systems to be installed were installed.
- The installed equipment/systems meet contract specifications in terms of quantity, quality, and rating.
- The installed equipment is operating and performing in accordance with contract specifications and is meeting all functional tests.
- The installed equipment/systems continue, during the term of the contract, to meet contract specifications in terms of quantity, quality, rating, operation, and functional performance.

This level of verification is all that is contractually required for certain types of performance contracts. Baseline and post-installation conditions (e.g., equipment quantities and ratings such as Wattages, kcal or therms) represent a significant portion of the uncertainty associated with many projects.

All end-use technologies can be verified using Option A; however, the accuracy of this approach is generally inversely proportional to the complexity of the measure. Thus, the savings from a simple lighting retrofit will typically be more accurately estimated with Option A than the savings from a chiller retrofit. If greater accuracy is required, Options B, C, or D may be more appropriate.

Within Option A, various methods and levels of accuracy in verifying performance are available. The level of accuracy depends on the quality of assumptions made, and it can also depend on whether an inventory method is used for ensuring nameplate data and quantity of installed equipment or whether short-term measurements are used for verifying equipment ratings, capacity, operating hours and/or efficiency. The potential to generate savings may be verified through spot/short-term metering conducted immediately before and/or immediately after installation, observation, and/or inspections. Annual (or some other regular interval) inspections may also be conducted to verify an ECM's or system's continued potential to generate savings.

Savings potential can be quantified using any number of methods, depending on contract accuracy requirements. Equipment performance can be obtained either directly (through actual measurement) or indirectly (through the use of manufacturer data). There may be sizable differences between published information and actual operating data. Where discrepancies exist or are believed to exist, field-operating data should be obtained. This could include 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. Baseline and post-installation equipment should be verified with the same level of detail. Either formally or informally, all equipment baselines should be verified for accuracy and for concurrence with stated operating conditions. Actual field audits are almost always required.

The measure-specific M&V methods based on Option A and presented here are as follows:

5.3 ECMs and applications Option A

ECM	Method Number	Performance Factors	Usage Factors
Process Technology improvements example) grinding, distillation, evaporation drying, cooling, heating	PT-A-01	kW or kcal/per unit of production (measured)	Production (stipulated)
Control system interventions	CS-A-01	kW/unit of production (measured)	Hours at each production rate (stipulated)
Boiler / Furnace equipment upgrades	TS-A-01	kW or kcal/ hr delivered output (measured)	Hours at each capacity, (stipulated)
Air compressor, Pump & Fan upgrades	TM-A-01	kW/delivered output (measured)	Hours at each capacity, (stipulated)

Heat Recovery Applications	HR-A-01 HR-A-02	kcal/output (stipulated) kcal/output (measured)	Hours/throughput (stipulated) Hours/throughput (stipulated)
Reactive power compensation	RP-A-01	kW, kVAR (stipulated) kWh, kVARh (measured)	KWh, kVARh (stipulated)
Lighting Efficiency	LE-A-01 LE-A-02	kW (stipulated), lumens kW (measured), lumens	Hours (stipulated) Hours (stipulated)
Lighting Controls	LC-A-01 LC-A-02	kW (stipulated), lumens kW (measured), lumens	Reduction in hours (stipulated) Reduction in hours (stipulated)
Constant -Load Motors Efficiency	CLM-A-01	kW (measured), RPM	Hours (stipulated), load
Variable –Speed- Drive Retrofit	VSD-A-01	kW (measured) at each load condition	Hours at each load condition (stipulated)
Chiller Replacements	CH-A-01 CH-A-02	kW/TR (stipulated) kW/TR (measured)	TR-hours (stipulated) TR-hours (stipulated

5.3.1 Process Technology improvements
Stipulated production Partially Measured performance
Methods PT-A-01

ECM DEFINITION

Process Technology improvement projects covered by this verification plan are as follows:

- Retrofits of existing process technology/ equipment with a more energy-efficient system

These projects reduce energy demand either in terms of thermal energy needs (heating or cooling) or electrical power required. However, the production is stipulated and some times is assumed to be same in the pre- and post-retrofit periods.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Product quality and rate may be specified.

M&V Method PT-A-01 requires spot or short-term performance measurements of a representative production (or time-period) of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.
Method PT-A-01

The performances can be measured in terms of energy used per unit of production. However, care should be taken that the production during the post retrofit and baseline conditions are comparable in cases of varying product-mix by converting each of the product produced to an equivalent standard product quantity.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy

To estimate energy savings for process technology improvement and control system interventions, projects use the following equation:

$$Energy\ Savings_t = [\ Energy/Unit\ of\ production_{baseline} - Energy/Unit\ of\ production_{post})\ \times Production_t$$

where:

$Energy\ Savings_t$	Energy savings realized during the post-installation time period *t*
$Energy/Unit\ of\ production_{baseline}$	Baseline energy use
$Energy/Unit\ of\ production_{post}$	Energy use during post-installation period

Demand

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Energy efficiency projects may have the added advantage of saving more energy in the associated systems. However, it may also increase the energy use in the associated sub systems. This need to be accounted for, on a site-specific basis.

5.3.2 Control System Interventions
Measured performance at specific load conditions
Hours at each capacity (stipulated)
CS-A-01

ECM DEFINITION

A control system intervention involve controlling the process parameters at specific set values by either varying the flow of steam or input power. For example, it can be a process temperature, pressure or any similar variables. These projects covered by this verification plan are as follows:

- Introducing a process control system to reduce energy use in terms of steam or fuel or power.

These projects reduce energy demand either in terms of fuel reduction or electrical power required. However, the process variation conditions and hours at each condition is stipulated and is assumed to follow the same pattern in the pre- and post-retrofit periods.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method CS-A-01 requires spot or short-term performance measurements of a representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand
In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method CS-A-01
Baseline and post-installation ratings (e.g., kW/cfm, kgs of fuel/ton of steam, COP) are measured. Annual hours of operation at each capacity is stipulated. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy
To estimate energy savings for boiler/furnace upgrades or air compressor, pump & fan upgrade projects use the following equation:

Calculate the energy savings using the following equations:

$$kWh \text{ or } kcal\ Savings = \Sigma\,[\ Operating\ Scenario\ Hours_i \times kW \text{ or } kcal/hr\ Savings_i\,]$$

where:

kW Savings	=	$kW_{baseline} - kW_{post}$
kcal Savings =		$kcal/hr_{baseline} - kcal/hr_{post}$
$kW_{baseline}$ or $kcal/hr_{baseline}$		the demand of the baseline in a particular operating scenario
kW_{post} or $kcal/hr_{post}$	=	the demand of the efficient equipment in a particular operating scenario
Operating Scenario	=	a particular mode of operation such as part-load or set-point value
Operating Hours	=	stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:

Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

5.3.3 Boiler / Furnace equipment upgrades
Measured performance at specific load conditions
Hours at each capacity (stipulated)
TS-A-01

ECM DEFINITION

Boiler or Furnace equipment upgrades involve improving the generation efficiency of the specific utility by the equipment under evaluation. For example, it can be generation of steam or melting or heating in the case of furnaces. These upgrade projects covered by this verification plan are as follows:

- Replacement of existing equipment (boiler/ furnace) with a more energy-efficient boiler / furnace.

These projects reduce energy demand either in terms of fuel reduction or electrical power required. However, the capacity or production rate and hours at each capacity is stipulated and is assumed to follow the same pattern in the pre- and post-retrofit periods.

Overview of Verification Methods

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method TS-A-01 requires spot or short-term performance measurements such as efficiency of the boiler, kWh or kgs of fuel required per ton of metal at a representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

Calculation of Demand and Energy Savings

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method TS-A-01

Baseline and post-installation ratings (e.g., kgs of fuel/ton of steam, kWh/ton melted kWh/ton heated, COP) are measured. Annual hours of operation at each capacity is stipulated. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for boiler/ furnace upgrades use the following equation:
Calculate the energy savings using the following equations:

$$\text{kWh or kcal Savings} = \Sigma\,[\,\text{Operating Scenario Hours}_i \times \text{kW or kcal/hr Savings}_i\,]$$

where:

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

kcal Savings = $kcal/hr_{baseline} - kcal/hr_{post}$

$kW_{baseline}$ or $kcal/hr_{baseline}$ the demand of the baseline in a particular operating scenario

kW_{post} or $kcal/hr_{post}$ = the demand of the efficient equipment in a particular operating scenario

Operating Scenario = a particular mode of operation such as part-load or set-point value

Operating Hours = stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:

Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

5.3.4 Pump, Fan, Compressor upgrades

Measured performance at specific load conditions
Hours at each capacity (stipulated)
TM-A-01

ECM DEFINITION

Pump, Fan, Compressor upgrades involve improving the generation efficiency of the specific utility by the equipment under evaluation. In case of pumps, fans and compressors, it is the quantity of output in terms of flow rate/hour. These upgrade projects covered by this verification plan are as follows:

- Replacement of existing equipment with a more energy-efficient equipment

These projects reduce energy demand either in terms of electrical power required. However, the capacity or production rate and hours at each capacity is stipulated and is assumed to follow the same pattern in the pre- and post-retrofit periods.

Overview of Verification Methods

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method TM-A-01 requires spot or short-term performance measurements of a representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

Calculation of Demand and Energy Savings

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method TM-A-01

Baseline and post-installation ratings (e.g., kW/cfm, COP) are measured based on standard test procedures. Annual hours of operation at each capacity is stipulated. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for boiler/furnace upgrades or air compressor, pump & fan upgrade projects use the following equation:
Calculate the energy savings using the following equations:

$$\text{kWh or kcal Savings} = \Sigma\,[\text{ Operating Scenario Hours}_i \times \text{kW or kcal/hr Savings}_i\,]$$

where:

kW Savings	=	$kW_{baseline} - kW_{post}$
kcal Savings =		$kcal/hr_{baseline} - kcal/hr_{post}$
$kW_{baseline}$ or $kcal/hr_{baseline}$		the demand of the baseline in a particular operating scenario
kW_{post} or $kcal/hr_{post}$	=	the demand of the efficient equipment in a particular operating scenario
Operating Scenario	=	a particular mode of operation such as part-load or set-point value
Operating Hours	=	stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Energy efficiency projects may have the added advantage of saving more energy in the associated systems. However, it may also increase the energy use in the associated sub systems. This need to be accounted for, on a site-specific basis.

5.3.5 Heat Recovery Applications
Stipulated Performance at specific load conditions
Hours at each capacity (stipulated)
HR-A-01, HR-A-02

ECM DEFINITION

A heat recovery system intervention involve recovering the heat/ (cold) from a process stream or exhaust gases or effluent in order to reduce the fuel or electricity required to heat or cool the stream. These projects covered by this verification plan are as follows:

- Introducing a waste heat recovery from the flue gases of a boiler, DG set
- Recovering heat from an effluent stream

- Exchange of heat between process streams

These projects reduce energy demand either in terms of fuel use and/or electrical power required. However, the performance is arrived at based on engineering calculations and just some of the typical temperature streams are spot-measured before and after. The throughput pattern in the pre- and post-retrofit periods and the hours of operation is stipulated.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. The process streams whose temperatures need to be monitored may be specified.

M&V Method HR-A-01 requires spot or short-term performance measurements of temperatures at baseline and post-installation conditions. This method will result in accurate savings estimates if throughput remains same.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method HR-A-01

Baseline and post-installation performances (e.g., temperature of a process stream before and after) are arrived at based on engineering calculations and just some of the typical temperature streams are spot-measured before and after. The throughput pattern in the pre- and post-retrofit periods and the hours of operation is stipulated. Energy savings are based on the heat recovered per hour divided by efficiency of generation of heat multiplied by the hours of operation stipulated. (The term 'heat' means both heating and cooling)

Method HR-A-02

Baseline and post-installation performances (e.g., temperature of a process stream before and after) are measured at typical process stream flow rates. Throughput is stipulated to ensure that comparisons are carried out in a fair manner. Energy savings are based on the heat recovered per hour divided by efficiency of generation of heat multiplied by the hours of operation stipulated. (The term 'heat' means both heating and cooling)

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for heat recovery projects use the following equation:
Calculate the energy savings using the following equations:

$$kWh \text{ or } kcal\ Savings = \frac{Heat\ recovered\ (mC_p\Delta T)\ as\ kcal/hour}{Thermal\ efficiency\ of\ heat\ generation} \times Hours/yr$$

where:

$mC_p\Delta T$	m is the mass flow rate of the process stream (this throughput is stipulated) C_p *specific heat* ΔT *temperature gain or reduction*
kW Savings =	$kW_{baseline} - kW_{post}$
kcal Savings =	$kcal/hr_{baseline} - kcal/hr_{post}$
$kW_{baseline}$ or $kcal/hr_{baseline}$	the demand of the baseline in a particular operating scenario
kW_{post} or $kcal/hr_{post}$ =	the demand of the efficient equipment in a particular operating scenario
Operating Hours =	stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

5.3.6 Reactive power compensation
Performance based on engineering computation
Stipulated hours of load conditions kW
Methods RP-A-01

ECM DEFINITION

The power factor improvement projects covered by this verification plan are as follows:

- Installation of capacitors and/or filters to improve the power factor and thereby reduce the demand charges or avoid the power factor penalties.

These projects will reduce the kVA required and improve the power factor. There are not significant energy savings (kWh) from a power factor improvement project. However, the demand and cost savings do occur and at times the penalty imposed by the electricity boards on low power factor is saved. In the pre-installation equipment survey, the kW demand and the corresponding kVA for different scenarios are measured and hours at each scenario is stipulated.

Overview of Verification Method

Engineering calculations based on the average kWh and the corresponding kVAh recorded in the energy meter will enable in estimating the additional capacitors required to improve the average power factor from existing level say 0.85 to 0.95. Spot measurements before and after or the energy bill (essentially will then become Option C) will enable verification of improvement in the power factor.

Calculation of Demand Savings

M&V Method RP-A-01 requires spot or short-term kVA measurement of a representative sample kW conditions at baseline and post-installation to establish demand. This method is more time-consuming and expensive, but it may result in more accurate savings estimates kVA measurements are done carefully.

Demand Savings = (Baseline kVA – Post-retrofit kVA) x demand charges

Power factor gains = $(pf_{baseline} - pf_{post\text{-}retrofit})$ *x Rs penalty per month x 12*

The demand savings in term of monetary gains are purely a function of the tariff.

5.3.7 Lighting Efficiency
No Metering and Metering of Fixture Wattages Only
Methods LE-A-01 and LE-A-02

ECM Definition

Lighting ECM projects covered by this verification plan are as follows:

- 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

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

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 does not require metering of fixtures. Fixture wattages will be from a standard table unless other documentation, such as the manufacturer's 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 it may result in more accurate savings estimates if fixture wattage measurements are done carefully.

Calculation of Demand and Energy Savings

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. The location of the equipment (e.g., the rooms it is in) and 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. Fixtures should be identified by the last-point-of-control (switch or circuit breaker).

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. If a fixture is not found 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 fixtures representative of the baseline and post-installation fixtures(actual values may vary by application). 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.

Adjustments to Baseline Demand

Before the new lighting fixtures are installed, 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.

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 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.

