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Performance Monitoring & Verification Protocols

Sri Lanka

Volume II
Guidelines for Typical Applications of Options

Industrial/Commercial Sectors
Concepts and Options for Determining Energy Savings
(Adapted from IPMVP-2002 & Indian M&V protocols)

PERFORMANCE MONITORING & VERIFICATION PROTOCOLS/GUIDELINES
INDUSTRIAL/COMMERCIAL SECTORS
GUIDELINES FOR TYPICAL APPLICATIONS AND OPTIONS
(ADAPTED FROM IPMVP-2000 & INDIAN M&V PROTOCOLS)
SRI LANKA

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NEXANT SARI/Energy

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List of Abbreviations

ARI	American Refrigeration Institute.
ASHRAE	American Society of heating, Refrigeration, and Air-Conditioning Engineers.
COP	Coefficient of performance
ECM	Energy conservation measure. Any step taken to reduce energy use.
EMCS	Energy management and control system. An automated system for controlling equipment.
ESCO	Energy services company.
IPLV	Integrated part load value
IPMVP	International Performance Measurement & Verification Protocol. Refers either to the document or the organization.
kJ	kiloJoules. A unit of energy, usually thermal.
kVA	kiloVolt-Amperes, a unit of electrical power.
kVAR	kiloVolt-Amperes Reactive, a unit of electrical power.
kW	kiloWatt, a unit of electrical power.
kWh	kiloWatt-hour, a unit of electrical energy.
M&V	Measurement and verification.
PF	Power factor. Expresses the relationship between actual and apparent power.
VSD	Variable-speed drive. Device to regulate the speed of an electric motor. Also known as variable-frequency drive (VFD), adjustable speed drive (ASD), and adjustable frequency drive (AFD).

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Preface

Purpose and Scope

This Volume of Performance and Monitoring Verification (M&V) Protocols provides Methods and Applications for determining energy savings in Sri Lanka. Its purpose is to provide users with information on how to apply the M&V options outlined in Volume I of the Performance Monitoring and Verification Protocols to specific applications.

Option A (partially measured retrofits) and Option B (periodically measured retrofits) are treated in greater detail with several examples in this volume. The examples presented are for a range of specific applications likely to be encountered — lighting efficiency, upgrades, and controls; motor efficiency and controls; variable speed drive retrofits; power factor corrections; constant load motor efficiency; boiler and furnace upgrades; chiller replacement; heat recovery applications; and control system upgrades. Although an example of a specific technology is not provided here, these guidelines can still be applied, but users will need to develop a method without the benefit of an example. Because Option C is a whole-facility approach, multiple examples of different applications are unnecessary. Option D (computer simulation) is an advanced topic for which it is difficult to provide specific guidance. Readers seeking more information on using Option D are referred to the International Performance Measurement and Verification Protocol M&V Guidelines for New Construction (under development) and ASHRAE Guideline 14 (2002).

Many potential energy-efficiency measures can be implemented in the commercial and industrial sectors. Although it is not possible to list every conceivable measure that could be implemented, the more common measures and typical measurement and verification (M&V) approaches are listed here. This section provides illustrations of ways that different M&V methods can be applied to common energy-efficiency measures. Although a particular measure is not listed here, these M&V protocols can still be applied, but a project-specific approach will have to be developed.

Measurement and verification approaches for different energy-efficiency measures are indicated in Table 1-1 below. Situations where an approach is usually suitable are denoted with a •; situations where an approach may be suitable under certain conditions are denoted with an o.

Table 1-1: M&V Option Applications

	1. Lighting Efficiency and Controls	2. Power Factor Correction	3. Motor and Drive Efficiency Improvements	4. Variable-Speed Drives	5. Boiler Improvements	6. Chiller Improvements	7. Air, Water, and Steam Distribution Systems	8. Thermal Energy Recovery	9. Cogeneration	10. Renewable Energy	11. Controls	12. Process Improvements
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1.1 Typical Measures

The suitability of specific M&V options for particular measures is discussed in the following sections. (Options A through D are described in detail in Volume I.) The measures discussed here include lighting efficiency and controls; power factor correction; motor and drive efficiency improvements; variable-speed drives; boiler upgrades; chiller replacement; air, water, and steam distribution; thermal energy recovery; cogeneration; renewable energy systems; control improvements; and process improvements.

1.1.1 Lighting Efficiency and Controls

Lighting efficiency improvements are particularly compatible with Option A methods because they are easily measured and easily isolated from the utility meter. Measuring the demand (kW) in the baseline and post-retrofit case verifies performance, which is not expected to significantly change during the project duration. Stipulating the operating hours allocates usage risk to the customer, which is appropriate where operating hours are known with reasonable certainty and are not expected to change over time.

Option B (long-term metering) may be applicable where operating hours are uncertain or are expected to change as a result of adding motion sensors or other controls. An Option B approach implies that at least one parameter (such as operating hours) will be measured periodically for several years. The decision to choose Option B over Option A (one-time metering) for lighting controls project is a function of the expected savings and the customer's risk tolerance.

Option C (utility bill analysis) can be used in limited cases, such as situations where lighting comprises the majority of the electrical load and the load reduction is expected be greater than **20%** of the current utility bill. Fluctuations in utility usage due to non-lighting loads and the need to wait several months to verify performance make Option C a less viable choice for lighting-only projects.

1.1.2 Power Factor Correction

Power factor correction reduces the reactive load inside a customer's facility, thereby reducing demand (kVA) charges on the utility bill. Option C can be used to directly verify reductions in demand charges and demand costs. For best results, demand reductions should be on the order of **10%** to **20%** of the baseline demand and should consider monthly changes with weather or other factors.
Where power factor correction is limited to a small portion of a facility and is expected to make less than a **10%** reduction in the total demand, an Option B approach is preferable. The reactive power can be measured periodically or continuously with a sub-meter to show that reactive power compensation continues to work.

Because power factor correction is intended to reduce the customer's utility bill through reductions in demand charges seen on the utility bill, there is little reason to choose an Option A approach.

1.1.3 Motor and Drive Efficiency Improvements

Motor efficiency improvements are particularly compatible with Option A methods, especially where loads are constant and operating hours are well-defined. If loads vary in either the baseline or post-retrofit case, short-term metering will be necessary to characterize the load to use an Option A method. If the loads vary in the post-retrofit case in a way that is difficult to characterize (e.g., weather-dependent), Option B may be more suitable. The decision to choose an Option A or Option B approach is a function of the magnitude of the savings and the ease or difficulty in characterizing the load pattern.

Unless a motor or bank of motors has a dedicated utility meter, Option C approaches rarely work for motor projects. Even if a dedicated utility meter exists, some tracking of operating hours (or other parameter) may be required in order to normalize the results.

1.1.4 Variable-Speed Drives

Additions of variable-speed drives to motor systems indicate that the post-retrofit load will vary over time. Option A is applicable if short-term metering can identify a load pattern that can be characterized over time or related to another parameter that is monitored.
Option B is often more suitable because of the highly variable nature of the load profile in the post-retrofit case. The decision to use an Option A or an Option B approach should be based on comparison of how easily the post-retrofit load conditions can be characterized against the cost of continuous monitoring.

Unless a motor or bank of motors has a dedicated utility meter, Option C approaches rarely work for motor and variable-speed drive projects. Even if a dedicated utility meter exists, tracking of operating hours, loads, or other parameters may be required to normalize the results.

1.1.5 Boiler Improvements

Boilers, furnaces, and other heat-producing equipment are subject to variations in load due to weather, production, or occupancy changes. In addition, these projects are typically capital intensive and sometimes have long payback periods. This increases the project risk and suggests using a long-term M&V approach to track performance instead of an Option A method. Option A methods are most appropriate for small projects where sub-meters are not available (e.g., multiple small furnaces) and where annual loads are reasonably constant.

Many gas- and oil-fired boilers have dedicated fuel meters that can be used to track fuel long-term consumption using an Option B approach. If dedicated meters are not present, an Option C approach might be applied by tracking gas consumption at the main meter or recording fuel oil deliveries. If dramatic load fluctuations are expected from year to year, a secondary variable (e.g., weather, production, or occupancy) may need to be recorded as well to normalize the energy use to baseline conditions.

An Option D (computer simulation) approach may be used for large facilities or where there are large number of small systems being installed. However, the cost of simulating a project is usually greater than direct measurement using an Option B approach.

Annual efficiency measurements are suggested to make certain that proper operations and maintenance procedures are being conducted, the proper fuel/air mixture is being maintained, and scaling or fouling has not degraded performance.

1.1.6 Chiller Improvements

Chillers, air-conditioners, and refrigeration systems are usually subject to load variations due to weather, production, or occupancy changes. In addition, these projects are typically capital intensive and sometimes have long payback periods. These factors increase the project risk and suggests using a long-term M&V approach to track performance. However, measuring the performance of refrigeration systems is not a trivial task and makes Option B an expensive approach. Option A can be used where a single baseline and a post-retrofit performance measurement can be made and annual loads stipulated. Although this approach

introduces more uncertainty into the savings estimates, the cost of additional metering and monitoring equipment may not be justified by the reduced uncertainty.
Option C can be used where chiller or refrigeration plants comprise a significant portion of a facility's load. It does not require measuring performance directly but instead tracks the customer's total energy use. If dramatic load fluctuations are expected from year to year, a secondary variable (e.g., weather, production, or occupancy) may need to be recorded in order to normalize the energy use to baseline conditions.

An Option D approach may be used for large facilities or where there a large number of small systems being installed. This approach may be especially useful where concurrent load reduction measures (e.g., reducing internal loads, infiltration, or solar gain) have been installed. The anticipated saving should be large enough to justify the cost of computer simulation modeling.

1.1.7 Air, Water, and Steam Distribution Systems

Compressed air, hot and chilled water, and steam systems sometimes suffer from poor design or neglected operations and maintenance. Increased air or water pumping costs, lost steam, or wasted condensate can often be reduced or eliminated through system upgrades or repairs and better maintenance practices. Many of these projects are especially amenable to Option A approaches where the baseline is defined by the wasted energy use. Repairing compressed air leaks and replacing faulty steam traps eliminate energy waste, which can then be claimed as savings. Long-term verification is performed by conducting inspections to look for the recurrence of leaks or losses.

Option B methods are often unsuitable for these types of projects because energy waste in the form of leaks or pumping losses will be eliminated. Post-retrofit measurements therefore offer little value.

Option C may be suitable where baseline losses were significant. An example of such a situation would be a steam system that is converted from open-loop (wasted steam and condensate) to closed-loop (total condensate recovery). Direct measurement of steam and condensate loss is difficult, but the resulting reduction in fuel use should be both significant and easy to measure.

1.1.8 Thermal Energy Recovery

Thermal energy recovery may be air-to-air, air-to-water, water-to-water, or other. The "best" M&V approach is a function of the type and quantity of energy being recovered and the type of energy being replaced. Option A may be suitable for process loads where temperatures are nearly constant while Option B might be needed for situations where temperatures and/or flow rates vary widely.
An Option C approach may be suitable where it is difficult or not cost-effective to measure a number of temperatures and flow rates. An Option D approach might be suitable for enthalpy (energy + humidity) recovery systems on buildings. Deciding which M&V Option to use requires an engineering analysis of how thermal energy will be recovered and an evaluation of the costs and benefits of the different M&V approaches.

1.1.9 Cogeneration

Cogeneration systems use fuel to generate both heat and electricity. They are typically costly projects and can be technically risky, making Option A methods unsuitable. An Option B method that measures fuel inputs, electrical outputs, and thermal energy used (not produced) is recommended. Electrical energy produced should be valued at post-retrofit energy prices with special attention paid to the demand reduction achieved at the customer's utility meter. Thermal energy used should be measured and valued at the current cost of producing thermal energy. Measuring the thermal output of a cogeneration plant is misleading since not all of the thermal energy produced is used. The cost of fuel to operate the cogeneration plant needs to be tracked and treated as an operating cost.