Another adjustment that may be required is if dramatic changes in lighting level are anticipated. If a retrofit is expected to increase lighting levels (at the customer's request), this may increase the energy consumption over the baseline even if more efficient fixtures are used. One possibility is to define the adjusted baseline as the power consumed to provide the *desired* lighting level using the *existing* equipment. If it is proposed to increase lux levels by 30%, then the baseline power would be increased by 30% to adjust for the proposed increase. This way, the new lighting system can be properly compared to what would have been required to obtain the desired lighting levels.

Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO as follows:

Method LE-A-01—No Metering

Fixture wattages will be from a standard table unless other, approved, documentation is provided.

Method LE-A-02—Fixture Wattage Metering

Fixture wattages will be measured.

Operating Hours

Operating hours will be stipulated i.e., agreed to by the customer and the ESCO. Sources of stipulated hours can be any of the following (in order of preference):

- Pre-metering of representative areas by the ESCO
- Building occupancy hours multiplied by a lighting load factor
- 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 type should have similar use patterns and comparable average operating hours.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy

To estimate energy savings for lighting efficiency projects use the following equation:

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

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 nonoperative 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*, assuming operating hours are the same before and after measure installation

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 the 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.

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 savings
3. Calculate interactive effects on a site-specific basis. One simple method of estimating lighting interactive factors is outlined by Rundquist.[1]

5.3.8 Lighting Controls:
No Metering and Metering of Fixture Wattages Only
Methods LC-A-01 and LC-A-02

ECM DEFINITION

The lighting projects covered by this verification plan are as follows:

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

These lighting controls projects reduce fixture operating hours.

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 the way that 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 the manufacturer's 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 it may result in more accurate savings estimates if fixture wattage measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

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

[1] Rundquist, "Calculating Lighting and HVAC Interactions," *ASHRAE Journal* 35, no. 11 (1993).

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. If a fixture is not found 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 30-minute, true root-mean-square (RMS wattage measurements from at least six fixtures representative of the baseline and post-installation fixtures (actual values may vary by application). 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.

Adjustments to Baseline Demand

Before the new lighting fixtures are installed, 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.

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. 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 fixture wattage of zero.

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, 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.

Savings for combined energy efficiency and lighting control projects are defined in the equation in part ?.

Operating Hours

Baseline and post-installation operating hours will be stipulated i.e., agreed to by the customer and the ESCO. Sources of stipulated hours can be any of the following (in order of preference):

- Metering of representative areas by the ESCO
- Building occupancy hours multiplied by a lighting load factor
- 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.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

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 the two equations for lighting efficiency and lighting control projects that follow.

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

$$\text{kWh Savings}_t = \Sigma_u \left([(\text{kW/fixture x Quantity})_{baseline} - (\text{kW/fixture x Quantity})_{post}] \text{ x Hours of Operation}_{post} \right)_{t,u}$$

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

$$\text{kWh Savings}_t = \Sigma_u [(\text{Hours of Operation}_{baseline} - \text{Hours of Operation}_{post}) \text{ x (kW/fixture x Quantity}_{baseline})]_{t,u}$$

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 the 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.

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 savings.

3. Calculate interactive affects on a site-specific basis. One simple method of estimating lighting interactive factors is outlined by Rundquist.[2]

5.3.9. Constant-Speed Motor Efficiency: Metering of Motor kW Method CLM-A-01

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 reduce 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 when the original motor was oversized for the load.
- 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.

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 customer and the 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) the following data for each motor:

- Nameplate data
- Operating schedule
- Spot metering data
- Motor application
- Location

Metering is required on at least a sample of motors to determine the average power draw for baseline and new motors. Demand savings are based on the average kW measured before new motors are installled minus the average kW measured after the 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 in calculating energy savings, will be stipulated.

[2] Rundquist, "Calculating Lighting and HVAC Interactions," *ASHRAE Journal* 35, no. 11 (1993).

Calculation of Demand and Energy Savings

Baseline Demand

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey.
- 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, pava factor (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 the one shown in Table M2 (Appendix B). Such measurements should be made using a true RMS meter with an accuracy at or approaching ±1% of reading.[3] 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.

Adjustments to Baseline Demand

Before new motors are installed, 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 owing 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.*

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[3] report 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, is 4.4%. As such, the resolution of meters used to measure instantaneous kW should be much smaller than 4.0%. 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.)

Post-Installation Demand

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.

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 effects 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 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.

Operating Hours

Operating hours will be stipulated i.e., agreed to by the customer and the ESCO. Sources of stipulated hours can be any of the following (in order of preference):

- Metering of representative motors
- Operation logs or documentation schedules from energy management systems
- 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.

EQUATIONS FOR CALCULATING 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>

$$\textit{kWh Savings (per each period)} = \textit{Period Hours} \times \textit{kW Savings}$$

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

If operating hours are different before and after measure installation:

kWh Savings (per each period) =

$$\textit{Baseline Period Hours} \times kW_{baseline} - \textit{Post-Installation Period Hours} \times kW_{post}$$

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 ?.
Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

5.3.10.Variable-Speed Drive Motor Efficiency:
Metering of Motor kW
Method VSD-A-01

ECM DEFINITION

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

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

- 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.
- 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.

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 customer and the 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) the following data for each motor and control device:

- Nameplate data
- Operating schedule
- Spot metering data
- Motor application
- Applicable end-use definitions
- Location

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, since 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 the following:

- 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)
- Stipulated hours per year for each operating scenario

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey.
- 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 this 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.

Adjustments to Baseline Demand

Before the new motors are installed, 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, owing 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*.

Post-Installation Demand

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

When the motor kW is recorded, 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, the assumptions are as follows:

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

Operating Hours

Operating hours will be stipulated i.e., agreed to by the customer and the ESCO. Sources of stipulated hours can be any of the following (in order of preference):

- Metering of representative areas
- Operator logs or documented schedules from energy management systems
- 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 at 80% speed or 30 kW for 6,260 hours per year.

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

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Calculate the kWh savings using the following equations:

$$kWh\ Savings = \Sigma\,[\ Operating\ Scenario\ Hours_i \times kW\ Savings_i\,]$$

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 contains examples of baseline and post-installation power draw measurements and savings calculations made using the equations above.

Example of a 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

5.3.11 Chiller Replacement:
Method CH-A-01, No Metering
Method CH-A-02, Verification of Chiller kW/ton

ECM DEFINITION

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

- Existing chillers replaced with more energy-efficient chillers
- Existing chillers replaced with those using a different energy source
- Changes in chiller controls that improve chiller efficiency

Two M&V methods are described in this chapter. For method CH-A-01, the chiller efficiency (e.g. kW/TR) and the chiller load (e.g., TRH per year) are stipulated. For method CH-A-02, the chiller efficiency is measured and the chiller load is stipulated. *Thus, these methods are appropriate only 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 the customer.*

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 the following (in a set format) for each chiller and control device:

- Nameplate data
- Chiller application
- Operating schedules
- Commissioning of chiller operation is expected.

Method CH-A-01—No Metering

Baseline and post-installation chiller ratings (e.g., kW/TR, IPLV[4], COP) are stipulated on the basis of 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/TR and post-installation kW/TR and (b) cooling load in ton-hours. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

Method CH-A-02—Performance Measured

Baseline and post-installation chiller ratings (e.g., kW/TR, IPLV, COP) 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

[4] Integrated Part-Load Values, which indicates seasonal performance.

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.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

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 customer 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 the integrated part load value (IPLV) or kW/TR 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
- Cooling tower fan(s) kW (kWh) if they are to be replaced or modified[5].

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 (e.g., summer).

Post-Installation Demand

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

Cooling Load

Cooling load will be stipulated i.e., agreed to by the customer and the ESCO. Sources of stipulated data can be any of the following (in order of preference):

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

Because of chiller upgrades may be commensurate with other projects, baseline and post-installation cooling loads may be different.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

For electric chiller upgrades, calculate the kWh savings using the following equations:

kWh Savings = (Cooling Load in Ton-Hours) x (Baseline kW/ton - Post-Installation kW/ton)

where:

Cooling Load in Ton-Hours	stipulated and can be different for baseline and post-installation
Baseline kW/ton	The stipulated or measured existing chiller performance
Post-installation kW/ton	The stipulated or measured new chiller performance

Demand savings may be calculated as:

Maximum demand reduction:

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

[5]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.

Average demand reduction:

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

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

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			

For chiller conversions that involve fuel switching (such as electric-driven compression to direct-fired absorption) savings must be calculated in terms of energy costs as follows:

Savings = (Baseline Cost - Post-Retrofit Cost)

Baseline Cost = (Cooling Load in Ton-Hours) x (kW/TR) x (Cost/kWh) + Demand Charges

Post-Retrofit Cost = (Cooling Load in Ton-Hours) x (Conversion factor) x (Fuel Cost per unit) / COP

where:

Cooling Load in Ton-Hours	stipulated and can be different for baseline and post-installation
Baseline kW/ton	The stipulated or measured existing chiller performance
COP	The stipulated or measured new chiller performance
Conversion factor	Converts TRh to units of purchased energy
Fuel Cost per unit	Cost of energy per unit for new chiller

If an electric chiller is being replaced with a non-electric chiller, demand savings may be calculated as:

Maximum demand reduction:

$$kW\ Savings_{max} = kW_{baseline} = (kW/TR) \times (Chiller\ Capacity,\ TR)$$

Average demand reduction:

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

Demand savings need to be calculated in the same method by which the electricity board calculates demand charges. Typically, an electric chiller will significantly contribute to the monthly demand charges of each facility. The value of these monthly charges should be estimated and added to the baseline energy costs. Table below contains a summary of example baseline and post-installation power draw measurements and savings calculations (using the above equations).

Table Example Reporting Format

Scenario	Operating hrs/Yr	Stipulated Cooling Load (TRH)	Baseline Energy Use, kWh	Baseline Energy Cost, Rs	Demand Cost, Rs	Total Baseline Cost, Rs	Fuel Cost, Rs	Savings, Rs
Winter	1,000	100,000	100,000	400,000	100,000	500,000	400,000	100,000
Spring	1,500	150,000	150,000	600,000	125,000	725,000	600,000	125,000
Summer	2,000	200,000	200,000	800,000	150,000	950,000	800,000	150,000
Fall	1,500	150,000	150,000	600,000	125,000	725,000	600,000	125,000
Totals	**6000**	**600000**	**600000**	**2400,000**	**500,000**	**2900000**	**2400000**	**500000**

5.4 Selected M&V Methods—Option B

The chapters in this section contain descriptions of measure-specific M&V methods associated with Option B. Option B is one of the four M&V options defined for the implementation of energy efficiency projects. The methods described here are for the most typical ECMs (e.g., process technology upgrades) and they are representative of the range of methods available. This chapter introduces Option B. The measure-specific M&V methods based on Option B and presented under 5.5

Option B involves a retrofit or system level M&V assessment. The approach is intended for retrofits with performance factors (e.g. end-use capacity, demand, power) and operational factors (lighting operational hours, cooling ton-hours) that can be measured at the component or system level. It is appropriate to use spot or short term measurements to determine energy savings when variations in operations are not expected to change. When variations are expected, it is appropriate to measure factors continuously during the contract.

Option B is typically used when any or all of these conditions apply:

- For simple equipment replacement projects with energy savings that are less than 20% of total facility energy use as recorded by the relevant utility meter or submeter
- When energy savings values per individual measure are desired
- When interactive effects are to be ignored or are stipulated using estimating methods that do not involve long-term measurements
- When the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor
- When submeters already exist that record the energy use of subsystems under consideration (e.g., a lighting circuit or a separate submeter for HVAC systems).

APPROACH

Option B verification procedures involve the same items as Option A but generally involve more end-use metering. Option B relies on the physical assessment of equipment change-outs to ensure the installation is to specification. The potential to generate savings is verified through observations, inspections, and spot/short-term/continuous metering. The continuous metering of one or more variables may only occur after retrofit installation. Spot or short-term metering may be sufficient to characterize the baseline condition.

M&V CONSIDERATIONS

Option B is for projects in which (a) the potential to generate savings must be verified and (b) actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A plus the determination of energy savings during the contract term through short-term or continuous end-use metering. Option B:

- Confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings.
- Determines an energy (and cost) savings value using short-term or continuous measurement of performance and operating factors.

All end-use technologies can be verified with Option B; however, the degree of difficulty and costs associated with verification increases as metering complexity increases. Energy savings accuracy is defined by the owner or is negotiated with the ESCO. The task of measuring or determining energy savings using Option B can be more difficult and costly than that of Option A. Results are typically more precise, however, than the use of stipulations as defined for Option A.

Methods involve the use of pre- and post-installation measurement of one or more variables. If operation does not vary between pre and post conditions, monitoring pre-installation operation is not necessary. Spot or short-term measurements of factors are appropriate when variations in loads and operation are not expected. When variations are expected, it is appropriate to measure factors continuously. Performing continuous measurements (i.e. periodic measurements taken over the term of the contract) account for operating variations and will result in closer approximations of actual energy savings. Continuous measurements provide long-term persistence data on the energy use of the equipment or system. These data can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit. In situations like constant-load retrofits, however, there may be no inherent benefit of continuous over short-term measurements. Measurement of all effected pieces of equipment or systems may not be required if statistically valid sampling is used. For example, population samples may be measured to estimate operating hours for a selected group of lighting fixtures or the power draw of certain constant-load motors that have been predetermined to operate in a similar manner.

5.5 ECMs and applications Option B

ECM	Method Number	Performance Factors	Usage Factors
Process Technology improvements example) grind ing, distillation, evap-oration drying, cooling, heating	PT-B-01	kW or kcal/per unit of production (measured)	Production (measured)
Control system interventions	CS-B-01	kW/unit of production (measured)	Hours at each production rate (measured)
Boiler / Furnace equipment upgrades	TS-B-01	kW or kcal/ hr delivered output (measured)	Hours at each capacity, (measured)
Air compressor, Pump & Fan upgrades	TM-B-01	kW/delivered output (measured)	Hours at each capacity, (measured)
Heat Recovery Applications	HR-B-01	Temp, kcal (measured)	Hours/throughput (measured)
Reactive power compensation	RP-B-01	kWh, kVARh (measured)	kWh, kVARh (measured)
Lighting Efficiency	LE-B-01	kW (measured or stipulated), lumens	Hours (measured)
Lighting Efficiency	LE-B-02	kW (measured), lumens	Hours (measured)
Lighting Controls	LC-B-01	kW (measured or stipulated), lumens	Hours (measured)
Lighting Controls	LC-B-02	kW (measured), lumens	Hours (measured)
Constant-Load Motor η	CLM-B-01	kW (measured)	Hours (measured)
Variable-Speed-Drive Retrofit	VSD-B-01	kW at each operating scenario (measured)	Hours at each operating scenario (measured)
Chiller Replacements	CH-B-01 CH-B-02	Energy use metered Energy use metered	Stipulate TR load Measure TR load
Generic Variable Load Project	GVL-B-01	Energy use metered	Load,hours metered

5.5.1 Process Technology improvements
Measured performance, Measured production
Methods PT-B-01

ECM DEFINITION

Process Technology improvement projects covered by this verification plan are as follows:

- Retrofits of existing process technology/ equipment with a more energy-efficient system

These projects reduce energy demand either in terms of thermal energy needs (heating or cooling) or electrical power required. However, the production is stipulated and is assumed to be same in the pre- and post-retrofit periods.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Product quality and rate may be specified.