In some cases, an Option C approach that compares the total energy use and costs between the baseline and the cogeneration case may be appropriate. Some adjustment may be necessary if operating schedules vary significantly over time.

1.1.10 Renewable Energy Systems

Renewable energy systems that produce electricity (e.g., photovoltaic and wind) are easily characterized with Option B methods by directly measuring energy outputs. Energy produced should be valued at the displaced (or avoided) energy cost, which may be fuel transported over long distances and not electricity. Battery replacement and maintenance costs should be treated as operating expenses and deducted from the savings.

Solar thermal, daylighting, and biomass (plant and animal waste) projects may be more difficult to measure cost-effectively. Option A methods that use extensive analysis and historical weather records (if available) may be more applicable instead. Energy produced should be valued at the displaced (or avoided) energy cost. Maintenance costs should be treated as operating expenses and deducted from the savings.

1.1.11 Controls

Energy controls range from simple timeclocks and photocell controls to sophisticated computerized energy management and control systems (EMCS). The selection of an appropriate M&V method is a function of what is being controlled, how the controlled equipment is controlled, the ease or difficulty of measurements, and the value of the expected savings.

Option A methods are suitable for simple controls on simple equipment such as a timeclock on an air handler fan. The timeclock reduces the fan operating hours in a simple and predictable fashion. Operation of the timeclock is easily verified through inspection.

Option B methods are more suitable for situations where loads and schedules are expected to change over time. An example is the addition of an economizer to a large air handling system to provide free cooling and eliminate chiller usage. Measuring air temperatures and damper position can be used to determine the amount of free cooling provided and ensure long-term performance of the system.

Option C should be considered where an EMCS is added to a large building. Calculating savings from an EMCS by measuring every facet of its performance is expensive and tedious. An Option C approach will capture the total system performance and provide feedback on potential improvements.

Option D can be used with an EMCS on a large building. This will also capture the interactions between the different aspects of the system, but some system and total energy-use measurements will still be needed to calibrate the simulation.

1.1.12 Process Improvements

Industrial process improvements cover a broad range of possible improvements or changes. It is difficult to generalize what methods might be most applicable to process changes, but in general the intent is to verify the reduction in energy use per unit of production. This requires tracking the energy use (and cost) either of a particular step or as a total process.

Option A might be applicable to situations where a simple change in process efficiency results in reduced energy use per unit of production. Energy and cost savings then become a function of monthly production, which may be stipulated to protect the energy services company (ESCO) from production changes.

Option B might be applicable to situations where changes result in better process control conditions (e.g., temperature and humidity) that should be tracked to ensure long-term performance. The results may be adjusted to account for changes in production.

Option C might be applicable to situations where one process replaces another. Since a new process may not be an improvement of the old, efficiency comparisons and direct measurements may be difficult or impossible. Instead, the total energy use and cost can be compared to monthly unit production. By considering costs, fuel switching is included in this method.

The sections in this chapter describe technology-specific M&V methods associated with Option A. The methods described here are for the most typical measures, such as lighting retrofits, efficient motors, piping modifications, and heat recovery. Option A is suitable where the savings uncertainty and the financial risks are low.

An Option A based M&V method involves a component or system level M&V assessment. The approach is intended for retrofits where either performance factors (e.g., end-use capacity, demand, power, and thermal energy use) or operational factors (e.g., operational hours and production-rate) can be spot or short-term measured during the baseline and post-installation periods. The factor not measured is stipulated based on the best available estimate, 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 for 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; and.
- 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; and.
- 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 wattage or kJ/hr) represent a significant portion of the uncertainty associated with many projects. 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 a project'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 in Table 2-1.

Table 2-1: Option A Applications

Energy Conservation Measure	Method Number	Performance Factors	Usage Factors
1. Lighting Efficiency and Lighting Controls	LE-A-01	kW (stipulated)	Hours (stipulated)
	LE-A-02	kW (measured)	Hours (stipulated)
	LE-A-03	kW (stipulated)	Hours (measured)
	LE-A-04	kW (measured)	Hours (measured)
2. Power Factor Correction	n/a		
3. Constant-Load Motor Efficiency	CLM-A-01	kW (measured)	Hours (stipulated or measured)
4. Variable-Speed-Drive Retrofit	VSD-A-01	kW (measured) at each load condition	Hours at each load condition (stipulated)
5. Boiler/Furnace Upgrades	BF-A-01	kW or kJ/hr delivered output (measured)	Hours at each capacity, (stipulated)
6. Chiller Replacement	CH-A-01	kW/TR (stipulated)	TR-hours (stipulated)
	CH-A-02	kW/TR (measured)	TR-hours (stipulated)
7. Generic Constant-Load Improvements	GCL-A-01	kW or kJ/hr (measured)	Hours (stipulated)
8. Heat Recovery Applications	HR-A-01	kJ recovered (measured)	Hours at each condition (stipulated)
9. Cogeneration Systems	n/a		
10. Renewable Energy Systems	n/a		
11. Controls	n/a		
12. Process Technology Improvements	n/a		

2.1 Lighting Efficiency

Four methods for achieving lighting efficiency are considered in this section:

- LE-A-01—No Metering;
- LE-A-02—Metering of Fixture Power;
- LE-A-03—Metering of Operating Hours); and
- LE-A-04—Metering of Power and Hours.

Energy Conservation Measure (ECM) Definition

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; and
- Installation of controls that reduce operating hours.

Overview of Verification Methods

The four verification methods presented in this section are intended to apply to lighting efficiency upgrades as well as lighting controls additions. The fixture powers or operating hours (or both) may be measured or stipulated.

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 increase or decrease lighting levels. Increases to existing lighting levels may require adjusting the baseline to account for the anticipated load increase. Therefore, it is recommended that illumination levels in a sample of affected spaces be measured prior to, and following, project installation. This verifies that similar illumination levels have been maintained or that a baseline adjustment is necessary if light levels were intentionally increased.

Table 2-2 illustrates the different permutations of measurement and stipulation that may be used. Whether a parameter is measured or stipulated depends on the magnitude of the project, the certainty to which the parameter can be estimated, and the willingness of the customer (or financier) to assume some of the uncertainty risk.

Table 2-2: Option A Methods for Lighting Projects

Method	Fixture Power (Watts)	Operating Hours	Typical Application
LE-A-01	stipulated	stipulated	Small lighting projects with constant hours
LE-A-02	measured	stipulated	Lighting projects with constant hours
LE-A-03	stipulated	measured	Lighting controls projects
LE-A-04	measured	measured	Large lighting projects with or without controls

Method LE-A-01 does not require metering of either parameter and therefore does not strictly comply with the International Measurement and Verification Protocol. It is included as an option here because it may be suitable for some small lighting projects where the value of the savings do not justify the cost of measurements. Fixture power (Watts) is to be based on manufacturer's specifications or other documented source. Operating hours are estimated based on known operating schedules.

Method LE-A-02 is probably the most common M&V approach for lighting. Measuring fixture powers reduces uncertainty in the savings estimate while placing the burden of proof on the ESCO that the project will perform as guaranteed. Stipulating the operating hours places the usage risk on the customer who controls the lights.

Method LE-A-03 is applicable where operating hours are not reliably known and where lighting controls will be extensively used. Estimating baseline and post-retrofit hours for lighting controls measures is often difficult; using measurements reduces this uncertainty. For fixture retrofits only, hours need to be measured only once. If occupancy sensors are used, operating hours should be measured before and after installation.

Method LE-A-04 is applicable for large lighting projects where small amounts of uncertainty in the savings estimate translate to large amounts of cost savings uncertainty. For lighting efficiency upgrades, hours need to be measured only once. If occupancy sensors are added, operating hours should be measured before and after installation.

Calculation of Demand and Energy Savings

Baseline and Post-Retrofit 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).

Methods LE-A-01 and LE-A-03— No Fixture Metering

Fixture powers are based on manufacturer's specifications or measurements for identical lamp/ballast/fixture combinations taken at other projects. It is important to note that manufacturer's data for older fixtures may not be available and that measurements may need to be taken of the baseline fixtures.

Methods LE-A-02 and LE-A-04— Fixture Power Metering

Fixture powers are measured using a true-power meter on a representative sample of fixtures after they have reached normal operating temperature. The average and the standard deviation of the power measurements are reported. 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.

Because the power reduction is based on the baseline and new fixture measurements, the precision of the measurement should be **5%** at **90%** confidence or better. This will produce an uncertainty in the power *reduction* on the order of **20%.** To achieve this level of precision will require between three and six measurements per fixture type.

It is recommended that a true-power meter capable of measuring harmonics be used to make the measurements. Magnetic ballasts introduce low power factors; electronic ballasts introduce harmonic distortion. Both effects may cause problems with the local distribution system such as excessive I^2R loss or overloaded neutral lines in three-phase systems.

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 lighting 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 powers 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 approach 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 lighting levels by **50%**, then the baseline power would be increased by **50%** to adjust for the lighting level increase. This way, the new lighting system can be properly compared to what would have been required to obtain the desired lighting levels. The customer and the financier should be aware that in this situation, utility bills may not decrease dramatically and may increase in rare cases. This is the result of comparing the installed project to *what would have been* instead of to *what was*.

Operating Hours

Methods LE-A-01 and LE-A-02— Stipulated Operating Hours

Operating hours are estimated and then stipulated for the duration of the contract. Space types should be divided into functional usage groups that have similar schedules (e.g., office, factory floor, and storage, and representative samples of these spaces should be examined for operating schedules and usage patterns.

Methods LE-A-03 and LE-A-04— Fixture Operating Hour Monitoring

Operating hours can be measured using portable data loggers that record either the cumulative run-time or when the light is turned on or off. The second approach is preferred as it allows determining the time-of-use of the fixture. Monitoring should be conducted for a period of at least two weeks with three being preferred.

Space types should be divided into functional usage groups that have similar schedules (e.g., office, factory floor, and storage) and representative samples of these spaces should be monitored. Measurement of operating hours for each usage group is typically performed to **20%** precision at **80%** confidence. This level of precision can usually be achieved using six to twelve measurement points. If operating hours remain unchanged, they can be measured either before or after project installation. If occupancy sensors are to be used, operating hours should be measured before and after sensor installation.

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings for lighting efficiency (no controls) projects, use the following equation:

$$kWh_{Total} = \sum_{All\ Groups} Hours_g \left[\left(QTY_{g,b}\right)\left(kW / fixture_{g,b}\right) - \left(QTY_{g,n}\right)\left(kW / fixture_{g,n}\right) \right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW/fixture_{g,b}$	Baseline lighting demand per fixture for usage group *g*
$kW/fixture_{g,n}$	New lighting demand per fixture for usage group *g*
$QTY_{g,b}$	Quantity of affected baseline fixtures for usage group *g,* adjusted for inoperative and non-operative lighting fixtures
$QTY_{g,nt}$	Quantity of installed new fixtures for usage group *g*
$Hours_g$	Annualized operating hours for usage group *g*

To estimate energy savings for lighting efficiency and/or controls projects where the operating hours change as a result of the project, use the following equation:

$$kWh_{Total} = \sum_{All\ Groups} \left[\left(Hours_{g,b}\right)\left(QTY_{g,b}\right)\left(kW / fixture_{g,b}\right) - \left(Hours_{g,n}\right)\left(QTY_{g,n}\right)\left(kW / fixture_{g,n}\right) \right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW/fixture_{g,b}$	Baseline lighting demand per fixture for usage group *g*
$kW/fixture_{g,n}$	New lighting demand per fixture for usage group *g*
$QTY_{g,b}$	Quantity of affected baseline fixtures for usage group *g,* adjusted for inoperative and nonoperative lighting fixtures
$QTY_{g,nt}$	Quantity of installed new fixtures for usage group *g*
$Hours_{g,b}$	Annualized baseline operating hours for usage group *g*
$Hours_{g,n}$	Annualized new operating hours for usage group *g*

If the facility is using a time-of-day rate, the energy savings for the peak and off-peak periods must be calculated separately. If operating hours are being measured, time-of-use (event) loggers must be used and extra data analysis will be required to separate the hours into the two periods.