M&V Method PT-B-01 requires long-term performance measurements of a representative production (or time-period) of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method PT-B-01

The performances can be measured in terms of energy used per unit of production. The production during the post retrofit and baseline conditions are also measured and varying product-mix is converted to an equivalent standard product quantity.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy

To estimate energy savings for process technology improvement and control system interventions, projects use the following equation:

$$Energy\ Savings_t = (Energy/Unit\ of\ production_{baseline} - Energy/Unit\ of\ production_{post}) \times Production_t$$

where:

$Energy\ Savings_t$	Energy savings realized during the post-installation time period *t*
$Energy/Unit\ of\ production_{baseline}$	Baseline energy use
$Energy/Unit\ of\ production_{post}$	Energy use during post-installation period

Demand

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Baseline adjustments

Baseline adjustments need to be made depending on the changes in the raw material composition, product mix variation, voltage, frequency and any other relevant factors.

5.5.2 Control System Interventions
Measured performance and Measured hours for different load conditions
CS-B-01

ECM DEFINITION

A control system intervention involve controlling the process parameters at specific set values by either varying the flow of steam or input power. For example, it can be a process temperature, pressure or any similar variables. These projects covered by this verification plan are as follows:

- Introducing a process control system to reduce energy use in terms of steam or fuel or power.

These projects reduce energy demand either in terms of fuel reduction or electrical power required. The process variation conditions and hours at each condition are monitored at frequent intervals as the process or situation may demand in the pre- and post-retrofit periods.

Overview of Verification Methods

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method CS-B-01 requires spot or short-term performance measurements of a representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

Calculation of Demand and Energy Savings

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method CS-B-01

Baseline and post-installation ratings (e.g., kW/cfm, kgs of fuel/ton of steam, COP) are measured. Annual hours of operation at each capacity is also measured. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for boiler/furnace upgrades or air compressor, pump & fan upgrade projects use the following equation:

Calculate the energy savings using the following equations:

$$\text{kWh or kcal Savings} = \Sigma\,[\,\text{Operating Scenario Hours}_i \times \text{kW or kcal/hr Savings}_i\,]$$

where:

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

$kcal\ Savings$ = $kcal/hr_{baseline} - kcal/hr_{post}$

$kW_{baseline}$ or $kcal/hr_{baseline}$ the demand of the baseline in a particular operating scenario

kW_{post} or $kcal/hr_{post}$ = the demand of the efficient equipment in a particular operating scenario

Operating Scenario = a particular mode of operation such as part-load or set-point value

Operating Hours = Measured hours for each operating scenario

Demand

Demand savings may be calculated as:

Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Baseline adjustments

Baseline adjustments need to be made depending on the changes in the set point changes, changes in process conditions, voltage, frequency and any other relevant factors.

5.5.3 Boiler / Furnace equipment upgrades
Measured performance, Measured hours at each capacity
TS-B-01

ECM Definition

Boiler or Furnace equipment upgrades involve improving the generation efficiency of the specific utility by the equipment under evaluation. For example, it can be generation of steam or melting or heating in the case of furnaces. These upgrade projects covered by this verification plan are as follows:

- Replacement of existing equipment (boiler/ furnace) with a more energy-efficient boiler / furnace.

These projects reduce energy demand either in terms of fuel reduction or electrical power required. However, the capacity or production rate and hours at each capacity is stipulated and is assumed to follow the same pattern in the pre- and post-retrofit periods.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method TS-B-01 requires long term performance measurements such as efficiency of the boiler, kWh or kgs of fuel required per ton of metal at a representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method TS-B-01

Baseline and post-installation ratings (e.g., kgs of fuel/ton of steam, kWh/ton melted kWh/ton heated, COP) are measured. Annual hours of operation at each capacity is stipulated. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy

To estimate energy savings for boiler/ furnace upgrades use the following equation: Calculate the energy savings using the following equations:

$$kWh\ or\ kcal\ Savings = \Sigma\ [[\ Operating\ Scenario\ Hours_i\ x\ kW\ or\ kcal/hr\ Savings_I]$$

where:

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

$kcal\ Savings$ = $kcal/hr_{baseline} - kcal/hr_{post}$

$kW_{baseline}$ or $kcal/hr_{baseline}$ the demand of the baseline in a particular operating scenario

kW_{post} or $kcal/hr_{post}$ = the demand of the efficient equipment in a particular operating scenario

Operating Scenario = a particular mode of operation such as part-load or set-point value

Operating Hours = stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Baseline adjustments

Baseline adjustments need to be made depending on the changes in the fuel quality, voltage, frequency and any other relevant factors.

5.5.4 Pump, Fan, Compressor upgrades
Measured performance at specific load conditions
TM-B-01

ECM DEFINITION

Pump, Fan, Compressor upgrades involve improving the generation efficiency of the specific utility by the equipment under evaluation. In case of pumps, fans and compressors, it is the quantity of output in terms of flow rate/hour. These upgrade projects covered by this verification plan are as follows:

- Replacement of existing equipment with a more energy-efficient equipment

These projects reduce energy demand either in terms of electrical power required. However, the capacity or production rate and hours at each capacity is stipulated and is assumed to follow the same pattern in the pre- and post-retrofit periods.

OVERVIEW OF VERIFICATION METHODS

The production is stipulated how the efficiency gains in terms of kW or kcal are determined.

Surveys are required of existing (baseline) and new (post-installation) system. Output quantity and parameters may be specified.

M&V Method TM-B-01 requires long term performance measurements of representative load capacity of baseline and post-installation conditions. This method will result in accurate savings estimates if performance measurements are done carefully.

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method TM-B-01

Baseline and post-installation ratings (e.g., kW/cfm, COP) are measured based on standard test procedures. Annual hours of operation at each capacity is measured. Energy savings are based on the summation of products of (a) the difference between average baseline (input-output ratio) and post-installation (input-output ratio) for a particular operating capacity and (b) output capacity. If fuel-switching occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs. It is important to record the power quality parameters such as voltage, frequency during such measurements as they play a significant role on the energy use especially in centrifugal pumps, fans, and compressors.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Energy

To estimate energy savings for boiler/furnace upgrades or air compressor, pump & fan upgrade projects use the following equation:
Calculate the energy savings using the following equations:

$$\textit{kWh or kcal Savings} = \Sigma\,[\,\textit{Operating Scenario Hours}_i \times \textit{kW or kcal/hr Savings}_I\,]$$

where:

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

kcal Savings = $kcal/hr_{baseline} - kcal/hr_{post}$

$kW_{baseline}$ or $kcal/hr_{baseline}$ The demand of the baseline in a particular operating scenario

kW_{post} or $kcal/hr_{post}$ = The demand of the efficient equipment in a particular operating scenario

Operating Scenario = a particular mode of operation such as part-load or set-point value

Operating Hours = Measured hours for each operating scenario

Demand

Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Baseline adjustments

Baseline adjustments need to be made depending on the changes in the set point changes, changes in process conditions, increase or decrease of energy used in associated sub-systems, voltage, frequency, maintenance condition of the machinery and any other relevant factors.

5.5.5 Heat Recovery Applications
Measured Performance at measured hours at each capacity
HR-B-01

ECM DEFINITION

A heat recovery system intervention involve recovering the heat/ (cold) from a process stream or exhaust gases or effluent in order to reduce the fuel or electricity required to heat or cool the stream. These projects covered by this verification plan are as follows:

- Introducing a waste heat recovery from the flue gases of a boiler, DG set

- Recovering heat from an effluent stream
- Exchange of heat between process streams

These projects reduce energy demand either in terms of fuel use and/or electrical power required. However, the performance is arrived at based on engineering calculations and just some of the typical temperature streams are spot-measured before and after. The throughput pattern in the pre- and post-retrofit periods and the hours of operation is stipulated.

OVERVIEW OF VERIFICATION METHODS

The performance is measured to verify the efficiency gains in terms of kW or kcal

Surveys are required of existing (baseline) and new (post-installation) system. The process streams whose temperatures need to be monitored may be specified.

M&V Method HR-B-01 requires continuous or long term measurements of temperatures at baseline and post-installation conditions. This method will result in accurate savings estimates even if throughput varies as it is measured & logged

CALCULATION OF DEMAND AND ENERGY SAVINGS

Baseline Demand

In the pre-installation survey, the equipment to be changed and the replacement equipment to be installed are inventoried.

Method HR-B-01

Baseline and post-installation performances (e.g., temperature of a process stream before and after) are arrived at based on engineering calculations and just some of the typical temperature streams are measured before and after. The throughput pattern in the pre- and post-retrofit periods and the hours of operation is also measured. Energy savings are based on the heat recovered per hour divided by efficiency of generation of heat multiplied by the hours of operation stipulated. (The term 'heat' means both heating and cooling)

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for heat recovery projects use the following equation:
Calculate the energy savings using the following equations:

$$\text{kWh or kcal Savings} = \frac{\text{Heat recovered } (mC_p\Delta T) \text{ as kcal/hour}}{\text{Thermal efficiency of heat generation}} \times \text{Hours/yr}$$

where:

$mC_p\Delta T$		m is the mass flow rate of the process stream (this throughput is stipulated) *C_p specific heat* *ΔT temperature gain or reduction*
kW Savings	=	$kW_{baseline} - kW_{post}$
kcal Savings	=	$kcal/hr_{baseline} - kcal/hr_{post}$
$kW_{baseline}$ or $kcal/hr_{baseline}$		the demand of the baseline in a particular operating scenario
kW_{post} or $kcal/hr_{post}$	=	the demand of the efficient equipment in a particular operating scenario
Operating Hours	=	stipulated hours for each operating scenario

Demand

Demand savings may be calculated as:
Maximum demand reduction:

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

Average demand reduction:

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

Demand savings (either steam or cooling system or power) can be calculated as average reduction in demand. Average reduction in demand is generally easier to calculate. It is defined as energy savings during the time period in question divided by the hours in the time period.

Baseline adjustments

Baseline adjustments need to be made depending on the changes in the set point changes, changes in process conditions, energy reduction in the up-stream/ down-stream processes that can affect the quantum of thermal energy to be recovered from the process stream, voltage, frequency and any other relevant factors.

5.5.6 Reactive power compensation
Performance based on engineering computation
Stipulated hours of load conditions kW
Methods RP-A-01

ECM DEFINITION

The power factor improvement projects covered by this verification plan are as follows:

- Installation of capacitors and/or filters to improve the power factor and thereby reduce the demand charges or avoid the power factor penalties.

These projects will reduce the kVA required and improve the power factor. There are not significant energy savings (kWh) from a power factor improvement project. However, the demand and cost savings do occur and at times the penalty imposed by the electricity boards on low power factor is saved. In the pre-installation equipment survey, the kW demand and the corresponding kVA for different scenarios are measured and hours at each scenario is measured.

OVERVIEW OF VERIFICATION METHOD

Engineering calculations based on the average kWh and the corresponding kVAh recorded in the energy meter will enable in estimating the additional capacitors required to improve the average power factor from existing level say 0.85 to 0.95. Spot measurements before and after or the energy bill (essentially will then become Option C) will enable verification of improvement in the power factor.

Calculation of Demand Savings

M&V Method RP-B-01 requires long-term kVA measurement of a representative sample kW conditions at baseline and post-installation to establish demand. This method is more time-consuming and expensive, but it may result in more accurate savings estimates kVA measurements are done carefully.

Demand Savings = (Baseline kVA – Post-retrofit kVA) x demand charges

Power factor gains = $(pf_{baseline} - pf_{post\text{-}retrofit})$ *x Rs penalty per month x 12*

The demand savings in term of monetary gains are purely a function of the tariff.

5.5.7.1 Lighting Efficiency:
Monitoring of Operating Hours
Method LE-B-01

PROJECT DEFINITION

- The lighting projects covered by this verification plan are as follows:
- 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

These lighting efficiency projects reduce demand. However, the fixtures have the same pre- and post-retrofit operating hours.

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 any of the following (in order of preference):

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

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures and rooms. The monitoring time period must be reasonable and account for any seasonal variations. For office buildings, this is typically three weeks or more.

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. Method LE-B-02 involves baseline and post-installation lighting circuit measurements to determine both demand and energy savings.

Calculating Demand and Energy Savings

Baseline Demand

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 may 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 fixtures representative of the baseline and post-installation fixtures (actual values may vary by application). 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.

Adjustments to Baseline Demand

Before the new lighting fixtures are installed, 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; 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 a 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.

Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO. The techniques discussed in part 11.3.1 can be used to inventory the installed equipment.

Operating Hours

To measure post-installation operating hours, three key issues must be defined:

- 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
- How long operating hours will be metered to determine a representative operating profile

Usage Groups

Building usage areas will be identified for areas with comparable average operating hours, as determined by the lights operating during the year or by 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 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 in Appendix C.

Meters

The ESCO will specify the meter to be used in the site-specific M&V plan. Measurements of operating hours are typically done with either of these:

- "Light loggers," which are 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)
- 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 nonlighting loads that cannot be distinguished from the lighting load. Thus, only when lighting and nonlighting loads are separable, may circuits be monitored.

Period of Monitoring

Monitoring provides 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 equipment should not be installed during significant holiday or vacation periods. If a holiday or vacation falls within the monitoring installation period, that period should be extended for the same number of days as the holiday or vacation.

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, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting operating hours during different times of the year.

The ESCO-supplied site-specific M&V plan will include the detailed the agreed-to sample plan and monitoring plan.

EQUATIONS FOR CALCULATING 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.

The 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.

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*

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.

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% add-on to lighting kWh savings to account for additional air-conditioning saving.
- Calculate interactive effects on a site-specific basis. One simple method of estimating lighting interactive factors is outlined by Rundquist.[6]

5.5.7.2 Lighting Efficiency: Metering of Lighting Circuits Method LE-B-02

PROJECT DEFINITION

The lighting projects covered by this verification plan are as follows:

- 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 reduce demand. However, the fixtures have the same pre- and post-retrofit operating hours.

OVERVIEW OF VERIFICATION METHOD

This M&V method involves measuring all, or a representative number of, lighting circuits to determine either or both of the following:

- Baseline and post-installation electrical energy consumption (kWh) in order to determine energy savings and average demand savings
- Baseline and post-installation electrical demand (kW) profiles in order to determine demand savings

Circuit measurements may be made of current flow (Amperes) or power draw (Watts) 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.

CALCULATING DEMAND AND ENERGY SAVINGS

Baseline Demand and Energy

Circuit measurements are the basis for calculating energy and demand savings with this M&V method. Equipment inventories, however, are strongly suggested to confirm 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

[6] Rundquist, "Calculating Lighting and HVAC Interactions," *ASHRAE Journal* 35, no. 11 (1993).