Demand

Demand savings as a result of a lighting upgrade will show up on the customer's electric meter as reduced kVA consumption. Because all of a building's lights rarely operate simultaneously, the demand reduction observed at the meter will never be the sum of the fixture power reductions. To determine the demand reduction observed at the meter, the fraction of fixtures operating when the metered peak demand is set needs to be known.

The fraction of operating fixtures is known as the *diversity factor*, which is used to calculate the demand reduction seen on the utility bill. It must be calculated for each usage group based on the estimated or measured operating hours. The following equation can be used to determine the diversity factor for each group.

$$DF_g = \frac{\text{number of fixtures}_g \text{ operating during the period when the building peak demand is set}}{\text{total number of fixtures in usage group } g.}$$

The diversity factor for each group can then be used to arrive at the total demand reduction as observed at the meter. The diversity factor for each group can be determined from walkthrough inspections (LE-A-01, LE-A-02) or through analysis of monitoring data (LE-A-03, LE-A-04).

$$kVA_{Total} = \sum_{All\ Groups} DF_g \left[\left(QTY_{g,b}\right)\left(\frac{kW / fixture_{g,b}}{PF_{g,b}}\right) - \left(QTY_{g,n}\right)\left(\frac{kW / fixture_{g,n}}{PF_{g,n}}\right) \right]$$

Power factor in the baseline and post-retrofit conditions is included to reflect that peak demand is billed as maximum kVA, not kW, and that the power factor of ballasts may change as a result of an upgrade. Magnetic ballasts have power factors less than one while electronic ballasts have power factors closer to unity. This is why power measurements should be taken with a true-power meter capable of measuring both real and reactive power.

Interactive Effects

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

- Ignore interactive effects; and
- Calculate interactive effects on a site-specific basis.

One method of estimating lighting interactive factors is outlined by Rundquist.[1]

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

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

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

For most lighting projects, the potential to perform can be verified through inspections to show that the installed equipment is still present and operating correctly. This involves checking to see that similar lamps and ballasts are installed and that occupancy sensors are still functioning as intended.

2.2 Constant-Speed Motor Efficiency

This section discusses Method CLM-A-01— Metering of Motor kW.

ECM Definition

Constant-speed motor efficiency projects involve the replacement of existing 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. Drive system changes (e.g., V-belts to toothed belts) may be included as part of the project. 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. The exception is when the baseline motors are significantly oversized for the load and additional savings can be achieved by replacing them with properly sized motors.

If motor changes are accompanied by undefinable changes in operating schedule, a significant change in flow rate, or the installation of variable-speed drives, other M&V methods may 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.

Pre-Installation Equipment Survey

Surveys are required to document existing motors. The surveys should include the following data for each motor:

- Location;
- Motor application;
- Operating schedule; and
- Nameplate data including: HP, voltage, running-load amps, rated efficiency, RPM.

Spot Metering of Existing and New Motors

Instantaneous measurements of three-phase amps, volts, power factor (PF), kVA, kW, and motor speed (RPM) should be recorded based on spot metering of each motor to be replaced. Such measurements should be made using a true RMS meter with an accuracy at, or approaching, ±**1%** of reading.

Rotational speed measurements are highly recommended. Changes in performance characteristics between standard motors and high-efficiency motors may cause fans and pumps to operate at a slightly different speed. Because fan and pump power is highly dependent upon rotational speed, small changes in motor speed may result in large changes in motor demand. Measuring the RPM with a stroboscopic tachometer will verify that the speed has remained constant or whether the drive pulleys need to be changed to compensate for the different motor characteristics.

Where there is a large population of motors of similar sizes and functions, it is possible to aggregate motors into usage groups. A sample of motors rather than the entire population can be measured and the results applied to all other motors.

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.*

Changes in Load Factor (Slip)

Standard-efficiency motors and high-efficiency motors of the same nominal speed may rotate at slightly 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 measured demand between the existing motor and a new high-efficiency motor. The ESCO will identify motors for which the difference in measured demand between the high-efficiency motor and the baseline motor differs by more than **20%** of the expected demand reduction. These motors should be examined further to determine the possible cause of the difference and determine what corrective action might be necessary.

Operating Hours

Baseline and post-installation hours of operation, used in calculating energy savings, may be measured or stipulated. The operating hours may be the same or different following retrofit. However, only operating hours that are well-defined (e.g., continuous operation or under timeclock or energy-management system control) may be stipulated.

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 chiller circulating pump motors. Each group type should have similar use patterns and comparable average operating hours.

If the operating schedule is not certain, it may be measured using motor data loggers that record when motors are started and stopped. These devices detect either vibrations or the presence of AC magnetic fields. A monitoring period of one week is recommended.

Calculation of Energy and Demand Savings

Energy

To calculate the total energy savings where the operating hours remain constant, the following equation may be used:

$$kWh_{Total} = \sum_{All\ Motors} Hours_i \left[kW_{i,b} - kW_{i,n}\right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW_{i,b}$	Baseline motor demand for motor *i*
$kW_{i,n}$	New motor demand for motor *i*
$Hours_i$	Annualized operating hours for motor *i*

To calculate the total energy savings where the operating hours are different between the baseline and the retrofit case, the following equation may be used:

$$kWh_{Total} = \sum_{All\ Motors} \left[Hours_{i,b}\, kW_{i,b} - Hours_{i,n}\, kW_{i,n}\right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW_{i,b}$	Baseline demand for motor *i*
$kW_{i,n}$	New demand for motor *i*
$Hours_{i,b}$	Baseline annualized operating hours for motor *i*
$Hours_{i,n}$	New annualized operating hours for motor *i*

Demand

Demand savings as a result of motor upgrades will show up on the customer's electric meter. Because all of a building's motors rarely operate simultaneously, the demand reduction observed at the meter will never be the predicted demand reduction obtained by summing all of the motor demand reductions. To calculate the demand reduction observed at the meter, the building load profile must be known so that the number of motors operating during the time of peak building demand can be determined. The ratio of the observed demand reduction at the utility meter to the connected load demand reduction is known as the *diversity factor,* which is defined as:

$$DF = \frac{number\ of\ motors\ operating\ during\ the\ period\ when\ the\ building\ peak\ demand\ is\ set}{total\ number\ of\ motors}$$

The diversity factor for each group can be determined from walkthrough inspections or through analysis of monitoring data.

The following equation can be used either with single motors or with motors aggregated into usage groups. For groups, consider a group as an individual motor.

$$kVA_{Total} = \sum_{All\ Motors} DF_i \left[\left(\frac{kW_{i,b}}{PF_{i,b}} \right) - \left(\frac{kW_{i,n}}{PF_{i,n}} \right) \right]$$

Where:

kVA_{Total}	Demand savings realized
DF_i	Diversity Factor for motor (or group) *i*
$kW_{i,b}$	Baseline demand for motor (or group) *i*
$kW_{i,n}$	New demand for motor (or group) *i*
$PF_{i,b}$	Baseline power factor for motor *i*
$PF_{i,n}$	New power factor for motor *i*

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

For most motor projects, the potential to perform can be verified through inspections to show that the installed equipment is still present and operating correctly. This involves checking to see that the motors and drive belts are installed and that any timeclocks or energy management system controls are still functioning as intended.[2]

[2] Timeclock pins have a habit of "disappearing" while energy management systems can be easily bypassed or reprogrammed.

2.3 Variable-Speed Drive Retrofit

This section discusses Method VSD-A-01—Metering of Motor kW.

ECM Definition

Variable-speed-drive motor projects involve the addition of variable-speed-drive (VSD) motor controllers, sometimes as a replacement for vane or three-way valve modulation. 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 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 conditions apply:

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

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

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.

Pre-Installation Equipment Survey

Surveys are required to document existing motors. The surveys should include the following data for each motor:

- Location (including floor plans);
- Motor application;
- Nameplate data including: HP, voltage, running-load amps, rated efficiency, RPM;
- Operating schedule; and
- Presence and type of any flow-modulating device (e.g., vane, valve) and what controls the device (e.g., signal- pressure, temperature, etc.).

Metering of Existing Motors

If there are multiple pieces of equipment with similar functions and motor sizes, metering is required on at least a sample of the existing motors to determine baseline motor power draw under different operating scenarios. If it is expected or known that a motor serves a constant load, only one spot measurement is required since the power draw does not vary with time or operating scenario. If it is unknown whether a motor serves a constant load or operating scenarios include different control valve or damper positions, then multiple measurements across a range of time or operating scenarios need to be conducted. If the operating range cannot be manually adjusted (e.g., weather conditions), short-term data logging of the motor and the relevant parameter can be performed instead.

Instantaneous measurements of three-phase amps, volts, PF, kVA, kW, and motor speed (RPM) should be recorded based on spot metering of each motor to be replaced. Such measurements should be made using a true RMS meter with an accuracy at or approaching ±**1%** of reading. The coincident time and relevant parameter (e.g., vane position, outside temperature) need to be recorded, measured, or monitored as well.

It is recommended that a true-power meter capable of measuring harmonics be used to make the measurements. Motors introduce low power factors; variable-speed drives introduce harmonic distortion. Both effects may cause problems with the local distribution system such as excessive I^2R loss or overloaded neutral lines in three-phase systems.

Metering of New Motors and Drives

If there are multiple pieces of equipment that have similar motors and drives installed, metering is required on at least a sample of the affected items. To characterize system operation, the motor should be operated across the load range while measuring input power to the VSD. In many cases, this can be accomplished by manually adjusting the speed of the VSD across the load range. If manual adjustment of the drive speed would lead to misleading results (e.g., in variable air-volume HVAC systems), the motor and drive input power and motor speed (or other relevant parameter) can be short-term monitored.

Instantaneous measurements of three-phase amps, volts, PF, kVA, kW, and motor speed (RPM) should be recorded based on spot metering of each installed drive. (Measuring the motor neglects the parasitic power consumption of the VSD itself.) Such measurements should be made using a true RMS meter with an accuracy at or approaching ±**1%** of reading. The meter used should be capable of accurately measuring true power of non-linear (waveform distorting) loads. The coincident time and relevant parameter (e.g., motor speed and outside temperature) need to be recorded, measured, or monitored as well.

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 project installation, adjustments to baseline demand may be required due to factors, such as remodeling or changes in occupancy or process conditions. 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.*

Operating Hours

Operating hours need to be defined for each operating scenario such as temperature range or flow condition. Consider the case of the tea withering process: In the baseline case, the supply fans operate for a fixed period of 12 to 18 hours at a constant load. A variable-speed drive is added to the supply fan to modulate the fan speed. In the new application, the fan is operated at **100%** for four hours, **75%** speed for four hours, and **50%** speed for the last four hours. Each speed represents an operating scenario with a quantifiable schedule that can be stipulated. If the flow changes based on a closed-loop feedback system, then experience or monitoring will be required to determine the typical number of operating hours for each scenario.

Calculation of Energy and Demand Savings

Energy

Energy savings are determined by comparing the baseline motor loads to the new loads at each scenario and then multiplying by the number of hours at each scenario. The following equation can be used to determine the energy savings for each motor.

$$kWh_{Total} = \sum_{All\ Scenarios} Hours_i \left[kW_{i,b} - kW_{i,n} \right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW_{i,b}$	Baseline demand for scenario *i*
$kW_{i,n}$	New demand for scenario *i*
$Hours_i$	Annualized operating hours for scenario *i*

An example of this energy savings equation and method is presented in Table 2-3. Baseline and post-retrofit demands are taken from measurements. Operating hours are stipulated based on expected system behavior. In this example, each scenario is expected for four hours per day, 250 days per year.