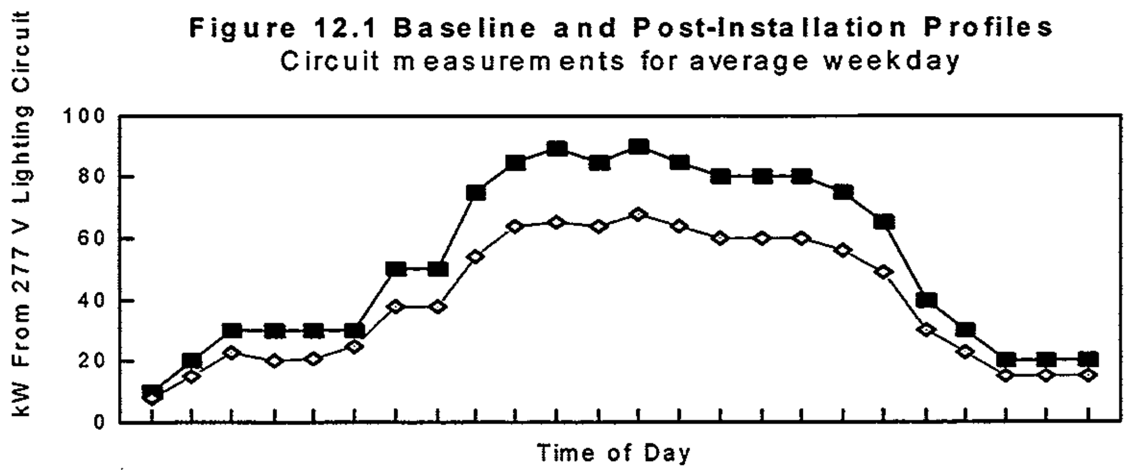
quantify non-operating fixtures for any required adjustments to the baseline and post-installation circuit measurements.

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

Circuit measurements are made 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. Figure 12.1 compares 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 the following:

- Only lighting loads that are affected by the retrofit are on the measured circuit(s)
- If other loads are on the circuit(s), the nonlighting loads should be minimal, and well defined, and they should not vary from before the retrofit to after it 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?
- What are the appropriate lighting circuit sample sizes?

Whether all the circuits or just a sample of them 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 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 M&V plan. Measurements of circuits are typically made with either of the following:

- 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.
- 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 (e.g., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available to the customer.

Period of Monitoring

Metering provides 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 metering period should be extended as many days as the holiday or vacation lasted.

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, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific M&V plan will include a detailed, agreed-to sample plan and metering plan.

Adjustments to Baseline Demand

Before new lighting fixtures are installed, 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.

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; 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.

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.

EQUATIONS FOR CALCULATING 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. The ESCO will extrapolate results from the metering data to determine demand and energy savings.

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.

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.

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% add on to lighting kWh savings to account for additional air conditioning saving.
- Calculate interactive affects on a site-specific basis.

5.5.8.1 Lighting Controls: Monitoring of Operating Hours Method LC-B-01

PROJECT DEFINITION

The lighting projects covered by this M&V plan are installation of occupancy sensors or daylighting controls with or without changes to fixtures, lamps, or ballasts. These lighting control projects reduce fixture operating hours.

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 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 any of the following:

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

Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures and 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 control projects. Method LC-B-01 requires pre- and post-installation equipment surveys in combination with pre- and post-installation metering of hours of operation to establish savings. Chapter 14 addresses Method LC-B-02, which involves baseline and post-installation lighting circuit measurements for determining both demand and energy savings.

CALCULATING DEMAND AND ENERGY SAVINGS

Baseline Demand

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 locations 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 determined from a standard table unless other documentation is provided. A standard table of fixture wattages should contain common lamp and ballast combinations. *If 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 fixtures representative of the baseline and post-installation fixtures (actual values may vary by application). 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.

Adjustments to Baseline Demand

Before new lighting fixtures are installed, 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.

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; 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 a 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.

Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO. The techniques discussed in part 13.3.1 can be used to inventory the installed equipment.

Operating Hours

To determine how operating hours will be measured (both before and after the control devices are installed), three key issues must be defined:

- *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

- How long the operating hours should be metered 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 operating during the year or by 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 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 M&V plan. Operating hours are typically measured with either of the following:

- "Light loggers," which are 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)
- 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 of 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 (e.g., at least every 30 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available to the customer.

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, may circuits be monitored.

Period of Monitoring

Monitoring provides 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 holiday or vacation lasted.

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, such as classrooms, or according to a scheduled activity, it may be necessary to determine lighting operation hours during different times of the year.

The ESCO supplied site-specific M&V plan will include the detailed, agreed-to sample plan and monitoring plan.

EQUATIONS FOR CALCULATING 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.

The 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. To calculate the respective energy savings and peak period demand savings for each usage area, the assigned party will apply these average operating hours to the baseline and post-installation demand 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.

Energy

To avoid double-counting 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 the following:

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

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

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

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

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.

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
- Calculate interactive affects on a site-specific basis

5.5.8.2 Lighting Controls:
Metering of Lighting Circuits
Method LC-B-02

PROJECT DEFINITION

The lighting projects covered by this verification plan are installations of occupancy sensors or daylighting controls with or without changes to fixtures, lamps, or ballasts. These lighting controls projects reduce fixture operating hours.

OVERVIEW OF VERIFICATION METHOD

This M&V method involves measuring all, or a representative number of, lighting circuits to determine either or both of the following:

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

CALCULATING DEMAND AND ENERGY SAVINGS

Baseline Demand and Energy

The basis for calculating energy and demand savings with this M&V method is circuit measurements. Equipment inventories, however, are strongly suggested to confirm 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.

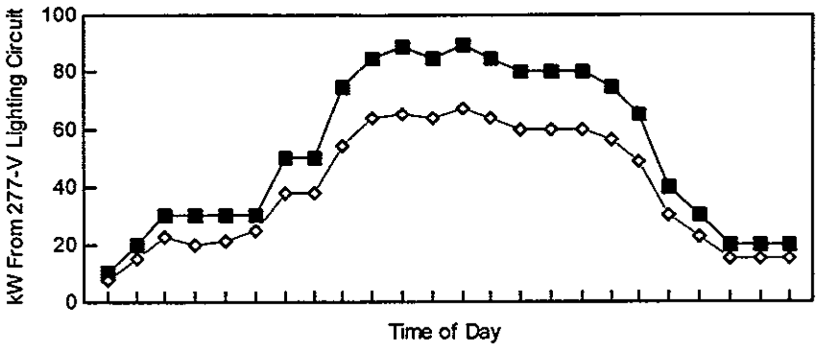
Pre-Installation Equipment Survey

In a pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed in 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

Circuit measurements 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. Comparing the power on the circuits before and after the retrofit determines both energy and demand savings. Figure ??? compares average load profiles for the energy draw of a lighting circuit both 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.

Figure 14.1 Baseline and Post-Installation Profiles
Circuit measurements for average weekday



The circuits must be carefully selected to ensure either of the following:

- That only lighting loads that are affected by the retrofit are on the measurement circuit(s)
- If other loads are on the circuit(s), the non-lighting loads should be minimal, well defined, and not vary from before the retrofit is complete to after it is complete.

If only a subset of affected lighting circuits is 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?
- What are 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 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 M&V plan. Circuits are typically done measured either of the following:

- 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.
- 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 (e.g., at least every 15 minutes). "Raw" as well as "compiled" data from the meter(s) must be made available to the customer.

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, such as in classrooms, or according to a scheduled activity, it may be necessary to determine lighting energy use and profiles during different times of the year.

The ESCO-supplied site-specific M&V plan will include a detailed, agreed-to sample plan and metering plan.

Adjustments to Baseline Demand

Before the new lighting fixtures are installed, adjustments to the baseline demand may be required for non-operating fixtures. After the 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.

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; 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 a 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.

Post-Installation Demand

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

EQUATIONS FOR CALCULATING 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. The ESCO will extrapolate results from the metering data to determine demand and energy savings.

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.

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.

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
- Calculate interactive affects on a site-specific basis

5.5.9 Constant-load motor Efficiency: Metering of Operating Hours Method CLM-B-01

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 reduce 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:

- Baseline motors may be replaced with smaller high-efficiency motors when the original motor was oversized for the load.
- 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.

Overview of Verification Method

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

- Nameplate data
- Operating schedule
- Spot and short-term metering data
- Motor application definitions
- 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 the new motors are installed minus the average kW measured after they are installed. Allowances may be made for differences in motor slip between existing and new motors.

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 the motors. In addition, metering can be used to (a) confirm constant loading and (b) determine average motor power draw (if normalization is required).

Calculating Demand and Energy Savings

Baseline Demand

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey
- Perform spot metering of existing motors
- Perform short-term metering of existing motors

The equipment survey is described in this subsection. Spot and short-term metering 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
- Location

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

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

Adjustments to Baseline Demand

Before the new motors are installed, 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.

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.*

Baseline Operating Hours

Baseline motor operating hours can be determined in either of these ways:

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

Short-term or long-term metering will be used to determine operating hours

Post-Installation Demand

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

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

If existing motors were short-term metered, their replacement, high-efficiency motors will also be subject to short-term metering. The data need be processed only to normalize the spot-metering results. There is no need to verify that the motor load is constant for the high-efficiency motors.

Post-Installation Operating Hours

Post-installation operating hours can be assumed to be either the same as or different from 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.

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. 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.
- The high-efficiency motor exhibits less slip and 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.

SPOT AND SHORT-TERM METERING

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.[7] 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.

Short-Term Metering

The ESCO will conduct short-term monitoring to do the following:

- Verify that motor loads are constant (baseline only).
- Normalize spot-metering kW measurement results.
- Determine operating hours

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. Sample selection and results of metering for the entire sample should be summarized.

ESCOs may conduct short-term metering using current transducers and data loggers. The equipment for short-term metering need be accurate only within ±5% of full scale, but it 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. Note that motor

[7] Gordon et. al. 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%. (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.)

load and kW do not correlate in a linear way with amperage across the full operating range of most motors.

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 average amperes measured in the short-term metering period with all hourly non-zero values. An application will be verified to be constant if 90% of all non-zero observations are within ±10% of these average amperes. The ESCO will record the number of non-zero observations, the number of observations within ±10% of the average amperes, 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, 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 it 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 begin 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:

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

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:

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

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).

Monitoring to Determine 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 period 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 M&V plan.

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 should be extended as many days as the holiday or vacation lasted.

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, as they do with HVAC systems, it may be necessary to determine operating hours during different times of the year.

Sampling

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

Equations for Calculating Energy and Demand Savings

Calculate normalized kW using the following equation:

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

Calculate the kWh savings using the following equations:

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

$$\text{kWh Savings (per each period)} = \text{Period Hours} \times (kW_{baseline,\ normalized} - kW_{post\ normalized})$$

If operating hours are different before and after ECM installation:

$$\text{kWh Savings (per each period)} =$$

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

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

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)
Demand savings may be calculated as follows:

Maximum demand reduction:

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

Average demand reduction:

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

5.5.10 Variable-Speed-Drive Retrofit: Continuous Post-Installation Metering Method VSD-B-01

ECM DEFINITION

Variable-speed-drive (VSD) efficiency projects involve the replacement of existing (baseline) motor controllers with VSD motor controllers. These projects reduce demand and energy use but do not necessarily reduce utility demand charges. Also, VSD retrofits 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 appropriate only for VSD projects in which, for the baseline and post-installation motors, the following conditions apply:

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

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 the following (in a set format) for each motor and control device:

- Nameplate data
- Operating schedule
- Spot metering data
- Motor application
- 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, 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 in calculating baseline energy use. If baseline independent-variable values are required to calculate 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 the following:

- Motor operating hours that are measured before or after the VSDs are installed
- A constant-motor kW value that is determined from pre-installation metering

Alternatively, motor kW can be calculated as a function of independent variables that are monitored during the post-installation period.

Post-installation demand and energy use are based on the following:

- Motor operating hours that 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

Alternatively, motor kW can be calculated as a function of independent variables that are monitored during the post-installation period.

Calculating Demand and Energy Savings

Baseline Demand and Energy

Baseline motor demand will either be any one of the following:

- A constant kW value
- A value that 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
- A value that varies as a function of some independent variable, such as outdoor air temperature or system pressure for a variable air volume system.

Steps involved in establishing the baseline demand are as follows:

- Conduct a pre-installation equipment survey
- Perform 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 the following in a set format:

- Motor and motor control nameplate data
- Motor horsepower
- Load served
- Operating schedule
- Spot metering data
- 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 same location is used for both the baseline and post-installation measurements.

The ESCO will conduct short-term monitoring for constant load, baseline motors to do the following:

- Verify that motor loads are constant
- Normalize spot-metering kW measurement results.

The ESCO will conduct short-term monitoring for variable-load, baseline motors to do the following:

- 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
- Define the relationship between motor kW and the appropriate independent variables, 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

Baseline Operating Hours

Baseline motor operating hours can be determined at either of the following times:

- Before ECM installation, if the hours are assumed to be different from post-installation operating hours
- 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 part 16.5.

Adjustments to Baseline Demand and Energy

Before the new motors are installed, 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.

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.*

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.

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 that 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 they do with 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 randomly selected month during each contract year.

Post-Installation Operating Hours

Post-installation operating hours can be assumed to be either the same as or different from the pre-installation operating hours. If the hours are assumed to be same before and after the new motors are installed then post-installation monitoring of motors with VSDs can be used to determine operating hours. Typically, post-installation monitoring will be used because waiting for the results of baseline monitoring could delay VSD installation.

Operating hours can be established per a certain time period (e.g., weekday hours) or per different operating scenarios (e.g., at different VSD speeds). Operating hours monitoring is discussed in part 16.5.

SAMPLING

The ESCO will spot meter all of the motors; however, the short- or long-term metering may need to be done only 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 project, at least one motor must be subject to short-term metering by the ESCO.

MONITORING TO DETERMINE OPERATING HOURS

Operating hours may be the same before and after the VSDs are installed, or they 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 these:

- 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 16 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 specified in the site-specific M&V plan. The period of time will be proposed by the ESCO and approved or modified by the Federal agency.

Monitoring provides an estimate of annual equipment operating hours and energy use. The duration and timing of the installation of run-time monitoring have strongly influence 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 monitoring period should be extended for as many days as the holiday or vacation lasted.

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, as they do with HVAC systems, it may be necessary to determine operation hours during different times of the year.

EQUATIONS FOR CALCULATING ENERGY AND DEMAND SAVINGS

Calculate the kWh savings using the following equations:

$$\text{kWh Savings (per each Operating Scenario)} = \text{Operating Scenario Hours} \times \text{kW Savings per each Operating Scenario}$$

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:

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

PRE- AND POST-INSTALLATION SUBMITTALS

For each site, the ESCO submits a project pre-installation report that includes the following:

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

The ESCO submits a project post-installation report following project completion and defines projected energy savings for the first year. The report includes many of the components in the project pre-installation report, adding information on *actual* rather than expected ECM installations.