Table 2-3: Calculation of Energy Savings

Scenario	Baseline kW	Percent VSD Speed	Post-Installation kW	Demand Reduction, kW	Operating Hours/Year	kWh Savings
1	30	**100%**	30	0	1,000	0
2	30	**75%**	14	16	1,000	16,000
3	30	**50%**	5	25	1,000	25,000
Totals					**5,000**	**41,000**

Demand

Variable-speed drive projects may offer little or no demand savings seen at the utility meter. If they are used in HVAC applications where load is a function of weather conditions, then typically the load is at its maximum when the weather is most extreme. For process loads, some demand savings may be realized, but estimating them reliably requires information about the VSD load profile and the concurrent plant load profile. For many applications, it may be difficult to estimate and justify demand reductions that will be seen at the customer meter. If significant demand reductions are anticipated as a result of a variable speed drive project, they should be verified from the utility bill (an Option C approach).

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak}$$

Annual Verification Activities

For most VSD projects, the potential to perform can be verified through inspections to show that the installed equipment is still present and operating correctly. This involves checking to see that the drives are functional and that they are modulating the motor speed. Often, sensors used to modulate speed may fail and leave the motor operating at **100%.** Drives operating at **100%** speed (50 Hz) are functional but not saving energy.

2.4 Boiler or Furnace Upgrades

This section describes Method BF-A-01—Measured Performance at Specific Load Conditions, Hours at Each Capacity (Stipulated).

ECM Definition

Boiler or furnace equipment upgrades involve improving the specific fuel utilization efficiency. Projects covered by this verification plan are as follows:

- Replacement of existing equipment with more energy-efficient boilers or furnaces (includes replacing single units with multiple staged units);
- Installation of economizers ;
- Installation of automatic controls;
- Boiler or furnace insulation to reduce shell loss;
- Water treatment / blowdown control;
- Flash steam recovery from deaeration tanks; and
- Fuel switching.

These projects reduce the rate of fuel or firewood consumption. The specific fuel consumption or the combustion efficiency are measured while the hours at each output level are stipulated and assumed to follow the same pattern in the pre- and post-retrofit periods.

Overview of Verification Method

M&V Method BF-A-01 requires spot or short-term performance measurements, such as combustion efficiency of the boiler or amount of fuel required per unit of output at a representative load capacity of baseline and post-installation conditions.

The operating hours at each load condition are estimated and then stipulated for the contract period.

Baseline Energy Use

Baseline energy use is a function of equipment performance and operating hours. Baseline performance can often be measured; either directly in terms of fuel consumption per unit of output or indirectly using a combustion gas analyzer. If at all possible, these measurements should be taken across a sample of the load range to characterize the equipment.

The number of hours at different load ranges need to be estimated based on typical weather conditions or production records. The hours at different load ranges will be stipulated and form the basis of the energy savings estimate.

Post-Retrofit Energy Use

Performance measurements of the new equipment should be taken to ensure that the equipment has been installed and commissioned properly. These measurements should be taken at similar load ranges as in the baseline case.

If fuel switching has occurred between the baseline and post-retrofit case (e.g., electric heat to fuel), it is acceptable to convert the baseline and post-retrofit energy use to energy costs. It may also be necessary to consider specific fuel heating values to arrive at energy inputs.

The number of hours at each load range are expected to be the same as in the baseline case.

Equations for Calculating Energy Savings

To estimate energy savings for boiler or furnace upgrades, use the following equation if the energy *inputs* are known:

$$kJ_{Savings} = \sum \left[Hours_i\right]\left[kJ/hr_{input,i,b} - kJ/hr_{input,i,n}\right]$$

or

$$L_{Savings} = \sum \left[Hours_i\right]\left[L/hr_{input,i,b} - L/hr_{input,i,n}\right]$$

where:

$kJ_{Savings}$, $L_{savings}$	Realized energy savings, kJ or L (liters)
$kJ/hr_{input,i,b}$, $L/hr_{input,i,b}$	Baseline fuel consumption rate for scenario *i*
$kJ/hr_{input,i,n}$, $L/hr_{input,i,n}$	New fuel consumption rate for scenario *i*
$Hours_i$	Hours at a particular mode of operation or output level

If energy inputs are units other than kJ or liters of fuel (e.g., kg of firewood), the equation can be modified accordingly.

To estimate energy savings for boiler or furnace upgrades, use the following equation if the energy *outputs* are known and combustion efficiency was measured:

$$kJ_{Savings} = \sum \left[Hours_i\right]\left[kJ/hr_{output,i}\right]\left[\frac{1}{\eta_{b,i}} - \frac{1}{\eta_{n,i}}\right]$$

where:

$kJ_{Savings}$	Realized energy savings, kJ
$kJ/hr_{output,i}$	Energy output rate for scenario *i*
$\eta_{b,i}$	Baseline efficiency for scenario *I*
$\eta_{n,i}$	New efficiency for scenario *I*
$Hours_i$	Hours at a particular mode of operation or output level

If output units are measured in different units (e.g., kg of steam), the equation can be modified. It may be necessary to calculate overall system efficiency from measured combustion efficiency to account for shell thermal losses.

An example of these equations and methods is presented in tabular format in Table 2-4. In this example, the method applied to a boiler upgrade with measured efficiencies. Operating hours are stipulated based on expected system behavior.

Table 2-4: Calculation of Energy Savings

Scenario	Output, kJ/hr	Baseline Efficiency	Post-Installation Efficiency	Savings, kJ/hr	Operating Hours/Year	kJh Savings
1	100,000	**75%**	**82%**	11,382	500	5,690,000
2	80,000	**74%**	**81%**	9,343	1,000	9,340,000
3	60,000	**72%**	**80%**	8,333	2,000	16,670,000
4	40,000	**70%**	**78%**	5,861	1,000	5,860,000
5	20,000	**68%**	**76%**	3,096	500	1,550,000
Totals					**5,000**	**39,110,000**

Cost Savings

Fuel cost reductions result from a decrease in energy use (e.g., kJ, liters). The monthly cost savings is the monthly energy saved multiplied by the appropriate fuel unit cost. If savings are calculated as kJ, the specific energy content of the fuel in question needs to be known. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. Fuel cost savings are therefore:

$$Savings, Rs = (Savings, l)(Unit\ Cost, Rs / l)$$

or

$$Savings, Rs = \frac{(Savings, kJ)(Unit\ Cost, Rs / l)}{(Specific\ Energy\ Content, kJ / l)}$$

In the event that the heating source is changed from electricity to fuel, savings based on efficiency increases do not apply. The cost saving is the difference between the original operating cost and the new system cost. If electrical and fuel use can be quantified, the savings are:

$$Savings, Rs = (Energy\ Used_{baseline}, kWh)(Unit\ Cost, Rs / kWh) + (Demand, kVA)(Unit\ Cost, Rs / kVA) - (Fuel\ Used, l)(Fuel\ Unit\ Cost, Rs / l)$$

If the electrical use is known but the fuel use is unknown or unmetered, the cost savings are:

$$Savings, Rs = (Energy\ Used_{baseline}, kWh)(Electricity\ Unit\ Cost, Rs / kWh) + (Demand, kVA)(Unit\ Cost, Rs / kVA) - \frac{(Energy\ Used_{baseline}, kWh)(3{,}600\ kJ / kWh)(Fuel\ Unit\ Cost, Rs / l)}{(Specific\ Fuel\ Energy\ Content, kJ / l)(1 / \eta_{new})}$$

Boiler or furnace efficiency is necessary in the third term to account for fuel use inefficiencies. The assumption is made that electricity is converted to heat with **100%** efficiency in the baseline case.

Annual Verification Activities

With Option A, annual fuel use or efficiency measurements are not required. Inspections should be made to verify installation and proper equipment operation, including that air/fuel ratios are correct or that economizers are functional and not fouled.

2.5 Chiller Replacement

In this section, two chiller replacement M&V methods are discussed:

- Method CH-A-01, No Metering; and
- Method CH-A-02, Measurement of Chiller kW/ton.

ECM Definition

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

- Existing chillers replaced with more energy-efficient chillers;
- Existing chillers replaced with those using a different energy source; and
- Changes in chiller controls that improve chiller performance.

For Method CH-A-01, the chiller performance (e.g., kWh/kJ and kW/ton) and the chiller load (e.g., kJ per year and ton-hour per year) are stipulated. For Method CH-A-02, the chiller performance 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 loads can be defined and stipulated by the ESCO.*

Because Method CH-A-01 does not use measured values, it does not comply with the International Measurement and Verification Protocol. It is included here for cases where Method CH-A-02 is too expensive or difficult relative to the anticipated savings.

This option is not recommended for thermal-energy storage (TES) systems because TES shifts energy use and demand to off-peak periods. They save little energy but reduce costs because less expensive electricity is used to provide cooling. An Option C approach is recommended for these systems to verify actual cost reduction.

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; and
- Operating schedules.

Method CH-A-01-No Metering

Baseline and post-installation chiller ratings (e.g., kW/ton[3], kWh/kJ, integrated part load value (IPLV)[4], and coefficient of performance (COP) are stipulated on the basis of manufacturers' or other data. Annual cooling loads (e.g., annual or monthly kJ or ton-hours) are also stipulated. Energy savings are based on the product of (a) the difference between average baseline kWh/kJ and post-installation kWh/kJ and (b) cooling load in kJ/hr. If fuel-switching[5] occurs, then savings are the difference between baseline energy costs and the post-retrofit energy costs. (Fuel switching may occur if an electric chiller is converted to an absorption chiller or to a direct-drive engine-driven chiller.)

Method CH-A-02-Measured Performance

Baseline and post-installation chiller ratings (e.g., kW/ton, kWh/kJ, 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 kJ or ton-hours) are stipulated. Energy savings are based on the product of (a) the difference between baseline kWh/kJ and post-installation kWh/kJ at each load rating and (b) cooling load in kJ.

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. Load reductions may be the result of lighting retrofits, conversion of constant-volume to variable-air-volume systems, or other HVAC changes.

Chiller measurements and characterization is neither simple nor inexpensive. For a chiller, two water-temperature and one water-flow measurements with high precision need to be taken. For a direct-expansion system, two precision air temperatures, relative humidities, and air mass flow measurements are required.

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;
- Chilled water piping diagrams and quality of insulation;
- Load served;
- Operating schedule;
- Chiller application; and
- Equipment locations.

Baseline Demand

Method CH-A-01—Stipulated Chiller Efficiencies

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[3] 'ton' is an American unit equal to 12,000 BTU/hr or 3.5 kJ/s.

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

[5] Examples include replacing an electric chiller with a steam-driven or fuel oil-fired absorption cooler or an engine-driven compressor.

For this approach, 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 kW/ton, annual average kWh/kJ, kWh/kJ for different cooling loads, or IPLV.

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 measured as true power;
- Chilled water flow, entering and leaving temperatures for calculating cooling load;
- Air supply and discharge temperatures, relative humidities, and velocities (DX units only);
- Chiller circulating and condenser pumps kW if they are to be replaced or modified; and
- Cooling tower fan(s) kW if they are to be replaced or modified.

Because of the small temperature differences in return and supply chilled water, temperature measurements should be made using sensors with accuracy at or approaching ±**2%** of reading. Matched platinum resistance temperature probes are often used.

For chillers, water mass flow needs to be measured concurrently with temperatures. For short-term measurements, ultrasonic flow meters are typically used because of their non-invasive nature. However, ultrasonic flow meters are very expensive (Rs 800,000). Differential pressure across an orifice plate can be used, but not all systems have one. Installing one requires shutting down the chiller. As a last resort, the pressure drop across the evaporator could be measured and compared to the manufacturer's flow specifications, but this is usually the least accurate flow measurement method.

For direct-expansion coolers, the airflow across the coil will need to be measured, also not a trivial task. This is typically performed using a pitot-tube anemometer and taking the average of multiple measurements. The entering and leaving air enthalpy needs to measured, meaning that temperature and relative humidity (or wet-bulb temperature) will have to be measured on both sides of the cooling coil.

In addition, condenser water return temperature (or outside air temperature if the condenser is air-cooled) needs to be monitored as well. Chiller performance is often specified at American Refrigeration Institute (ARI) conditions of 26.6 ^{o}C (80 ^{o}F) returning condenser water temperature. If the temperature is different from this, the measured performance will need to be adjusted using a polynomial equation as outlined in the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Equipment Handbook.

If at all possible, multiple measurements are made while the cooling system operates at different loads so that the complete range of chiller performance can be evaluated. Optimally, baseline metering is performed during a period when a range of cooling loads exist. If only a single operating point can be measured, it will be necessary to use the ASHRAE polynomial performance curves to predict performance at other operating conditions.

Some of the issues raised here illustrate the complexity of chiller performance measurement. It is neither trivial nor inexpensive, thus the reason for providing Method CH-A-01. However, for projects with significant savings and significant uncertainty, the effort to accurately characterize the baseline condition is justified.

Post-Installation Demand

Method CH-A-01—Stipulated Chiller Efficiencies

For this approach, 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. Chiller efficiency can be presented in several formats, depending on the type of load data that will be stipulated. Possible options include kW/ton, annual average kWh/kJ, kWh/kJ for different cooling loads, or IPLV.

Method CH-A-02—Metering of Existing Chillers

For this M&V method, the new chiller efficiency is measured as in the baseline case. The same issues as for the baseline chiller apply to the new chiller.

Cooling Load

Cooling loads will be stipulated, i.e., agreed to by the customer and the ESCO. In the absence of long-term metering data, annual and monthly cooling loads will need to be estimated. This information can come from:

- Chiller logs showing supply and return chilled water temperatures if flow is known and constant;
- Short-term metering done as part of Method CH-A-02 and extrapolated to the rest of the year;
- Engineering calculations, such as ASHRAE's Cooling-Load Temperature-Difference Method, coupled with a bin-hour analysis and typical weather information; and
- Results of calibrated computer simulation programs.

Because chiller upgrades may be commensurate with other projects, baseline and post-installation cooling loads may be different. This may require repeating the cooling load calculations for the baseline and post-retrofit case.

Equations for Calculating Energy and Demand Savings

Energy

For electric chiller upgrades with no anticipated cooling load changes, the following equation may be used:

$$kWh_{Savings} = \sum [Hours_i][kJ/hr_i][kWh/kJ_{i,b} - kWh/kJ_{i,n}]$$

where:

$Hours_i$	Hours at cooling load *i*
kJ/hr_i	Cooling load *i*
$kWh/kJ_{i,b}$	Baseline chiller performance at load *i*
$kWh/kJ_{i,n}$	New chiller performance at load *i*

Demand

Building peak demand as seen at the utility meter is often driven by chiller load. The largest chiller demand usually occurs when the weather is most extreme. Therefore, it is reasonably safe to assume that the demand savings realized at the utility meter will be the demand savings realized at the full load capacity of the chiller. This simplifies the demand calculation to:

$$kVA_{Savings} = \left[kJ/hr_i\right]\left[\frac{kWh/kJ_{i,b}}{PF_{i,b}} - \frac{kWh/kJ_{i,n}}{PF_{i,n}}\right]$$

where:

kJ/hr_i	Maximum cooling load *i* during the month
$kWh/kJ_{i,b}$	Baseline chiller performance at load *i*
$kWh/kJ_{i,n}$	New chiller performance at load *i*
$PF_{i,b}$	Baseline power factor at load *i*
$PF_{i,n}$	New power factor at load *i*

If the project involves more than a one-for-one chiller replacement, more general forms of the previous equations may need to be used. If cooling loads are decreased as a result of other changes, the hours at each load range for the baseline and post-retrofit cases will need to be determined and applied to the appropriate chiller performances. If an absorption or engine-driven chiller is installed, the energy *costs* must be calculated in the baseline and post-retrofit cases and compared to determine the financial savings.

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$\begin{aligned} Savings, Rs = {} & (Savings, kWh)(Unit\ Cost, Rs/kWh) + \\ & (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA) \end{aligned}$$

or

$$\begin{aligned} Savings, Rs = {} & (Savings, kWh)_{Peak}(Unit\ Cost, Rs/kWh)_{Peak} + \\ & (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs/kWh)_{Off-Peak} + \\ & (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA) \end{aligned}$$

Annual Verification Activities

With Option A, annual measurements are not required. Operation of the new system should be inspected to ensure that the new chiller has the potential to live up to its expected performance. This includes checking to see that the refrigerant levels are correct, condenser water is clean and water chemistry is correct (to minimize fouling), and automated controls are functioning properly. A review of the operating logs can show operating characteristics and ensure that performance is maintained.

2.6 Generic Constant Load Improvements

This section describes Method GCL-A-01—Measurement of Baseline And Post-Retrofit Loads.

ECM Definition

This method applies to projects not covered under the technology-specific methods discussed previously. The fundamental requirement for application of this method is that the load or the load reduction remain constant and that the operating hours are readily characterized. This method is applicable to both electrical and thermal loads. Potential applications include (but are not limited to):

- Elimination of steam leaks in steam systems;
- Repair of leaks in compressed air systems;
- Piping changes in constant-flow fluid systems that reduce pumping losses; and
- Electrical system upgrades (e.g.' efficient transformers).

This method may not seem to be applicable to the first two applications because steam or compressed air loads vary with usage. However, losses due to leaks are essentially constant and can therefore be treated with this approach.

Overview of Verification Method

The approach presented here is generic in nature and needs to be expanded by the user to fit the intended application. In general, improvements in constant-load systems result in a continuous decrease in energy use. With this method, energy use of the baseline and post-retrofit cases are made to determine the energy use reduction per unit of time. If the operating hours per year are known, then the annual savings are readily determined.

In some cases, it may be difficult or impossible to directly measure use in the baseline or post-retrofit cases. For example, thermal losses due to leaking steam traps cannot be measured directly in the baseline case and will be eliminated in the post-retrofit case. Where this situation exists, engineering calculations must be made to estimate the energy loss under the current baseline conditions.

Calculation of Demand and Energy Savings

Baseline and Post-Retrofit Demand

In the pre-installation equipment survey, the affected system(s) and any 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.

Where possible, electrical or thermal measurements should be taken to determine the baseline or post-retrofit

Operating Hours

Operating hours for the affected system(s) can be determined through measurements or stipulated based on known and documented schedules.

Equations for Calculating Energy and Demand Savings

Energy

To estimate energy savings using this method, the reduction in energy use per unit of time and the monthly or annual operating hours need to be known. The following equations are the most generally applicable to this method:

$$kWh_{savings} = \sum Hours_i \left[kW_{i,b} - kW_{i,n} \right]$$

or

$$kJ_{savings} = \sum Hours_i \left[kJ/hr_{i,b} - kJ/hr_{i,n} \right]$$

where:

$kWh_{savings}$, $kJ_{savings}$	Annual kWh or kJ savings realized
$Hours_i$	Annual operating hours of device or system i
$kW_{i,b}$, $kJ/hr_{i,b}$	Baseline energy use per unit time of device or system i
$kW_{i,n}$, $kJ/hr_{i,n}$	New energy use per unit time of device or system i

If the facility is using an electrical time-of-day rate, the energy savings for the peak and off-peak periods must be calculated separately. If operating hours are being measured, time-of-use (event) loggers must be used and extra data analysis will be required to separate the hours into the two periods.

If the energy use per unit of time cannot be directly measured, it will need to be calculated from engineering calculations. For example, failed steam traps lose steam at a rate that depends on the orifice diameter and steam pressure. In the baseline case, steam losses will need to be calculated from the steam trap survey that includes orifice diameter and line pressure. In the post-retrofit case, the failed steam traps will be replaced and the leaks (losses) eliminated.

Demand

Electrical demand savings as a result of an efficiency project will show up on the customer's electric meter as reduced kVA consumption. Because all of a building's devices may not operate simultaneously, the demand reduction observed at the meter will never be the sum of the device power reductions. To determine the demand reduction observed at the meter, the fraction of devices operating when the metered peak demand is set needs to be known.

The fraction of operating devices is known as the *diversity factor*, which is used to calculate the demand reduction seen on the utility bill. The following equation can be used to determine the diversity factor:

$$DF = \frac{number\ of\ devices\ operating\ during\ the\ period\ when\ the\ peak\ demand\ is\ set}{total\ number\ of\ devices}$$

The diversity factor can then be used to arrive at the demand reduction seen at the meter. The diversity factor for each group can be determined from walkthrough inspections or through analysis of monitoring data.

$$kVA_{Savingsl} = DF\sum\left[\left(\frac{kW_{i,b}}{PF_{i,b}}\right)-\left(\frac{kW_{i,n}}{PF_{i,n}}\right)\right]$$

where:

$kVA_{savings}$	Monthly kVA savings realized
DF	Overall diversity factor
$kVA_{i,b}$	Baseline demand of device or system i
$PF_{i,b}$	Baseline power factor of device i
$kVA_{i,n}$	New demand of device or system i
$PF_{i,n}$	New power factor of device i

Power factor in the baseline and post-retrofit conditions is included to reflect that peak demand is billed as maximum kVA, not kW, and that the power factor of the affected devices may change as a result of an upgrade. Thus, power measurements should be taken with a true-power meter capable of measuring both real and reactive power.

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs/kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs/kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs/kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA)$$

Fuel cost reductions result from a decrease in energy use (kJ, liters). The monthly cost savings is the monthly energy saved multiplied by the appropriate fuel unit cost. If savings are calculated as kJ, the specific energy content of the fuel in question needs to be known. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. Fuel cost savings are therefore:

$$Savings, Rs = (Savings, l)(Unit\ Cost, Rs/l)$$

or

$$Savings, Rs = \frac{(Savings, kJ)(Unit\ Cost, Rs/l)}{(Specific\ Energy\ Content, kJ/l)}$$

Annual Verification Activities

For generic efficiency projects, the potential to perform can be verified through inspections to show that the installed equipment is still present and operating correctly. This involves checking to see that the installed equipment is present and operating as intended.

2.7 Heat Recovery Applications

This section discusses Method HR-A-01 for heat recovery applications.

ECM Definition

A heat recovery system installation or upgrade recovers heat (or cold) from a process or effluent stream that would otherwise be lost. Recovering heat (or cold) reduces the heating or cooling energy required for the process stream. Projects covered by this verification plan include:

- Recovering heat from a process effluent stream;
- Recovering heat (or cool) from an exhaust air stream; and
- Exchange of heat between process streams.

These projects reduce energy demand either in terms of fuel use and/or electrical power required. Temperatures of relevant process streams are measured and engineering equations used to calculate the heat recovered.

Overview of Verification Methods

Method HR-A-01 requires one-time temperature measurements at baseline and post-installation conditions. For most accurate results, flow needs to be measured as well. An energy or enthalpy balance needs to be performed to determine the heat recovered in the baseline case (if heat recovery exists at all) and in the post-retrofit case.

Calculation of Demand and Energy Savings

Baseline and Post-Retrofit Energy Use

Baseline and post-installation performances are based on measured temperatures and flows (and relative humidity if applicable). The throughput pattern in the pre- and post-retrofit periods and the hours of operation are measured. The relevant temperatures are the input and output temperatures across the heat (cool) recovery system. This recovered energy directly displaces heating or cooling energy from the primary source.

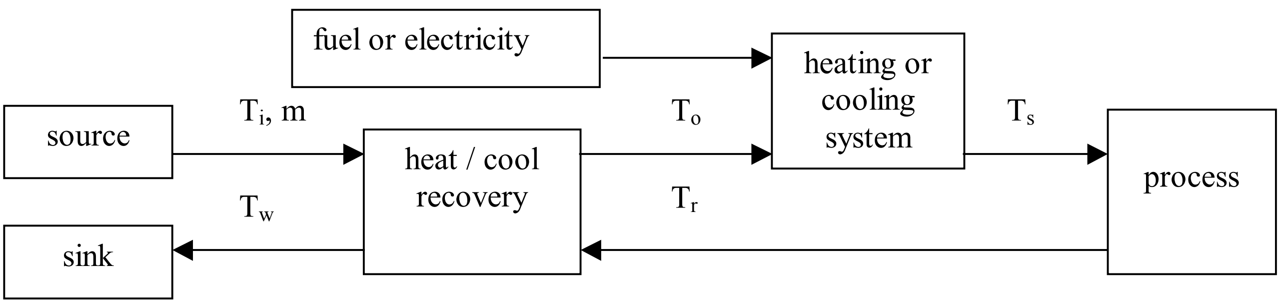

Figure 2-1: Heat and Cool Recovery System

Equations for Calculating Energy and Demand Savings

Energy

If an energy-recovery system is being installed where none previously existed, the savings are the total energy captured by the system. If an existing system is being upgraded or improved, the savings are the incremental energy captured by the new system relative to the old.