SITE-SPECIFIC MEASUREMENT AND VERIFICATION PLAN

The site-specific M&V approach may be specified in the ESPC between the customer and the ESCO and/or agreed to after the award of the project. In either case, before the customer should approve the project, the ESCO must submit a final M&V plan that addresses the following elements on a site-specific basis:

- Overview of approach
- Specification of savings calculations
- Specification of site survey plan
- Specification of data collection methods, schedule, duration, equipment , and reporting format
- 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 the following:

- Definition of operating modes for motors
- Sampling plan for motor power measurements
- Post-installation metering strategy for motor kW or independent variables
- Assessment of non-operating motors

5.5.11 Chiller Replacement:
Method CH-B-01, Metering of Chiller kW
Method CH-B-02, Metering of Chiller kW and Cooling Load

ECM DEFINITION

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

- Existing chillers replaced with more energy efficient chillers
- Changes in chiller controls that improve chiller efficiency

Two M&V methods are described in this chapter. 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.

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 the following (in a set format) for each chiller and control device:

- Nameplate data
- Chiller application
- 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 the following:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV)
- 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 the following:

- Measured or stipulated baseline chiller ratings (e.g., kW/ton, IPLV)
- Cooling loads measured during the post-installation period.

Baseline Demand

Steps involved in establishing the baseline demand are these:

- Conduct a pre-installation equipment survey
- Define the chiller efficiency (see Method CH-A-01) or meter the 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 the following in a set format:

- Chiller and chiller auxiliaries nameplate data
- Chiller age, condition, and ratings
- Load served
- Operating schedule
- Chiller application
- 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 on the basis of 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) [for example, per the appropriate standards of the Air-Conditioning and Refrigeration Institute] or kW/ton per incremental cooling loads.

Metering of Existing Chillers

The data collected to characterize the performance of the chiller depends on the whether the chiller's efficiency is sensitive to the condensor and chilled water temperature or not. Volume II of the Final Report for ASHRAE Research Project 827-RP, *Guidelines for In-Situ Performance Testing of Centrifugal Chillers*, provides detailed instructions for developing both a temperature-dependent and temperature-independent model of chiller performance. The models use linear regressions on metered data to characterize the performance of the chiller over a range of conditions. The wider the range of conditions experienced during the metering, the more accurate the models will be.

For temperature-independent chillers (chillers whose condenser and chilled water temperatures are close to constant), the following data will need to be collected:

- Chiller kW
- Chilled water flow, entering and leaving temperatures for calculating cooling load

For chillers subject to varying condenser and chilled water temperatures, all of the data noted above must be collected along with the following:

- Condenser water supply temperature
- Chilled water return temperature

If other features of the cooling plant are also modified by the proposed measures, they'll need to be metered as well. For instance, if the condenser water pumps, chilled water pumps, or cooling tower fans are affected, their demand (kW) should also be metered.

As much as possible, these data should be entered into standard forms. 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 when the cooling load is expected to vary over a wide range; often, more time is required.

Post-Installation Demand and Energy

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

Chiller energy use and demand profile will be measured either continuously throughout the term of the contract or 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 used to develop a model of the chiller performance, which can be applied when chiller performance isn't measured.

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Cooling Load

Cooling load does not have to be measured to determine post-installation energy use and demand because the post-installation chiller energy use is metered with these two M&V methods. The baseline-cooling load, however, must be determined to calculate 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 these:

- Pre-installation metering of cooling loads by the ESCO or Federal agency
- Results from other projects in similar facilities

If stipulated loads are used, a simple, temperature-independent model of chiller performance should be used, since the condenser water return temperature would be very difficult to stipulate successfully.

Baseline and post-installation cooling loads may be different. Typical weather data or actual weather data can be used to determine cooling loads. The problem with stipulating cooling loads is savings may be inappropriately biased because comparison of the baseline and post-installation energy use of different cooling loads.

Method CH-B-02—Energy Use and Cooling Load Metered

Cooling loads are measured with this method. Therefore, baseline cooling loads are based on the post-installation cooling load. Data that should be metered include the following:

- Chilled water flow
- Chilled water entering and leaving temperatures (air-flow measurements are required for DX systems)
- Outside air temperature or weather data (for reference)

If a temperature-dependent model of chiller performance is used, the condenser water return temperature should also be metered.

Equations for Calculating Energy and Demand Savings

Calculate the kWh savings using the following equations:

kWh Savings =

[(Baseline Cooling Load in Ton-Hours) x (Baseline kW/Ton)] - Post-Installation kWh

where:

Cooling Load in Ton-Hours = stipulated, measured, or calculated;
Baseline kW/ton = stipulated or measured existing chiller performance; and
Post-installation kWh = measured for the new chiller(s).

Demand savings may be calculated as follows:

Maximum demand reduction:

$$kW\ Savings_{max} = (kW_{baseline} - kW_{post})_{at\ maximum\ cooling\ load,t}$$

Average demand reduction:

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

5.5.12 Generic Variable Load: Continuous Post-Installation Metering Method GVL-B-01

PROJECT DEFINITION

This M&V method plan covers projects that improve the efficiency of end uses that exhibit variable energy demand and/or variable operating hours. Here are some examples:

- Replacing motors that serve variable loads with high-efficiency motors
- Upgrading building automated systems
- Installing new air-conditioning equipment
- Installing thermal insulation

For this M&V method, the savings associated with the ECMs must be verified with end-use metering.

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 of the existing systems, or a representative sample, 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:

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

- 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.

METERING AND CALCULATING BASELINE DEMAND AND ENERGY SAVINGS

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 the 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.

Establishing Baseline Model

The ESCO will meter system input energy (e.g., kWh, kCal) and demand (e.g., kW, kCal/h) over a representative time period before any efficiency modifications are made (note that demand is measured if contract payments include a demand savings-based component). This metering will be applied to devices that will be directly affected by the ECM. The duration of input metering will be long enough to document the full range of system operation. The ESCO will propose an appropriate duration in the site-specific M&V plan. Typically, observations will be made at 15-minute intervals, unless the ESCO demonstrates that longer intervals are sufficient.

Energy Standards

If the project is subject to any energy standards or minimum performance standards, these standards may need to be accounted for in the baseline model.

If multiple, similar equipment components or systems are to be modified (e.g., 10 supply fans), the ESCO may propose metering only a sample in the site-specific plan.

Variable Measurements

While the input energy use is being monitored, the ESCO will meter one or both of the following at the same time:

- Independent variables that affect the energy and demand use. are ambient temperature, control set points, and building occupancy.

- Dependent variables (system output) that indicate the energy and demand use. This 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 can be directly influenced by highly variable independent variables such as weather conditions. For these projects, the ESCO may choose to develop a regression model that links independent variable data to energy input. The ESCO can present specific methods for doing this in the site-specific M&V plan, and considered for approval by the Federal agency.

The ESCO will combine the 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. These are some examples of criteria for establishing statistical validity:

- The model makes intuitive sense; e.g., the explanatory variables are reasonable, the coefficients have the expected sign (positive or negative), and they 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 (coefficient of determination) is reasonable given the type of data being modeled.
- All data entered into the model are thoroughly documented, and model limits (the range of independent variables for which the model is valid) are specified

The customer may make the final determination on the validity of models and monitoring plans and may request additional documentation, analysis, and/or metering from the ESCO, as necessary.

Note: The ESCO must 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 must carefully analyze systems to identify a quantifiable output that exhibits a direct relationship to the input energy.

POST-INSTALLATION METERING AND CALCULATING SAVINGS

Two approaches are defined here for calculating savings:

- 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).
- 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).

Calculating Savings by Metering Post-Installation Energy and Variables

After installing the ECM, the ESCO will continuously meter the system energy input and monitor the output (e.g., tons of cooling) or independent variables (e.g., weather) over the life of the claimed energy savings. Metering and monitoring will be done in the same way as the monitoring done 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):

$$\text{Energy savings}_i = (kW_b - kW_m) \times T_i$$

where:

$kW_{baseline}$ = system	Baseline kW calculated from System Baseline Model and corresponding to the same variable (e.g., time interval, output, weather, conditions) as kW_m
kW_m =	Measure kW obtained through continuous post-installation metering
T_i =	Length of time interval

(Note that kW is used in this equation, but other factors such as kCal/hr may be appropriate).

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.

Calculating Savings by Metering Post-Installation Variables

The ESCO may meter the post-installation system energy input and monitor the post-installation conditions in order to develop a Post-Installation System Model. The ESCO would then monitor system output (and/or other relevant variables) during a representative period on a regular basis. This representative period will be similar to the 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.

When choosing this alternative, the ESCO will use two equations to calculate savings or one equation to calculate 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 then calculate the savings by taking the difference of the baseline and post-installation system data input and multiplying by the appropriate time interval.

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 rather than actual weather data.

5.6 Selected M&V Methods —Option C

This Option C approach uses regression models and utility billing data (therms, fuel oil and/or kWh, and kW) to calculate annual energy savings. In general, Option C should be used with complex equipment replacement and controls projects for which predicted savings are relatively large—i.e., greater than 10% to 20% of the site's energy use, on a monthly basis.

Unlike the Option C approach in which billing comparison methods are used, regression Analyses can take into account many independent variables and thus provides a more reliable estimate of energy savings.

Utility billing analysis using regression models is applicable for measurement and verification when the impacts of the ECMs are too complex to analyze cost effectively with Option B and when the rigor of Option D is not required. Billing analysis is appropriate when:

- Savings are above noise—that is, the estimated energy savings are greater than at least 10% to 20% of the monthly utility bill being analyzed.
- There is a high degree of interaction between multiple measures at a single site.
- The ECM improves or replaces the building energy management or control system.
- The ECM involves improvements to the building shell or other measures that primarily affect the building load (e.g., thermal insulation, low-e windows).
- The measurement of individual component savings is not relevant.
- Other approaches are too expensive.

Regression analysis is a time-consuming task that requires experienced, qualified analysts. Specific difficulties associated with Option C methods include the following requirements:

Using at least 12, and preferably 24, months of pre-installation data to calculate a baseline model

Using at least 9, and preferably 12, months of post-installation data to calculate first-year savings

Collecting adequate data in order to generate accurate baseline and post-installation models

If required, adjusting the analyses so as to have the baseline meet minimum operating conditions or energy standards (e.g., minimum ventilation rates that exceed current conditions).

Utility billing regression analysis is a highly specialized discipline. Contractors who plan to use this option should use this chapter for guidance and request that the federal agency review specific Option C issues. The M&V method described here is based in part on materials in the 1998 IPMVP. Information on the IPMVP can be found on the Web at www.ipmvp.org. Valuable insights into utility bill analysis can be found in the IPMVP.

Energy consumption under Option GVL-C-01 is calculated by developing statistically representative models of whole-facility energy consumption (i.e., therms and/or kWh). The types of models depend on the number of independent variables that affect energy use and the complexity of the relationships. The types of models that may be used include the following:

- One-parameter
- Two-parameter
- Change-point
- Multivariate.

The best model is one that is simple and yet produces accurate and repeatable savings estimates. Finding the best model often requires the testing of several to find one that is easy enough to use and meets statistical requirements for accuracy. This chapter discusses generic modeling issues, with an emphasis on multivariate modeling. There are three approaches to calculating savings:

A baseline model is defined using regression analysis. The independent variables are input and estimated energy consumption is output. The model results are compared against actual post-installation meter readings to determine savings.

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. A single "savings" model is generated that includes both baseline and post-installation factors. This approach is usually simpler and generates more reliable estimates, since it is also based on more data points than the second approach described here.

This part describes some of the required data analysis protocols. The regression analysis requires information that spans the full range of normal values for the independent variables. For weather-dependent ECMs, this usually means collecting data for at least one full heating and/ or cooling season. The rule of thumb is that at least 12 months of data, before the date of the ECM installation, is required; however, at least 24 months of data are desirable, particularly if energy consumption is very sensitive to weather or other highly variable factors. If data are missing, the period of data collection should be extended

The regression analysis requires at least 9 months of data collected after the date of installation to determine impacts for the first year, and preferably 12 months of data before submitting the first-year M&V savings report. The billing analysis models should be updated until at least 18 months of post-installation data have been used to determine the independent-variable coefficients. The regression model coefficients can be either fixed during the term of the contract or continuously updated.

The criteria used to identify and eliminate outliers needs to be documented in the project-specific M&V plan. Outliers are data beyond the expected range of values (e.g., a data point more than two standard deviations away from the average of the data). The elimination of outliers, however, must be explained; it is not sufficient to eliminate a data point simply because it is beyond the expected range of values. If data are found to be abnormal because of specific mitigating factors, then the data point can be eliminated from the analysis. If a reason for the unexpected data cannot be found, the data should be included in the analysis. Outliers will be defined according to "common sense" as well as common statistical practice. Outliers can be defined in terms of consumption changes and actual consumption levels.

Multivariate regression is an effective technique that controls 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 of pre-and post-installation consumption loads. 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 project specific basis, it is critical to investigate the systems that affect and are affected by the project and select all independent variables that have direct relationships to energy use. Data need to be collected for the dependent and explanatory variables in a suitable format over a significant period of time. For example, collecting chiller energy use over a wide range of ambient temperatures and indoor temperatures may require several months of data collection.

A regression model (or models) should be developed that describes changes between pre-installation and post-installation energy use for the affected site (or sites), taking into account all explanatory variables. For affected utility electric billing meters with time-of-use data, the regression model(s) will yield savings by the hour or critical time-of-use period. For meters with only monthly consumption data, the models will be used to predict monthly savings.

In the regression analysis, utility meter billing data (monthly or hourly) on a project-specific basis is used to prepare models for comparing energy use before the installation of ECMs to energy use after they are installed. Any differences, after adjusting for non-retrofit-related factors, are then defined as the gross load impacts of the project at the site.

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

5.7 Selected M&V Methods —Option D

This section discusses the calibrated computer simulation analysis method of measurement and verification. Use of Option D is appropriate for complex projects in industries though is not common due to the high M&V costs involved and where multiple ECMs will be installed or where tracking complex process operation conditions is necessary.

Because a computer simulation allows a user to model the complex interactions that govern the facility's energy use, it can be a very powerful tool to use in estimating a project's energy savings. Even for the simplest projects, however, simulation modeling and calibration are time-intensive activities and should be performed by an accomplished building simulation specialist. Calibrated simulation analysis is an expensive M&V procedure, and should only be used for projects that generate enough savings to justify its use.

The following steps are involved in performing Option D M&V:

- In the site-specific M&V plan, document the strategy for calculating savings.
- Collect required data from EB bill records, architectural drawings, site surveys, direct measurements of specific equipment in the facility.
- Adapt the data and enter them into the simulation program input files.
- Run the simulation program for the existing building.
- Calibrate the simulation program by comparing its output with utility bills and measured data.
- Refine the existing model until the program's output is within acceptable tolerances of the measured data.

Chapter 6 Move Forward & Conclusions

The ESCO industry in India is maturing and the need for a protocol has definitely been felt. This is one of the first attempts in bringing together all the stakeholders in the industry to talk in one voice and language on the measurement and verification of energy savings. The following are some of the most important conclusions and aspects on moving forward with the M&V protocol work initiated in India.

- The protocol in India becomes specific due to the unique issues such as power quality, the concept of ESCO being new among end-users, Financial institutions and ESCOs. However, these variables can be suitably accounted for if care is taken in the initial M&V plans by the end-user, the ESCO and the FI.

- Though IPMVP is sector neutral, as it is generic, it is required to constantly update the India specific protocol with more applications and typical ECMs.