The effectiveness *e* of the heat recovery system can be defined as the fraction of available energy recovered. Assuming that the mass flow on the supply and return sides are identical, the effectiveness of the heat recovery system can be defined as:

$$e = \frac{T_i - T_o}{T_i - T_r} = \frac{\text{recovered energy}}{\text{available energy}}$$

where:

T_i	Temperature of input stream
T_o	Temperature of output stream
T_r	Temperature of return stream

Over time, the effectiveness of a heat recovery system may degrade due to scaling or fouling of the heat exchange surface. As the effectiveness decreases, the recovered energy decreases.

For all energy recovery systems, the efficiency of the heating plant or the performance of the cooling plant needs to be taken into account. Since it is often difficult or impossible to know the specific efficiency or performance of heating and cooling systems at specific times, the average efficiency or performance should be used instead.

Under Option A, the temperatures of the supply and return stream will be measured in the baseline and post-retrofit cases once. If the process flow rate is constant, it may be measured or stipulated. If the process flow rate varies, it should be measured at each scenario in such a way that the operating hours at each scenario can be estimated. For constant-flow heat recovery applications where a boiler or furnace acts as the heating source, use the following equation:

$$kJ_{Saved} = \frac{t\dot{m}c_p(T_o - T_i)}{\eta}$$

where:

kJ_{Saved}	Total reduction in thermal energy use
t	Operating hours per year
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg ^{o}C
T_o, T_i	Measured supply and return temperatures of stream, ^{o}C
η	Average heating system efficiency

If an existing heat recovery system is being upgraded, the previous equation needs to be modified to account for the increase in heat recovery. In this situation, the output temperature

T_o is expected to be greater than in the baseline case. Comparing a new heat recovery system to the old reduces to the following:

$$kJ_{Saved} = \frac{t\dot{m}c_p (T_{o,n} - T_{o,b})}{\eta}$$

where:

kJ_{Saved}	Total reduction in thermal energy use
t	Operating hours per year
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg °C
$T_{o,b}$	Measured baseline supply temperatures of stream, °C
$T_{o,b}$	Measured new supply temperatures of stream, °C
η	Average heating system efficiency

The savings in kiloJoules need to be converted to units of fuel. To do this, the specific energy content (lower heating value) of the fuel being saved needs to be known. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. If electric heat is being displaced, the conversion factor is 3,600 kJ per kWh.

For applications where cooling energy is being displaced in a constant-flow application, use the following equation:

$$kWh_{Saved} = \frac{t\dot{m}c_p (T_i - T_o)}{3{,}600\, COP} = \frac{t\dot{m}c_p (T_i - T_o)}{12{,}648} (kW / ton)$$

where:

kWh_{Saved}	Total reduction in electrical chiller energy use
t	Operating hours per year
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg °C
T_o, T_i	Measured supply and return temperatures of stream, °C
COP	Average chiller coefficient of performance (dimensionless)
kW/ton	Average chiller performance, kW per ton (12,000 BTU/h) of cooling provided

The previous equation assumes that an electric-driven chiller is being used to provide cooling. The equation is given in two forms depending on what chiller information is available: COP and kW/ton (common units for American-made chillers).

Demand

Demand savings are applicable only to electric cooling applications. Demand savings are equivalent to the maximum demand reduction available, provided that the demand reduction occurs at a time coincident with the building or facility peak demand.

$$kW_{Saved} = \frac{1}{PF}\text{Max}\left[\frac{\dot{m}c_p(T_i - T_o)}{3{,}600\,COP}\right] = \frac{1}{PF}\text{Max}\left[\frac{\dot{m}c_p(T_i - T_o)}{12{,}648}(kW/ton)\right]$$

where:

kVA_{Saved}	Monthly demand reduction
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg ^oC
T_o, T_i	Measured supply and return temperatures of stream, ^oC
COP	Average chiller coefficient of performance (dimensionless)
kW/ton	Average chiller performance, kW per ton (12,000 BTU/h) of cooling provided
PF	Chiller power factor at full load

Cost Savings

Fuel cost reductions result from a decrease in fuel use (e.g., kJ, liters, m^3). The monthly cost savings is the monthly energy saved multiplied by the appropriate fuel unit cost. The specific energy content (lower heating value) of the fuel being saved needs to be known as well. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. Fuel cost savings are then:

$$Savings, Rs = (Savings, kJ)(Energy\ Content, kJ/l)(Unit\ Cost, Rs/l)$$

Substitute kilograms or cubic meters for liters as necessary.

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs/kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs/kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs/kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs/kVA)$$

Annual Verification Activities

Under Option A, the operating hours and flow rates may be stipulated. Verification of potential to perform can be accomplished by taking three temperature measurements to demonstrate that the heat exchanger effectiveness has not significantly deteriorated.

This chapter describes measure-specific M&V methods associated with Option B — retrofit or system level M&V assessment. Option B is one of the four M&V options defined for the implementation of energy efficiency projects. The methods described in Chapter 3 are for the most typical ECMs and they are representative of the range of methods available.

The approach is intended for retrofits with performance factors (e.g., end-use capacity, demand, and power) and operational factors (e.g., lighting operational hours, and 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:

- 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;
- Energy savings values per individual measure are desired;
- Interactive effects are to be ignored or are stipulated using estimating methods that do not involve long-term measurements;
- Independent variables that affect energy use are not complex and excessively difficult or expensive to monitor; and
- 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. An Option B approach:

- Confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings; and.
- 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 reliable, 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 before and after 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) accounts 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 determined to operate in a similar fashion.

Table 3-1: ECMs and Applications of Option B

ECM	Method Number	Performance Factors	Usage Factors
1. Lighting Efficiency and Controls	LE-B-01	kWh (measured)	Hours (measured)
	LE-B-02	kW (measured)	Hours (measured)
2. Power Factor Correction	PF-B-01	kVA, kVAR (measured)	kVA, kVAR (measured)
3. Constant-Load Motor Efficiency	CLM-B-01	kW (measured)	Hours (measured)
4. Variable-Speed-Drive Retrofit	VSD-B-01	kW at each operating scenario (measured)	Hours at each operating scenario (measured)
5. Boiler / Furnace equipment upgrades	BF-B-01	kJ/hr delivered output (measured)	Hours at each capacity, (measured)
6. Chiller Replacements	CH-B-01	kWh (measured)	Load (stipulated)
	CH-B-02	kWh (measured)	Load (measured)
7. Distribution System Improvements (Generic variable-load variable-hours)	GVL-B-01		
8. Heat Recovery Applications	HR-B-01	kJ/output (measured)	Hours at each condition (stipulated)
9. Cogeneration	CO-B-01	kW, kWh, kJ (measured)	Hours (measured)
10. Renewable Energy Systems	RE-B-01	kW, kWh, kJ (measured)	Resource availability
11. Controls	CS-B-01		
12. Process Technology Improvements	PT-B-01	kW or kJ/per unit of production (measured)	Production (measured)

3.1 Lighting Efficiency

Two M&V methods are available under Option B for lighting efficiency projects:

- Method LE-B-01 requires pre- and post-installation equipment surveys in combination with post-installation lighting circuit measurements for determining both demand and energy savings.
- Method LE-B-02 involves baseline and post-installation monitoring of hours of operation for establishing savings.

This section describes Method LE-B-01—Metering of Lighting Circuits. Method LE-B-02—Monitoring of Fixture Operation is described in Section 3.2, Lighting Efficiency and Controls.

Project Definition

The lighting projects covered by this verification plan under Method LE-B-01 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; and
- Lighting efficiency projects that reduce demand with no changes to operating hours.

This method is not easily applicable to projects with controls or motion sensors because baseline operating hours are not explicitly measured; thus such projects should consider a plan using Method LE-B-02.

Overview of Verification Method

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

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

Baseline Demand and Energy

Circuit measurements are the basis for calculating energy and demand savings with this M&V method. Equipment inventories are required 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 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 7-1 compares average load profiles for a lighting circuit's energy draw following 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.

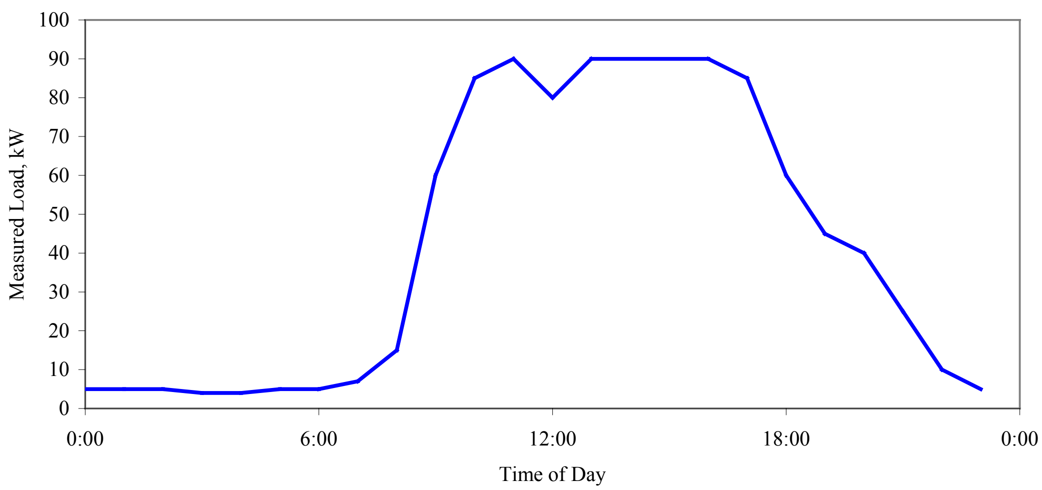

Figure 3-1 Metered Weekday Average Post-Installation Load Profile

The circuits must be carefully selected to ensure that:

- Only lighting loads that are affected by the retrofit are on the measured circuit(s); and
- The lighting circuits selected should be representative of the desired space type.

The following issues must be addressed:

- Which lighting loads (usage groups) 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 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 spot measurements 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. It is usually not required for lighting projects.

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 powers or from fixture power 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 power 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 customer. 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 calculations. 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 daily energy savings for lighting efficiency projects use the following equation:

$$kWh_{savings,g} = \sum_{i=1:00}^{24:00} (Load\ Factor_{i,g})(kW_{b,g} - kW_{n,g})$$

where:

$kWh_{Savings,g}$	The daily kilowatt-hour savings for usage group *g*
$Load\ Factor_{i,g}$	The measured load factor for hour *i*, usage group *g*
$kW_{b,g}$	The connected baseline lighting load for usage group *g*
$kW_{b,g}$	The connected post-retrofit lighting load for usage group *g*

If lighting levels are deliberately and significantly increased, the baseline power level in the previous equation can be adjusted as in Option A.

The load factor at any hour *i* is the number of lamps operating during each hour relative to the total number of lamps. This can be calculated by comparing the measured load to the connected load of the measured lighting circuit.

$$Load\ Factor_i = \frac{kW_{measured,i}}{kW_{connected}}$$

Consider the following lighting retrofit: The baseline connected load was 150 kW; the new connected load is 100 kW. Demand reduction is 150 kW – 100 kW or 50 kW. All fixtures are connected to a single distribution panel that will be metered at single point. Table 3-2 shows the average post-retrofit readings for each weekday hour. The load factor is calculated by dividing the measured load (kW) by the post-retrofit connected load (100 kW). The kW saved for each hour is the load factor multiplied by the demand reduction (50 kW). To calculate the annual energy savings, the daily energy savings are multiplied by the number of weekdays the building operates (approximately 240).

Table 3-2: Lighting Load Profile and Energy Savings

Time	Measured kW post-retrofit	Load Factor (measured kW) / (100 kW)	kW saved (Load Factor) (50 kW)
0:00	5	**5%**	2.5
1:00	5	**5%**	2.5
2:00	5	**5%**	2.5
3:00	4	**4%**	2
4:00	4	**4%**	2
5:00	5	**5%**	2.5
6:00	5	**5%**	2.5
7:00	7	**7%**	3.5
8:00	15	**15%**	7.5
9:00	60	**60%**	30
10:00	85	**85%**	42.5
11:00	90	**90%**	45
12:00	80	**80%**	40
13:00	90	**90%**	45
14:00	90	**90%**	45
15:00	90	**90%**	45
16:00	90	**90%**	45
17:00	85	**85%**	42.5
18:00	60	**60%**	30
19:00	45	**45%**	22.5
20:00	40	**40%**	20
21:00	25	**25%**	12.5
22:00	10	**10%**	5
23:00	5	**5%**	2.5
Total kWh	**1,000**		**500**

Demand

The measured load profile can be used to determine the peak demand and the peak demand reduction. Since lighting is a major driver of peak demand, the maximum lighting demand will often be coincident with the maximum facility demand. By summing the load profiles for all usage groups, the total demand reduction profile can be obtained. The maximum value of the total load profile is the expected demand reduction seen at the utility meter.

$$kVA_{savings} = Max_{i=1:00}^{24:00} \sum_{g} (Load\ Factor_{i,g}) \left(\frac{kW_{b,g}}{PF_{b,g}} - \frac{kW_{n,g}}{PF_{n,g}} \right)$$

where:

$kVA_{savings}$	Demand savings at the site
Max	The maximum value of the profile
$Load\ Factor_{i,g}$	The Load Factor at hour *i* for usage group *g*
$kW_{b,g}$	Baseline connected load for usage group *g*
$kW_{n,g}$	New connected load for usage group *g*
$PF_{b,g}$	Baseline power factor of usage group *g*
$PF_{n,g}$	New power factor of usage group *g*

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

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

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

Annual Verification Activities

Ongoing fixture power measurements will verify performance of the installed lighting fixtures. If savings deviate from expected values, a review of the metering information will determine whether operating hours or performance has changed.

3.2 Lighting Efficiency and Controls

This section describes Method LE-B-02—Monitoring of Fixture Operation.

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; and
- Lighting controls and occupancy sensors.

These lighting efficiency projects reduce energy use by reducing demand and/or operating hours.

Overview of Verification Method

Method LE-A-02 measures the fixture powers before and after the retrofit and then measures the operating hours annually to derive the energy savings. Post-installation hours of operation will be determined by monitoring a statistically valid sample of fixtures and rooms. This method is useful where the actual energy savings need to be known every year.

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.

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 powers are based on spot or short-term measurements.

Fixture Power Metering

Baseline and post-retrofit fixture powers will be measured using a true-power meter on a representative sample of fixtures after they have reached normal operating temperature. The average and the standard deviation of the power measurements will be reported.

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.

The baseline demand may be adjusted by using values from fixture power 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 power of zero.

Post-Installation Demand

The post-installation conditions identified in the post-installation equipment survey will be defined by the ESCO. Fixture metering will occur once on a sample of fixture types similar to the baseline case.

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;
- How long operating hours will be metered to determine a representative operating profile; and
- Whether controls or sensors will be installed.

The facility in question needs to be surveyed to identify usage groups that have similar schedules. The number of samples is a function of the number of spaces within each usage group and the desired precision.

The duration and frequency of monitoring should be defined. For typical office spaces, three weeks is considered a typical monitoring period. In most cases, frequency will be annually.

If controls or sensors are not installed, measuring baseline hours is not required. The hours measured in the post-retrofit period will be used to calculate the savings. If controls or sensors are installed, then the baseline operating hours need to be measured in order to have a reference against which to claim savings since the operating hours will be different between the baseline and post-retrofit case.

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 a sample of fixtures.

Loggers

The ESCO will specify the data logger to be used in the site-specific M&V plan. Measurements of operating hours are typically done with light loggers, which are devices that measure the operating times of individual fixtures through the use of photocells.

The loggers may be required to measure and record data indicating operating hours for each utility time-of-use costing period (peak / off-peak). The ESCO must use a data logger that records status at frequent intervals (i.e., at least every 15 minutes) or tracks the turn-on and turn-off times. Raw data from the meter(s) should be provided.

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 hour 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 excluded from analysis.

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 sample plan and monitoring plan.

Equations for Calculating Energy and Demand Savings

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:

$$kWh_{Total} = \sum_{All\ Groups} \left[\left(Hours_{g,b}\right)\left(QTY_{g,b}\right)\left(kW / fixture_{g,b}\right) - \left(Hours_{g,n}\right)\left(QTY_{g,n}\right)\left(kW / fixture_{g,n}\right) \right]$$

where:

kWh_{Total}	Total kilowatt-hour savings realized
$kW / fixture_{g,b}$	Baseline lighting demand per fixture for usage group *g*
$kW / fixture_{g,n}$	Post-retrofit lighting demand per fixture for usage group *g*
$QTY_{g,b}$	Quantity of baseline fixtures for usage group *g*
$QTY_{g,n}$	Quantity of affected fixtures for usage group *g*
$Hours_{g,b}$	Baseline operating hours for usage group *g*. If sensors or controls are not installed, this will be the same as the post-retrofit hours.
$Hours_{g,n}$	Post-retrofit operating hours for usage group *g*. If sensors or controls are not installed, this will be the same as the baseline hours.

If lighting levels are deliberately and significantly increased, the baseline power level in the previous equation can be adjusted as in Option A.

Demand

Demand savings as a result of a lighting upgrade will show up on the customer's electric meter as reduced kVA consumption. Because all of a building's lights rarely operate simultaneously, the demand reduction observed at the meter will never be the sum of the fixture power reductions. To determine the demand reduction observed at the meter, the fraction of fixtures operating when the metered peak demand is set needs to be known.

The fraction of operating fixtures is known as the *diversity factor*, which is used to calculate the demand reduction seen on the utility bill. It must be calculated for each usage group based on the estimated or measured operating hours. The following equation can be used to determine the diversity factor for each group.

$$DF_g = \frac{number\ of\ fixtures_g\ operating\ during\ the\ period\ when\ the\ building\ peak\ demand\ is\ set}{total\ number\ of\ fixtures\ in\ usage\ group\ g.}$$

The diversity factor for each group can then be used to arrive at the total demand reduction as observed at the meter. The diversity factor for each group can be determined through analysis of the monitoring data.

$$kVA_{Total} = \sum_{All\ Groups} DF_g \left[\left(QTY_{g,b}\right)\left(\frac{kW / fixture_{g,b}}{PF_{g,b}}\right) - \left(QTY_{g,n}\right)\left(\frac{kW / fixture_{g,n}}{PF_{g,n}}\right) \right]$$

where:

kVA_{Total}	Total kVA demand savings realized
DF_g	Diversity factor for group *g*
$kW / fixture_{g,b}$	Baseline lighting demand per fixture for usage group *g*
$kW / fixture_{g,n}$	Post-retrofit lighting demand per fixture for usage group *g*
$PG_{g,b}$	Baseline power factor for usage group *g*
$PG_{g,n}$	Post-retrofit power factor for usage group *g*
$QTY_{g,b}$	Quantity of baseline fixtures for usage group *g*
$QTY_{g,n}$	Quantity of affected fixtures for usage group *g*

Power factor in the baseline and post-retrofit conditions is included to reflect that peak demand is billed as maximum kVA, not kW, and that the power factor of ballasts may change as a result of an upgrade. Magnetic ballasts have power factors less than one while electronic ballasts have power factors closer to unity. This is why power measurements should be taken with a true-power meter capable of measuring both real and reactive power.

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%** add-on to lighting kWh savings to account for additional air-conditioning saving.
3. Calculate interactive effects on a site-specific basis. One simple method of estimating lighting interactive factors is outlined by Rundquist.[7]

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

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

$$Savings, Rs = (Savings, kWh)_{Peak} (Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak} (Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

Ongoing fixture data logging will verify operating hours of the installed lighting fixtures. If operating hours are similar to previous years, then savings should also be similar. The fixtures can be inspected to ensure that the lamps are the correct type and operating correctly when the data loggers are installed.

3.3 Power Factor Correction

This section describes Method PF-B-01—Measurement of Reactive Power.

ECM Definition

The power factor improvement projects covered by this verification plan include the installation of capacitors and/or filters to improve the power factor and thereby reduce the demand charges.

These projects will reduce the kVA and kVAR demand and improve the overall power factor. There are usually not significant energy savings (kWh) from a power factor improvement project. 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 maximum kVA and the corresponding billed power factor can be used to estimate the capacitance required to increase the power factor. Reactive power measurements of the affected distribution line can be used to verify power factor improvement. Method PF-B-01 is recommended where power factor correction affects only a small portion of a facility and the improvement may not be easily seen in the utility bill. Where power factor correction is expected to result in significant kVA reduction in the utility bill, an Option C approach is recommended.

Baseline Demand

Short-term monitoring of the distribution circuit being affected is necessary to establish the existing reactive power and power factor. Both real (kW) and reactive (kVAR) power need to be measured as a function of time for a period of a few weeks to determine what the average reactive demand and power factor is. If the reactive power remains constant over time, then the average reactive power can serve as the baseline. If the reactive power fluctuates but the average power factor remains relatively constant, then the average power factor can serve as the baseline.

Calculation of Demand Savings

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

Power factor correction involves adding a capacitor bank to the electrical distribution system to offset inductive loads and reduce the total reactive power seen at the meter. Reducing reactive power use reduces the kVA demand at the meter even if real power (kW) is not decreased. The relationship between real power (kW), reactive power (kVAR), and apparent power (kVA) is familiar to electrical engineers when expressed as a phasor diagram shown in the following figure.

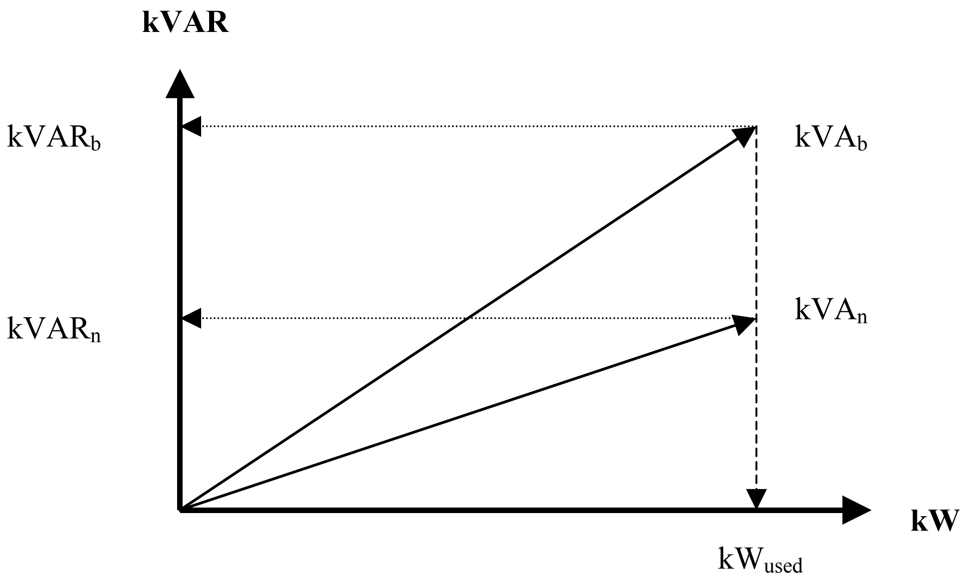

Figure 3-2 Relationship between kVA, kVAR, and kW

The horizontal axis represents the true-power demand (kW) that is necessary to perform work (e.g., operate lights, turn motors). The vertical axis is the reactive power (kVAR) resulting from inductive loads on the system (e.g., motors, fluorescent lamp ballasts). Apparent power (kVA) is represented by the hypotenuse of the resulting right triangle. Reactive power performs no useful work but does increase the magnitude of the apparent power. Reducing the reactive power reduces the apparent power and thus the billed demand.