- This protocol need to be maintained and made as a living document to incorporate changes and improvements reflecting new research, improved methodologies and improved M&V data.

- In India, the end-users need to be constantly trained on the use of M&V.

- The advantage that M&V can be used in defining and allocation of risks aids in making M&V as a tool for financing energy efficiency projects.

- The FIs can make use of the trading of emissions to finance energy saving projects more attractively.

- The third party savings verifiers is likely to gain importance in the near future. Accreditation issues need to be addressed with care, to avoid the M&V becoming a hindrance to the energy efficiency gains.

The international protocol provides an established and independent mechanism to determine energy savings to financiers of energy saving projects and the end-users. The understanding of the M&V protocol by all the stakeholders will make them equipped to make an appropriate business decision about the risk and reward of an energy efficiency investment.

Appendix A Definitions and References

Definitions

Baseline Adjustments – The non-routine adjustments arising during the post-retrofit period that cannot be anticipated and which require custom engineering analysis

Baseyear Conditions – The set of conditions which gave rise to the energy use/demand of the baseyear.

Baseyear Energy Data – The energy consumption or demand during the baseyear.

Baseyear – A defined period of any length before implementation of the ECM(s).

Commissioning – A process for achieving, verifying and documenting the performance of equipment to meet the operational needs of the facility within the capabilities of the design, and to meet the design documentation and the owner's functional criteria, including preparation of operator personnel.

CV (RMSE) – Coefficient of Variation of the RMSE

Degree Day – A degree day is measure of the heating or cooling load on a facility created by outdoor temperature. When the mean daily outdoor temperature is one degree below a stated reference temperature such as 18..C, for one day, it is defined that there is one heating degree day. If this temperature difference prevailed for ten days there would be ten heating degree days counted for the total period. If the temperature difference were to be 12 degrees for 10 days, 120 heating degree days would be counted. When the ambient temperature is below the reference temperature it is defined that heating degree days are counted. When ambient temperatures are above the reference, cooling degree days are counted. Any reference temperature may be used for recording degree days, usually chosen to reflect the temperature at which heating or cooling is no longer needed.

Energy Conservation/ Efficiency Measure (ECM or EEM) – A set of activities designed to increase the energy efficiency of a facility. Several ECM's may be carried out in a facility at one time, each with a different thrust. An ECM may involve one or more of: physical changes to facility equipment, revisions to operating and maintenance procedures, software changes, or new means of training or managing users of the space or operations and maintenance staff.

EMS or Energy Management System – A computer that can be programmed to control and/or monitor the operations of energy consuming equipment in a facility.

Energy Performance Contract	–	A contract between two or more parties where payment is based on achieving specified results; typically, guaranteed reductions in energy consumption and/or operating costs.
Energy Savings	–	Actual reduction in electricity use (kWh), electric demand (kW), or thermal units (Btu).
ESCO or Energy Services Company	–	A firm which provides a range of energy efficiency and financing services and guarantees that the specified results will be achieved under an energy performance contract.
M&V or Measurement & Verification	–	The process of determining savings using one of the four IPMVP Options.
Metering	–	Collection of energy and water consumption data over time at a facility through the use of measurement devices.
Monitoring	–	The collection of data at a facility over time for the purpose of savings analysis (i.e., energy consumption, temperature, humidity, hours of operation, etc.)
M&V Option	–	One of four generic M&V approaches defined herein for energy savings determination.
Post-Retrofit Period	–	Any period of time following commissioning of the ECM.
R^2	–	R Squared
Regression Model		Inverse mathematical model that requires data to extract parameters describing the correlation of independent and dependent variables
RMSE	–	Root mean square error
Simulation Model	–	An assembly of algorithms that calculates energy use based on engineering equations and user-defined parameters.
Verification	–	The process of examining the report of others to comment on its suitability for the intended purpose.

References

1. **IPMVP (International Performance Measurement and Verification Protocol) 2000** and **IPMVP 1997**, available at www.ipmvp.org
2. **FEMP (Federal Energy Management Program) M&V Guideline, 2000,** http://www.eren.doe.gov/femp/financing/measguide.html
3. J. Stephen Kromer, Steven R Schiller and John Elliot, **Measurement and Verification Protocols** - M&V Meets the Competitive and Environmental Marketplaces
4. Nexant Inc, INTESCO Asia Limited, Schiller Associates, **Seminar & Course Material on Measurement & verification of Energy Savings**, Dec. 5-8, 2000 Mumbai and Dec. 11-14, 2000 New Delhi.
5. **Feedback on discussions & interactions among India specific core group members on Measurement & Verification Protocol** Nov-Dec. 2000

Appendix B Checklist for M&V Plan

- ☐ Project site and measures are defined.
  - ☐ What savings will be claimed? (energy, interactive effects, O&M, rate change...)
  - ☐ How will these ancillary savings be treated?

- ☐ M&V method(s) (chapters), from M&V Guideline, is defined.

- ☐ Details of how calculations will be made are defined. All equations are shown.
  - ☐ Provided information shows how collected data and assumptions are used.
  - ☐ Energy pricing information and assumptions are defined. (fixed cost, inflated...)

- ☐ Baseline Equipment and Conditions.
  - ☐ Existing equipment (inventory and performance) is defined.
  - ☐ Space conditions (lux levels, temps, etc.) are defined.
  - ☐ Assumptions and stipulations- show supporting information or measurements.
  - ☐ How and why any baseline adjustments will be made is discussed.

- ☐ Post-Installation Equipment and Conditions.
  - ☐ Plan for defining new equipment (inventory and performance) is described.
  - ☐ Plan for defining new space conditions (lux levels, temps, etc.) is described.
  - ☐ Assumptions and stipulations- show supporting information or measurements to be taken.

- ☐ Metering equipment is specified.
  - ☐ Schedule of metering, including duration and when it will occur, is defined.
  - ☐ Who will provide equipment, establish and ensure its accuracy and perform calibration procedures, is described.
  - ☐ How data from metering will be validated and reported, including formats, are defined.
  - ☐ How electronic, formatted data, directly from a meter or data logger, will be provided.
  - ☐ Any sampling that will be used, sample sizes, documentation on how sample sizes were selected, is defined.

- ☐ Annual verification and measurement activities are defined.
  - ☐ Who will conduct the M&V activities and prepare M&V analyses and documentation is defined.
  - ☐ How quality assurance will be maintained and repeatability confirmed is defined.
  - ☐ Reports are defined, including what they will contain and when they will be provided.
  - ☐ Electronic formats and software programs to be used for reporting are defined.

- [ ] Initial and annual M&V costs for each measure (totals only).

Appendix C : Extracts of suggestions from core group members

Discussion Material: 2

Measurement & Verification Protocol
Industrial, Commercial and Residential Sectors

Based on your experiences on ESCO projects, in your opinion, do you consider the following as the measurement & verification issues that need to be addressed: (Please mention whichever you feel are the issues among 1 to 8. You may feel free to add other M&V issues)

Basic concept

Energy Savings = Base-line - Post retrofit + adjustments

Comparing energy consumption of two different time periods is difficult due to a variety of factors nevertheless is possible.

1. Difficulties exist in establishing baseline & post retrofit conditions due to various factors

2. Measurement & calibration is an expensive affair

3. How long to measure (both in baseline and post retrofit conditions) is not clearly known?

4. Accountability of risks for the variables that can affect the energy consumption and thus the savings

5. Inadequate metering in the existing conditions and inaccurate past data makes base-line establishment a critical issue

6. We face problems of educating the end-user on the need for taking into account the variables that may affect the base-line consumption and the M&V procedures

7. Absence of minimum energy standards

8. Convincing FIs is an issue.

9. Risk factor is high in energy efficiency projects and M&V shall mitigate and reduce the risks involved.

The IPMVP (International Performance Measurement and Verification Protocol) has four options of M&V which have been grouped broadly as :

Option A : One time or limited measurement with stipulations on factors such as hours of usage. (for retrofit applications)

Option B : Continuous Measurement (for retrofit applications)

Option C : Whole billing analysis using regression or statistical techniques on the known variables such as capacity utilisation that affect energy use

Option D : Computer Simulation of the plant

- Which of the Energy Conservation Measures (ECMs) do you feel can be analyzed under each of these options?

- Do you feel all the ECMs can be covered under any one of these options?

Industrial
Equipment replacement: Motors, Boilers, Compressors, Pumps, Blowers - Option A

Technology Upgrades: Improvements in unit operations such as grinding, drying, evaporation, distillation - Option B

Control system interventions, Variable Speed Drive Applications - Option B

Multiple ECMs: A combination of the above - Combination of the above options or Option C

Others: Cogeneration, Waste Heat Recovery Option B

Commercial
Lighting Efficiency Improvements - Option A
Chiller Upgrades - Option B
Air-conditioning improvements - Option D

Residential
Renewable Energy Use - Option A
Fuel switching for water heating applications - Option A
Pump improvements - Option A or Option B

Please feel free to add any other typical ECM examples

CONTRIBUTIONS:

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sivakumar@mail.cgl.co.in

All the ECMs can be covered under any one or combination of the options as agreeable to both partners.
ECM should include fuel savings, fuel switching ,load shifting and energy reduction measures and also Reactive Power Compensation Schemes that reduce reactive power consumption of end users leading to higher Power factor and lower Power Costs.

Mark Stetz
marks@schiller.com

- Regarding the mention about how to treat reactive power savings. The addition of capacitor banks, high-efficiency distribution transformers can all reduce reactive power consumption. My recommendation would be to approach this using an IPMVP Option C (Electricity Board bill analysis). The reason for doing so is that Electricity Boards report reactive power consumption, either as power factor or as kVARh. To establish the baseline, use one year's worth of utility bills and determine the average power factor. Automatic capacitor banks are designed to maintain a constant pf.
- If the power factor is not reported but kVARh is, calculate the monthly power factor as
  pf= kWh / sqrt (kWh^2 + kVARh^2) and average them. Applying to the pre-retrofit and post-retrofit period. Recalculate the post-retrofit amount at the baseline power factor. The cost savings are easily determined from the difference between the recalculated bill and actual bill.
  I hope this helps demonstrate how IPMVP principles can be applied to measures not specifically described.

Discussion Material: 3

Measurement & Verification- Energy Efficiency Projects

1. Is there a need for a measurement and verification (M&V) protocol for energy savings projects?
2. If Yes, can the IPMVP 2000 be adaptable to India specific?
3. Are there any financial issues to be addressed in the proposed protocol?

CONTRIBUTIONS:

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sivakumar@mail.cgl.co.in

- Yes, there is a need for M&V protocol. Establishing an India specific M&V protocol will definitely give guidance to the project partners in developing a M&V methodology specific to their project and finalising it in a mutually agreeable manner.
- IPMVP can be adapted to India specific application.
- The performance related risks are scattered among several participants. To overcome this, M&V protocol should include realistic risk allocation, which involves the identification, measurement and allocation of risks for each project in the following areas.

a) Hardware risks(including construction costs, equipment performance, technical risks etc.) should be allocated to ESCO.
b) Functional risks (occupancy/ production level risks, base year data, process control etc.) can be shared by ESCO and owner.
c) Energy price risks: shared between ESCO and owner.

Amit Bhatt
amit.bhatt@in.abb.com

- There is no doubt that M&V Protocol is a must for ESCO business.

- It is both desirable and timely that these standards are established. An M&V Protocol, adhering to the basic tenets of a standard, i.e., reliable ,accurate ,replicable should symbolise the best practices being followed internationally. It is better that the IPMVP 2000 is suitably 'Indianised' as it already incorporates these tenets. The gradual but irreversible integration of Indian economy with international markets is itself building up pressure on Indian manufacturers to become more efficient and competitive in a global environment.

- A robust M&V protocol could serve as an important differentiator for financiers. The fact that a company is willing to subject itself to protocol procedure would convey important message to the financier about sincerity and openness of the management to incorporate the energy efficiency solution. A financing decision is based on the identification and allocation of various risks. An established, time_tested and widely accepted protocol will certainly increase the comfort level of financiers by addressing the issue and removing the element of uncertainty around it.

Appendix D : M&V Resource Material

Part I Measurement and Verification Resources - India

The list indicates a selection of some of the major resources available in India.

Overview of M&V Tools

Report Section	Includes	Purpose in M&V
Resource Organisations	ATIRA CII EMC TERI USAID	Organisations active in the energy efficiency field
Software and Hardware Tools	SEE UTISAVE ECOLUMEN Alacrity Electronics Limited Crompton Greaves Limited Enercon Systems Pvt. Ltd. Schneider Electric, India	Software resources for design and measurement Manufacturers of energy efficient eqipment
Indian Standards	Standards for lighting	Guidelines for measurement

1 RESOURCE ORGANISATIONS

1.1 AHMEDABAD TEXTILE INDUSTRY'S RESEARCH ASSOCIATION (ATIRA)

ATIRA has more than three decades of experience in the field of energy conservation in the textile industry in India as well as other SAARC countries. ATIRA provides guidelines for energy saving to the entire textile industry in India. The R&D activities in the energy conservation areas has contributed to fuel economy, humidification, electrical energy & chemical processing. ATIRA is recognised as energy auditors by various state energy development agencies and has conducted large number of audits.

Contact: PO Ambavadi Vistar, Ahmedabad- 380015 Ph: 079-6442671, 6568995 Fax: 079-6569874 Email:atira@adl.vsnl.net.in

1.2 CONFEDERATION OF INDIAN INDUSTRY (CII)

CII have a huge base spanning a large number of industrial members. Energy audits in all types of industries, specific energy conservation norms for different sectors of industry.

Contact : www.ciionline.org

1.3 Energy Management Cell- PHDCCI

Provides consultancy services in energy audit, conservation, and management.

Contact : PHD House, Opp. Asian Games Village, New Delhi - 110 016

1.4 TATA ENERGY RESEARCH INSTITUTE (TERI)

TERI is an autonomous not for profit, research institute committed to efficient use of raw materials, protecting the environment and conserving natural resources.

Contact : Darbariseth block, Habibat place, Lodhi Road
New Delhi - 110 003

1.5 UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID)

Manages ECO - India's US$25 million Energy Conservation and Commercialization project.Technical assistance and training for commercialization of conservation.

Contact : Office of Environmental, Energy and Enterprise , USAID, American Embassy, Chankayapuri New Delhi - 110 0021

2 SOFTWARE AND HARDWARE TOOLS

SOFTWARE

2.1 SEE-UTISAVE
SEE-Tech Solutions Pvt. Ltd.

(Save Electricity in Utilities) *See-UtiSave* helps to identify & quantify energy wastage and facilitates selection & implementation of energy saving measures in electrical utilities. *See-UtiSave* helps to understand the energy interactions, effects of various design & operating parameters on efficiency and quantify energy losses in transformers, power factor improvement, motors, compressors & cooling tower and monitor energy consumption versus production at SEB/Feeder/DB level). It is highly interactive, user friendly and provides required knowledge base in the Help. The user can customize *See-UtiSave* by incorporating his plant particulars.

2.2 ECOLUMEN

ECOLUMEN (energy efficient lighting designer) by TATA INFOTECH LTD. (TIL) Is a lighting designing software developed for design solutions in energy efficiency. TIL works on a program describing services and solutions to power sector through technology and product development.

Available through : Manesh Commercial Centre, 276, Dr. Annie Besant Road, Worli, Mumbai - 400 025

HARDWARE

2.3 ALACRITY ELECTRONICS LIMITED
Manufacturers of KRYKARD range of range of measuring and monitoring instruments.
Contact : 12-B, Valmiki Street, T.Nagar, Chennai

2.4 Crompton Greaves Ltd.- Energy Division
One of the largest manufacturers of electrical and electronic equipment in India.

Contact: 3-A, Kodambakkam High Road P B No. 3316, Chennai 600034.www.cgl.co.in

2.5 ENERCON SYSTEMS PVT. LIMITED

Design, manufacturer and supply of energy management systems for monitoring analysis and control of electrical energy. Products: energy management network systems, smart demand controller power and energy monitors, trivector monitor, universal power and energy meters, digital panel meters, smart analyser clamp on current probes & fused voltage probes, analog volt and ammeters.

Available through : enerconsys@vsnl.com, www.enerconindia.com

2.6 SCHNEIDER ELECTRIC, INDIA

Schneider provides innovative solutions for electrical distribution, industrial control and building automation.

Available through: www.schneider-india.co.in

3. INDIAN STANDARDS (Partial list of relevant standards)

Standard	Particulars
IS 2418	Tubular fluorescent lamps for general lighting and services requirements and tasks
IS 6665	Code of practice for industrial lighting
IS 13021	Part 1: supplied electronic ballasts for tubular fl lamps - general & safety equipments part 2 - performance requirements
IS 2418	Tubular fluorescent lamps for general lighting service part 1- Requirement and tests part2- Standard lamp data sheets part3- Dimensions of G-5 & G-13 bi - pin caps
IS 325: 1961	Three phase induction motors
IS 2672:1966	Code of practise for library lighting
IS 4347:1967	Code of practise for hospital lighting
IS 6665:1972	Code for practise for industrial lighting
IS 10947:1984	Code of practice for lighting for ports and harbours
IS 11116:1984	Code of practice for lighting for airport aprons
IS 12290:1987	Isolating transformers for airport lighting
IS 12291: 1987	Constant current regulators for airport systems
IS 6841	EEE ballast

Appendix D : M&V Resource Material

Part II : Measurement & Verification Resources

Prepared by

SCHILLER ASSOCIATES
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June 9, 2000

for

U.S. Department of Energy's
Federal Energy Management Program (FEMP)

Measurement & Verification
Resources

Measurement and Verification
Resources

Measurement and verification (M&V) of energy savings, generated through building systems retrofits and upgrades, requires special project planning as well as unique engineering practices. Although several common practices exist for M&V of energy savings, it is not an exact science. There are many resources available that can be used to learn more about the engineering techniques and tools used for verification of energy savings. This document lists some of those resources. It is not intended to be a comprehensive listing of resources, but rather indicative of the types of tools that are available.

Table 1: Overview of M&V Tools

Report Section	Includes	Purpose in M&V
M&V Guidelines	❖ FEMP IPMVP ASHRAE 14P	Provide M&V standards based on accepted, proven strategies.
Case Studies	California SPC Program FEMP	Example applications of M&V strategies.
Software & Hardware Tools	❖ Building energy simulation software System performance simulation software Utility cost management software Software and hardware tools for data acquisition and management	Available tools that can be used to: model building and systems to estimate savings; track utility costs to verify savings; measure equipment operations; measure and recording of variable operating parameters; process recorded data.

1 M&V Guidelines

Several guidelines have been published on measurement and verification energy savings. Each of the Guidelines listed in this section are unique, albeit similar, and are intended for use in different instances. All of these documents provide standard M&V methods that are proven and accepted strategies.

1.1 FEMP M&V Guidelines Version 2.0

The Federal Measurement and Verification (M&V) Guideline provides procedures and guidelines for quantifying the savings resulting from the installation of energy conservation measures. Intended for use in Energy Savings Performance Contracting (ESPC) and utility program projects, the guideline provides the methodology for establishing energy cost savings called for in the ESPC rule. These guidelines are available at www.eande.lbl.gov/CBS/femp/MVdoc.html.

1.2 International Performance Measurement and Verification Protocol

The International Performance Measurement and Verification Protocol (IPMVP) is a document which discusses procedures that, when implemented, allow building owners, energy service companies, and financiers of buildings energy efficiency projects to quantify energy conservation measure (ECM) performance and energy savings. The IPMVP provides an overview of current best practice techniques available for verifying savings from both traditionally- and third-party-financed energy and water efficiency projects. These guidelines are available at www.ipmvp.org/.

1.3 ASHRAE PROPOSED GUIDELINE 14P

The ASHRAE guideline is called *Measurement of Energy and Demand Savings*, Advanced Working Draft #1, December 13, 1999 © ASHRAE. The proposed requirements in this draft are subject to change before final approval by ASHRAE. ASHRAE Guideline 14P was developed by ASHRAE to provide guidance on the minimum acceptable level of performance in the measurement of energy and demand savings for the purpose of a commercial transaction based on that measurement. ASHRAE Guideline 14P deals only with the measurement of energy and demand savings. Other tasks are needed in any energy performance contract. Review copy is available at http://www.ashrae.org/standards/availdft.htm.

2 Case Studies

One of the best ways to understand measurement and verification of energy savings is to learn from examples. Several sources of case studies and related materials are listed below.

2.1 California SPC Program Case Studies

Several example M&V Plans are included in Appendix D of the California Utility SPC Program M&V Guidelines. Included in this document are M&V Plan Template, VSD Installation M&V Plan, Constant Speed Chiller Replacement M&V Plan, Variable Speed Chiller Replacement M&V Plan, and Calibrated Simulation M&V Plan. It is available at www.pge.com/spc/large_nr/forms.html.

2.2 FEMP CASE STUDIES

Demonstrations projects provide first-hand details on some of the latest federal projects at www.eren.doe.gov/femp/prodtech/successstories.html.

- The Evaluation of a 4000-Home Geothermal Heat Pump Retrofit at Fort Polk, Louisiana

Final Report, Report ORNL/CON 460 (1998), by P.J. Hughes and J.A. Shonder, Chapter 7 "Measurement and Verification of Energy Savings" Additional information is available at http://www.eren.doe.gov/femp/financing/ghpresources.html#savings.

3 TOOLS for Data collection and Analysis: Software & Hardware

Several types of software and hardware related to energy analysis are available. Some software is available at no cost, while other programs can be purchased. This is not intended to be a comprehensive list of all programs that are available nor a recommendation for any particular tool, but rather an indicator of the types of existing tools. The software is categorized as either: Building Energy Simulation, System Performance Simulation, Utility Cost Management, or Data Acquisition and Management. Information on additional energy software tools can be found at www.eren.doe.gov/buildings/tools_directory/ and eande.lbl.gov/CBS/eXroads/soft.html.

3.1 BUILDING ENERGY SIMULATION SOFTWARE

- BLAST

BLAST (Building Loads Analysis and System Thermodynamics) performs hourly simulations of buildings, air handling systems, and central plant equipment in order to provide mechanical, energy and architectural engineers with accurate estimates of a building's energy needs. The zone models are based on the fundamental heat balance method, are the industry standard for heating and cooling load calculations. BLAST output may be utilized in conjunction with the LCCID (Life Cycle Cost in Design) program to perform an economic analysis of the building/system/plant design. Available through Building Systems Laboratory, University of Illinois, 1206 West Green Street, Urbana, Illinois 61801, telephone (217) 333-3977, facsimile (217) 244-6534 or www.bso.uiuc.edu. Software prices range from $450 for an upgrade package to $1500 for new installations.

- DOE-2

Performs hourly simulation of new and existing buildings based on the building's climate, architecture, materials, operating schedules, and HVAC equipment. Appropriate for use with Option D.
Available through LBNL, Buildings Technology Program, Kathy Ellington, fax: (510) 486-4089 or http://gundog.lbl.gov/.

- VisualDOE2.5

VisualDOE is a graphical version of DOE2. Users can model complex buildings and HVAC systems. Provides results in graphical format. Software is available from Eley Associates, 142 Minna Street, San Francisco, California 94105. Phone: 415-957-1977, fax: 415-957-1381, email: info@eley.com. http://www.eley.com/.

- Energy-10

Energy-10 is a simple graphical building simulation program for evaluating buildings while still in the design stage. Good for residences and small offices. Can be used to evaluate different potential energy-efficiency measures including passive solar. Available through the Sustainable Buildings Industries Council (SBIC), 1331 H Street, N.W., Suite 1000, Washington, DC 20005, Phone: (202) 628-7400, fax: (202) 393-5043, email: sbic@sbicouncil.org, http://www.sbicouncil.org/

3.2 System Performance Simulation Software

- CoolTool

Software offers component level modeling of chiller plant, simulating performance of electric chillers & cooling towers. Provides hourly energy cost analyses of chiller water plant equipment and control alternatives. Appropriate for use with Option D. Electric chiller model is now in beta release.
Available through Pacific Energy Center, Mark Hydeman, 851 Howard Street, San Francisco, CA 94103, tel: (415) 972-5498, fax: (415) 1290, www.hvacexchange.com/cooltools.

- QuickChill

Designed to evaluate performance changes when converting from R-11or R-12 to another refrigerant. Can also be used to evaluate chiller staging strategies and condenser & evaporator water temperature reset. Software was developed by the US Environmental Protection Agency and is available at http://www.epa.gov/buildings/esbhome/tools/software.html.

- Market Manager

Simulation software using standard ASHRAE algorithms that allow modeling of building systems, sub-systems, and components. Appropriate for use with IPMVP/FEMP Options C and D.
Available through SRC SYSTEMS, INC., 2855 Telegraph Ave., Suite 410, Berkeley, CA 94705, tel: (510) 848-8400, fax: (510) 848-0788, www.src-systems.com.

3.3 Utility Cost Management Tools

- Energy Accounting: A Key Tool in Managing Energy Costs

Energy accounting is a system to record, analyze and report energy consumption and cost on a regular basis. This downloadable guide will discuss some of the reasons for energy accounting, go into background information needed to understand it, and explain how to get started with a program. With emphasis on computer software, this document will discuss some of the methods and means of energy accounting, focusing in on energy accounting software packages. The appendix reviews and provides information on five of the most popular, commercially available energy accounting software packages. It is available at www.energy.ca.gov/reports/efficiency_handbooks/index.html.

- FASER 2000

Tracks, analyses, and reports utility billing data, as a result detects billing and metering errors, identifies electrical and mechanical problems, and highlights cost saving opportunities. Appropriate for use with IPMVP/FEMP Option C.

Available through OmniComp, Inc., 220 Regent Court, State College, PA 16801, tel: 1-800-726-4181, fax: (814) 238-4673, www.faser.com.

- METRIX

METRIX is software designed to track utility usage and costs in order to track operating cost savings or verify the impacts of utility performance measures. Metrix creates a historical baseline using a multi-variant linear regression to correct for weather and other independent variables that affect utility cost. It establishes performance targets and can track an unlimited number of sites, facilities, and meters. Appropriate for use with IPMVP/FEMP Option C.
Software prices range from $2,495 to $4,495 depending on the type of license purchased. See web site to download an evaluation version. Available through SRC Systems Inc., Suite 410, 2855 Telegraph Avenue, Berkeley, California 94705, telephone (510) 848-8400, facsimile (510) 848-0788 or www.src-systems.com.

3.4 Tools for Data Aquisition and Management

- Abacus

Provides wireless meter information that can be used to detect abnormal energy use and assess the impact of measures immediately. Use could include monitoring for IMPVP/FEMP Options B and C.
Available through Ameren (abacus.amerren.com).

- ARC Systems

Complete line of compact Information Loggers Small data loggers record temperature, relative humidity, electric current, pressure and other standard variables without plugs, power supplies, signal conditioning or complex in-field setups. Equipment can be used for monitoring for IPMVP/FEMP Option A, B, and D. Information is available at www.acrsystems.com/menu.htm.

- ACRx™

ACRx acquires and processes technical data (air temperatures, refrigerant temperatures and pressures, etc.) to identify pending service needs, can be used for monitoring for Option A, B, and D.
Available through Field Diagnostic Services, Inc., North American Technology Center, 680 Jacksonville Road, Warminster, PA 18974, Tel: (215) 672 9600, Fax: (215) 672 9560, www.acrx.com.

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Analysis West

Analysis West is a manufacturer and distributor of energy monitoring and software products for energy and HVAC professionals. Runtime DataWatcher datalogger records the runtime of fuel-fired heating systems, including hard-to-measure water heaters and millivolt heating systems. A separate sensor allows the unit to also log motors, air conditioners and other electrical appliances. Up to 11 months of data can be stored in the logger. Digital Power Meters allow you to measure the true power consumed (Watts) by plug-in electrical appliances and lights. Total kilowatt-hours used over an extended monitoring period are also recorded.
Information is available at www.energytools.com/.

- Architectural Energy Corporation

Architectural Energy Corporation's (AEC) MicroDataLogger® portable data acquisition system is a battery or line-powered, four-channel data logger and hand-held meter which records time-series data from virtually any sensor or transducer, including temperature, relative humidity, pressure,
electrical current, power, air flow, velocity or lighting levels. Made for use with Enforma™ software, which allows visualization and analyses of short-term data taken from portable loggers. Collect and analyze system-wide HVAC, controls and lighting performance data over time. Detect HVAC problems, determine energy use baselines, and verify savings of lighting retrofits, commission or re-commission building HVAC, control, and lighting systems. Use could include monitoring for IMPVP/FEMP Option A, B, and D. Available through Architectural Energy Corporation, 2540 Frontier Ave., Suite 201, Boulder, CO 80301, tel: (303) 444-4149, fax: (303) 444-4304, www.archenergy.com.

- Boonton Test Solutions

Products include test instruments & sensors, including power meters. Appropriate for short-term measurements associated with IPMVP/FEMP Options A & B.
Information is available at www.boonton.com/.

- CellNet Online Meter Reader

Real-time energy use tracking to detect abnormal energy use and assess the impact of measures immediately after installation. Use could include monitoring for Options B and C.
Available through CellNet Data Systems, 125 Shoreway Road, San Carlos, CA, www.myEnergyInfo.com.

- Continental Control Systems

Continental designs and manufactures AC power and energy meters. Available products include standard pulse-output watt-hour transducers and LonWorks interoperable power, energy, and demand meters. Applications include utility sub-metering, end-use metering, equipment performance monitoring, verification, evaluation, and diagnostics.
Information is available at www.ccontrolsys.com/.

- E-MON Corporation

Solid state electric meters and meter reading systems and software. E-MON D-MON electric meters install easily to meter KWH and/or demand of electricity. E-MON CE-MON systems and software can be installed on either E-MON meters or any manufacturer's meters for automatic meter reading and profiling. Information is available at www.emon.com/.

- Fluke Corporation

Manufactures, distributes and services electronic test tools.
Information is available at www.fluke.com/.

- Highland Technology

Precision Electronic Instrumentation including energy measurement products.
Information is available at www.highlandtechnology.com/.

- Measuring and Monitioring Services

Services include end-use metering, load research, energy monitoring and analysis, water system monitoring as well as related hardware and software products.
Information is available at www.mmsinc.com/.

- MeterTeck Inc.

Data collection and management, including services, hardware, and software.
Information is available at www.metretek.com/.

- Onset Computer Corp.

Onset offers over 70 models of miniature data loggers and logger/controller engines. The popular HOBO & StowAway loggers, paired with BoxCar Pro software for Windows, allow you to quickly and easily record temperature, relative humidity, light intensity, lighting run time, rainfall, AC current, DC voltage, motor on/off, light on/off, open/closed states and events.
Available through Onset Computer Corporation, 536 MacArthur Blvd., Pocasset, MA 02559-3450, tel: (508) 563-9000, fax: (508) 563-9477, www.onsetcomp.com.

- Pacific Science & Technology Inc.

A variety of energy monitoring products, including tools designed to record the time-of-use and run-time of devices, current, temperature, and pulse counts, true RMS 3-phase recording power meter.
SmartLog is data analysis software for use with PS&T loggers. Tool provides graphs and results of the data. Tool can convert data to text format for further analysis with spreadsheet, etc. Works with PS&T loggers only. Use could include monitoring for IPMVP/FEMP Option A, B, and D. Available through Pacific Science and Technology, Inc., 64 NW Franklin Ave., Bend, OR 97701, tel: (541) 388-4774, fax: (541) 385-9333, web www.pacscitech.com/.

- PowerFocus

Forecasting of energy use by load using predicted models. Use could include assisting with building monitoring for Options B and C - analysis of utility bills, refrigeration and HVAC energy usage.

Available through Power Control Technologies, Tel: (410) 403-4000
www.powerfocus.com.

- PSI Flow Instruments

Process control and instrumentation, including a wide range of flow meters.
Information is available at www.psi-kc.com/html/products/flow.html.

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Texas A&M

Various software programs designed to help users manipulate and analyze energy consumption data are available through Texas A&M at www-esl.tamu.edu/software/software.html

- TimeFrame

TimeFrame offers a database for data collection of lighting and motor projects. Consists of sensors (current or voltage types) that are hardwired at the site and remote computer for data collection and storage and analysis. Data retrieval is remote via modem. Use could include monitoring for Option A, B, and D.
Available through Measuring and Monitoring Service Inc., 620 Shrewsbury Ave., Tinton Falls, NJ 07701, tel: (800) 942-2703, fax: (732) 576-8067, www.mmsinc.com.

- Veris Technology

Veris offers a variety of energy automation sensors including power meters, remote energy reporting tools, and metering software.
Information is available at www.veris.com/.

- Vistron

Vistron offers products for energy measurement and remote meter reading. Products include run time meters for any intermittently operated electric device and a remote register of a utility meter.
Information is available at www.vistron.com/.

Appendix E: Measurement Techniques

Electricity

The most common way of sensing alternating electrical current (AC) for energy efficiency and savings applications is with a current transformer or current transducer (CT). CTs are placed on wires connected to specific loads such as motors, pumps or lights and then connected to an ammeter or power meter. CTs are available in split core and solid torroid configuration. Torroids are usually more economical than split-core CTs, but require a load to be disconnected for a short period while they are installed. Split-core CTs allow installation without disconnecting the load. Both types of CTs are typically offered with accuracies better than one percent.

Voltage is sensed by a direct connection to the power source. Some voltmeters and power measuring equipment directly connect voltage leads, while others utilize an intermediate device, a potential transducer (PT), to lower the voltage to safer levels at the meter.

Though electrical load is the product of voltage and current, separate voltage and current measurements should not be used for inductive loads such as motors or magnetic ballasts. True RMS power digital sampling meters should be used. Such meters are particularly important if variable frequency drives or other harmonic-producing devices are on the same circuit, resulting in the likelihood of harmonic voltages at the motor terminals. True RMS power and energy metering technology, based on digital sampling principles, is recommended due to its ability to accurately measure distorted waveforms and properly record load shapes.

It is recommended that power measurement equipment meeting the IEEE Standard 519-1992 sampling rate of 3 kHz be selected where harmonic issues are present. Most metering equipment has adequate sampling strategies to address this issue. Users should, however, request documentation from meter manufacturers to ascertain that the equipment is accurately measuring electricity use under waveform distortion. Power can be measured directly using watt transducers. Watt-hour energy transducers that integrate power over time eliminate the error inherent in assuming or ignoring variations in load over time. Watt-hour transducer pulses are typically recorded by a pulse-counting data logger for storage and subsequent retrieval and analysis. An alternate technology involves combining metering and data logging functions into a single piece of hardware.

Hand-held wattmeters, rather than ammeters, should be used for spot measurements of watts, volts, amps, power factor or waveforms. Regardless of the type of solid-state electrical metering device used, it is recommended that the device meet the minimum performance requirements for accuracy of the American National Standards Institute standard for solid state electricity meters, ANSI C12.16-1991, published by the Institute of Electrical and Electronics Engineers. This standard applies to solid-state electricity meters that are primarily used as watt-hour meters, typically requiring accuracies of one to two percent based on variations of load, power factor and voltage.

Runtime

Determination of energy savings may involve measuring the time that a piece of equipment is on, and then multiplying it by a short term power measurement. Constant load motors and lights are examples of equipment that may not be continuously metered with recording watt-hour meters to establish energy consumption. Self-contained battery-powered monitoring devices are available to record equipment runtime and, in some cases, time-of-use information. This equipment provides a reasonably priced, simple to install approach for energy savings calculations.

Temperature

The most commonly used computerized temperature measurements devices are resistance temperature detectors (RTDs), thermocouples, thermistors, and integrated circuit (IC) temperature sensors.

Resistance Temperature Detectors or RTDs – These are common equipment for measuring air and water temperature in the energy management field. They are among the most accurate, reproducible, stable and sensitive thermal elements available. An RTD measures the change in electrical resistance in special materials. RTD's are economical and readily available in configuration packages to measure indoor and outdoor air temperatures as well as fluid temperatures in chilled water or heating systems. Considering overall performance, the most popular RTDs are 100 and 1,000 Ohm platinum devices in various packaging including ceramic chips, flexible strips and thermowell installations. Depending on application, two, three and four-wire RTDs are available. Required accuracy, distance, and routing between the RTD and the data logging device can determine the specific type of RTD for a project. Four-wire RTDs offer a level of precision seldom required in the energy savings determination, and are most commonly found in high precision services or in the laboratory. Three-wire RTDs compensate for applications where an RTD requires a long wire lead, exposed to varying ambient conditions. The wires of identical length and material exhibit similar resistance-temperature characteristics and can be used to cancel the effect of the long leads in an appropriately designed bridge circuit. Two-wire RTDs must be field-calibrated to compensate for lead length and should not have lead wires exposed to conditions that vary significantly from those being measured.

Installation of RTDs is relatively simple with the advantage that conventional copper lead wire can be used as opposed to the more expensive thermocouple wire. Most metering equipment allows for direct connection of RTDs by providing internal signal conditioning and the ability to establish offsets and calibration coefficients.

Thermocouples – They measure temperature using two dissimilar metals, joined together at one end, which produce a small unique voltage at a given temperature that is measured and interpreted by a thermocouple thermometer. Thermocouples are available in different combinations of metals, each with a different temperature range. Apart from temperature range, consider chemical abrasion and vibration resistance and installation requirements while selecting a thermocouple.

In general, thermocouples are used when reasonably accurate temperature data are required. The main disadvantage of thermocouples is their weak output signal, making them sensitive to electrical noise and always requiring amplifiers. Few energy savings determination situations, except for thermal energy metering, warrant the accuracy and complexity of thermocouple technology.

Thermistors – These are semiconductor temperature sensors usually consisting of an oxide of manganese, nickel, cobalt or one of several other types of materials. One of the primary differences between thermistors and RTDs is that thermistors have a large resistance change with temperature. Thermistors are not interchangeable, and their temperature-resistance relationship is non-linear.

They are fragile devices and require the use of shielded power lines, filters or DC voltage. Like thermocouples, these devices are infrequently used in savings determination.

Integrated Circuit Temperature Sensors – Certain semiconductor diodes and transistors also exhibit reproducible temperature sensitivities. Such devices are usually ready-made Integrated Circuit (IC) sensors and can come in various shapes and sizes. These devices are occasionally found in HVAC applications where low cost and a strong linear output are required. IC sensors have a fairly good absolute error, but they require an external power source, are fragile and are subject to errors due to self-heating.

Humidity

Accurate, affordable and reliable humidity measurement has always been a difficult and time-consuming task. Equipment to measure relative humidity is available from several vendors, and installation is relatively straightforward. However, calibration of humidity sensors continues to be a major concern and should be carefully described in the M&V Plan and documented in savings reports.

Flow

Different types of flow measurement may be used for quantities such as natural gas, oil, steam, condensate, water, or compressed air. This section discusses the most common liquid flow measurement devices. In general, flow sensors can be grouped into two different types of meters:

1 Intrusive Flow Meters (Differential Pressure and Obstruction)
2 Non-Intrusive Flow Meters (Ultrasonic and Magnetic)
Choosing a flow meter for a particular application requires knowing the type of fluid being measured, how dirty or clean it is, the highest and lowest expected flow velocities, and the budget.

Differential Pressure Flow Meters – The calculation of fluid flow rate by measuring the pressure loss across a pipe restriction is perhaps the most commonly used flow measurement technique in building and industrial applications. The pressure drops generated by a wide variety of geometrical restrictions have been well characterized over the years, and, these primary or "head" flow elements come in a wide variety of configurations, each with specific application strengths and weaknesses. Examples of flow meters utilizing the concept of differential pressure flow measurement include Orifice Plate meter, Venturimeter, and Pitot Tube meter. Accuracy of differential pressure flow meters is typically in the vicinity of 1-5% of the maximum flow for which each meter is calibrated.

Obstruction Flow Meters – Several types of obstruction flow meters have been developed that are capable of providing a linear output signal over a wide range of flow rates, often without the severe pressure loss penalty incurred with an orifice plate or venturi meters. In general, these meters place a small target, weight or spinning wheel in the flow stream that allows fluid velocity to be determined by the rotational speed of the meter (turbine) or by the force on the meter body (vortex).

Turbine meters – They measure fluid flow by counting the rotations of a rotor that is placed in a flow stream. Turbine meters can be an axial-type or insertion-type. Axial turbine meters usually have an axial rotor and a housing that is sized for an appropriate installation. An insertion turbine meter allows the axial turbine to be inserted into the fluid stream and uses existing pipe as the meter body. Because the insertion turbine meter only measures fluid velocity at a single point on the cross-sectional area of the pipe, total volumetric flow rate for the pipe can only be accurately inferred if the meter is installed according to manufacturer's specifications. Most important with insertion turbine meters is installation in straight sections of pipe removed from internal flow turbulence.

This type of meter can inserted without having to shut down the system. Insertion meters can be used on pipelines in excess of four inches with very low pressure loss. Turbine meters provide an output that is linear with flow rate. Care must be taken when using turbines as they can be damaged by debris and are subject to corrosion. Insertion meters can be damaged during insertion and withdrawal.

Vortex meters – They utilize the same basic principle that makes telephone wires oscillate in the wind between telephone poles. This effect is due to oscillating instabilities in a low pressure field after it splits into two flow streams around a blunt object. Vortex meters require minimal maintenance and have high accuracy and long-term repeatability. Vortex meters provide a linear output signal that can be captured by meter/monitoring equipment.

Non-Interfering Flow Meters – They are well suited to applications where the pressure drop of an intrusive flow meter is of critical concern, or the fluid is dirty, such as sewage, slurries, crude oils, chemicals, some acids, process water, etc.

Ultrasonic flow meters – They measure clean fluid velocities by detecting small differences in the transit time of sound waves that are shot at an angle across a fluid stream. Accurate clamp-on ultrasonic flow meters facilitate rapid measurement of fluid velocities in pipes of varying sizes. An accuracy rate from 1% of actual flow to 2% of full scale are now possible, although this technology is still quite expensive. Recently, an ultrasound meter that uses the Doppler principle in place of transit time has been developed. In such a meter a certain amount of particles and air are necessary in order for the signal to bounce-off and be detected by the receiver. Doppler-effect meters are available with an accuracy between 2% and 5% of full scale and command prices somewhat less than the standard transit time-effect ultrasonic devices. Meter cost is independent of pipe size. Ultrasonic meters can have low installation costs since they do not require shutting down systems to cut pipes for installation.

Magnetic flow meters – They measure the disturbance that a moving liquid causes in a strong magnetic field. Magnetic flow meters are usually more expensive than other types of meters. They have advantages of high accuracy and no moving parts. Accuracy of magnetic flow meters are in the 1-2% range of actual flow.

Pressure

Mechanical methods of measuring pressure have been known for a very long time. U-tube manometers were among the first pressure indicators. But manometers are large, cumbersome, and not well suited for integration into automatic control loops. Therefore, manometers are usually found in the laboratory or used as local indicators. Depending on the reference pressure used, they can indicate absolute, gauge, or differential pressure. Things to keep in mind while selecting pressure measurement devices are: accuracy, pressure range, temperature effects, outputs (millivolt, voltage or current signal) and application environment

Modern pressure transmitters have come from the differential pressure transducers used in flow meters. They are used in building energy management systems and are capable of measuring pressures with the necessary accuracy for proper building pressurization and air flow control.

Thermal Energy

The measurement of thermal energy flow requires the measurement of flow and some temperature difference. For example, the cooling provided by a chiller is recorded in Btu and is a calculated value determined by measuring chilled water flow and the temperature difference between the chilled water supply and return
lines. An energy flow meter performs an internal Btu calculation in real time based on input from a flow meter and temperature sensors. It also uses software constants for the specific heat of the fluid to be measured. These electronic energy flow meters offer an accuracy better than 1%. They also provide other useful data on flow rate and temperature (both supply and return).

When a heating or cooling plant is under light load relative to its capacity there may be as little as a 5°F difference between the two flowing streams. To avoid significant error in the thermal energy measurement the two temperature sensors should be matched or calibrated to the tightest tolerance possible. It is more important that the sensors be matched, or calibrated with respect to each another, than for their calibration to be traceable to a standard. Suppliers of RTDs can provide sets of matched devices when ordered for this purpose.

Typical purchasing specifications are for a matched set of RTD assemblies (each consisting of an RTD probe, holder, connection head with terminal strip and a stainless steel thermowell), calibrated to indicate the same temperature, for example within a tolerance of 0.1°F over the range of 25°F to 75°F. A calibration data sheet is normally provided with each set.The design and installation of the temperature sensors used for thermal energy measurements should consider the error caused by: sensor placement in the pipe, conduction of the thermowell, and any transmitter, power supply or analog to digital converter. Complete error analysis through the measurement system is suggested, in recognition of the difficulty of making accurate thermal measurements.

Thermal energy measurements for steam can require steam flow measurements (e.g., steam flow or condensate flow), steam pressure, temperature and feedwater temperature where the energy content of the steam is then calculated using steam tables. In instances where steam production is constant, this can be reduced to measurement of steam flow or condensate flow (i.e., assumes a constant steam temperature-pressure and feedwater temperature-pressure) along with either temperature or pressure of steam or condensate flow.