The relationship between real, reactive, and apparent power is expressed as:

$$kVA = \left[kW^2 + kVAR^2\right]^{1/2}$$

The demand savings resulting from power factor correction is the apparent power reduction due to power factor correction.

$$kVA_{Savings} = \left[kW^2 + kVAR_b^2\right]^{1/2} - \left[kW^2 + kVAR_n^2\right]^{1/2}$$

where:

$kVA_{Savings}$	Reduction in monthly billed demand
kW	Real power demand
$kVAR_b$	Baseline reactive power demand
$kVAR_n$	New reactive power demand

Cost Savings

Electricity cost reductions result from a decrease in apparent demand (kVA). The monthly cost savings is the apparent demand reduction multiplied by the appropriate demand rate. In equation form:

$$Savings, Rs = (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

Periodic measurements (monthly) of real and reactive power will verify performance of the capacitor banks.

3.4 Constant-Load Motor Efficiency

The section describes Method CLM-B-01-Monitoring of Operating Hours.

ECM Definition

Constant-load motor efficiency projects involve the replacement of existing motors with high-efficiency motors that serve constant-load systems. Drive system changes (e.g., V-belts to toothed belts) may be included as part of the project. These measures are considered constant-load if the power draw of the motors does not vary over time. The operating hours may be variable and unpredictable. These projects reduce demand and energy use.

This M&V method is appropriate for projects where constant-load motors are replaced with efficient constant-speed motors. Additional savings can sometimes be achieved by replacing oversized motors with properly sized motors.

If motor changes are accompanied by a change in flow rate or the installation of variable-speed control, other M&V methods are more appropriate. If the baseline and new motors operate continuously, Method CLM-A-01 (described in Section 2.2 of Chapter 2) is more appropriate.

Overview of Verification Method

Method CLM-B-01 is the only specified technique for verifying constant-load motor efficiency projects. Metering is required on at least a sample of motors to determine average power draw for baseline and new motors.

This method is suitable for motors with variable operating hours that can be correlated to another parameter or for projects where the operating hours are unpredictable. Operating hours for the baseline and/or the post-installation period will be determined with short-term or long-term metering on at least a sample of the motors. The metering duration is a function of how easy or difficult it is to extrapolate the results to the rest of the year.

Pre-Installation Equipment Survey

Surveys are required to document existing motors. The surveys should include the following data for each motor:

- Location;
- Motor application;
- Operating schedule or what controls the operation (e.g., thermostat, float switch); and
- Nameplate data including: HP, voltage, running-load amps, rated efficiency, RPM.

Spot Metering of Existing and New Motors

Instantaneous measurements of three-phase amps, volts, PF, kVA, kW, and motor speed (RPM) should be recorded based on spot metering of each motor to be replaced. Power measurements should be made using a true RMS meter with an accuracy at or approaching ±**1%** of reading.

Where there is a large population of motors of similar sizes and functions, it is possible to aggregate motors into usage groups. A sample of motors rather than the entire population can be measured and the results applied to all other motors.

Because this method is intended for motors that cycle on and off, the controlling parameter should be documented and observed while the motor is being metered. Examples include thermostatically controlled fans, float-level controlled pumps for filling water tanks, etc. Understanding why the motor cycles will help understand whether motor operation will remain about the same throughout the year or change due to external influences.

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 motor 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*.

Changes in Load Factor (Slip)

Standard-efficiency motors and high-efficiency motors of the same nominal speed may rotate at slightly different rates when serving the same load, a characteristic known as *slip*. Because fan and pump power is highly dependent upon speed, small changes in motor speed may result in large changes in motor demand. For this reason, measuring the baseline motor RPM using a stroboscopic tachometer is recommended.

Considerable reductions in savings due to slip may be observed in the difference in measured demand between the existing motor and a new high-efficiency motor. The ESCO will identify motors for which the difference in measured demand between the high-efficiency motor and the baseline motor differs by more than **20%** of the expected demand reduction. These motors should be examined further to determine the possible cause of the difference and determine what corrective action might be necessary. If the actual motor speed is different from the baseline case, the drive pulleys may need to be changed to reduce fan impeller speed.

Operating Hours

The intent of this M&V approach is to monitor the operating hours of the new motor(s). In some cases, the operating hours of the baseline motor does not need to be monitored. This is the case if:

- The existing motor operates continuously and the new motor will be cycled, *or*

- Existing controls cycle both motors (motor replacement only).

In the first case, the baseline operating hours are clearly established (8,760 hrs/yr). In the second case the baseline operating hours will be the same as the new motor operating hours. If the existing controls will be replaced along with the motor such that the operating hours will change, then monitoring of the baseline operating hours is recommended.

Monitoring is intended to provide an estimate of annual equipment operating hours. The duration and timing of the installation of run-time monitoring will have a strong influence on the accuracy of operating-hours estimates. Monitoring duration should be long enough to reliably capture the motor behavior. Run-time monitoring should not be installed during significant holiday or vacation periods.

If less than continuous monitoring is used, the operating hours during the monitored period will be extrapolated to the full year. For situations in which motor operating hours might vary seasonally or according to a scheduled activity (as with HVAC systems), it may be necessary to determine operating hours during different times of the year.

Monitoring equipment can be data loggers capable of recording Amperes, or it can be data loggers that record the on/off status of a motor (event logger). Even loggers can be based on either vibration or magnetic fields. If an EMCS is installed in the facility, it can be used to monitor the motor status.

Calculation of Energy and Demand Savings

Energy

To calculate the total energy savings where the operating hours remain constant between the baseline and post-retrofit case, the following equation may be used:

$$kWh_{Total} = \sum_{All\ Motors} Hours_i \left[kW_{i,b} - kW_{i,n}\right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized
$kW_{i,b}$	Baseline motor demand for motor *i*
$kW_{i,n}$	New motor demand for motor *i*
$Hours_i$	Measured and annualized operating hours for motor *i*

To calculate the total energy savings where the operating hours are different between the baseline and the retrofit case, the following equation may be used:

$$kWh_{Total} = \sum_{All\ Motors} \left[Hours_{i,b}\, kW_{i,b} - Hours_{i,n}\, kW_{i,n}\right]$$

where:

kWh_{Total}	Kilowatt-hour savings realized.
$kW_{i,b}$	Baseline demand for motor *i*
$kW_{i,n}$	New demand for motor *i*
$Hours_{i,b}$	Baseline annualized operating hours for motor *i*
$Hours_{i,n}$	Measured annualized operating hours for motor *i*

If the facility is using a time-of-day rate, the energy savings for the peak and off-peak periods must be calculated separately. If operating hours are being measured, time-of-use (event) loggers must be used and extra data analysis will be required to separate the hours into the two periods.

Demand

Demand savings as a result of motor upgrades will show up on the customer's electric meter. Because all of a building's motors rarely operate simultaneously, the demand reduction observed at the meter will never be the predicted demand reduction obtained by summing all of the motor demand reductions. To calculate the demand reduction observed at the meter, the building load profile must be known so that the number of motors operating during the time of peak building demand can be determined. The ratio of the observed demand reduction at the utility meter to the connected load demand reduction is known as the *diversity factor,* which is defined as:

$$DF = \frac{number\ of\ motors\ operating\ during\ the\ period\ when\ the\ building\ peak\ demand\ is\ set}{total\ number\ of\ motors}$$

The diversity factor for each group can be determined through analysis of monitoring data. If monitoring results show that the motor cycles frequently (e.g., more than once per hour), then the duty cycle (**%** run time) should be used as the diversity factor.

The following equation can be used either with single motors or with motors aggregated into usage groups. For groups, consider a group as an individual motor.

$$kVA_{Total} = \sum\nolimits_{All\ Motors} DF_i \left[\left(\frac{kW_{i,b}}{PF_{i,b}} \right) - \left(\frac{kW_{i,n}}{PF_{i,n}} \right) \right]$$

where:

kVA_{Total}	Demand savings realized.
DF_i	Diversity factor for motor (or group) *i*
$kW_{i,b}$	Baseline demand for motor (or group) *i*
$kW_{i,n}$	New demand for motor (or group) *i*
$PF_{i,b}$	Baseline power factor for motor *i*
$PF_{i,n}$	New power factor for motor *i*

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak} (Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak} (Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

For motor projects where operating hours are monitored, savings can be verified through analysis of the monitoring data. Savings will depend on the measured operating schedule; unanticipated changes to the schedule may adversely affect the savings.[8]

3.5 Variable-Speed-Drive Retrofit

This section discusses Method VSD-B-01—Variable-Speed-Drive Retrofit.

ECM Definition

Variable-speed-drive[9] efficiency projects involve the installation of variable-speed- drive motor controllers where none previously existed. 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 applicable to all VSD projects. The monitoring duration is a function of how reliably the motor and drive power can be extrapolated from measured values. If there is a high degree of correlation between motor power and another parameter, then period short-term monitoring may be used. If the motor power use is difficult to correlate to any parameter (appears random), then continuous monitoring is recommended.

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).

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

[8] Timeclock pins have a habit of "disappearing" while energy management systems can be easily bypassed or reprogrammed.

[9] Also known as Variable Frequency Drives (VFD) or Adjustable Speed Drives (ASD).

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.

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. Motor location and corresponding building floor plans should be included with the survey submittal. The surveys should include the following (in a set format) for each motor:

- Nameplate data (make, model, frame, HP, RPM, volts, amps, power factor, efficiency);
- Operating schedule (daily, weekly);
- Spot and short-term metering data (kW, kVAR, kVA, RPM);
- Motor application (fan, pump, etc.); and
- Location.

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. Meters used to measure motor power need to have an accuracy of ±**1%** or better.

Measurements from motors of the same size serving similar functions can be averaged and the results extrapolated to other motors of the same size serving similar functions. Readings from different-sized motors or for motors serving different functions should not be averaged or extrapolated to non-similar functions.

For variable-speed-drive projects, baseline demand can either be constant or change with some external factor. Constant baseline demand projects are easier to determine savings. Variable baseline demand projects require characterizing the factor that affects the demand as well as the actual relationship between the factor and the demand. This relationship will be used in the retrofit case to estimate what the baseline demand would have been.

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 *typically operating* but has broken parts and is *intended for repair*.

Post-Installation Demand and Energy

Monitoring of at least a sample of variable speed drives will be performed to determine post-retrofit energy use. Most VSDs have provisions for monitoring kW, RPM, and other relevant parameters. Monitoring interval should be 15 minutes, although 30 or 60 minutes can be used if the load changes slowly.

If the baseline motor is constant load, only kW needs to be monitored. If the baseline motor loading changed with some external parameter, then that parameter and/or RPM should be monitored as well. Tracking external parameters and RPM will allow the baseline demand to be estimated from the relationship established in the baseline case.

If less than continuous monitoring is used, the data collected during the monitoring period will be extrapolated to the full year. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, 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.

Sampling

Energy service companies 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.

Equations for Calculating Energy and Demand Savings

Energy

Monitoring data consists of kW readings at some time interval such as 15 minutes or one hour. This information is evaluated to determine the energy savings for each motor and drive using the following equation:

$$kWh_{savings} = \Delta t \sum_i (kW_{b,i} - kW_{n,i})$$

where:

$kWh_{Savings}$	Total kilowatt-hour savings for each motor
$kW_{b,I}$	Baseline motor load for monitoring interval *i* (This will be a calculated value.)
$kW_{n,i}$	Measured VSD demand for monitoring interval *i*
Δt	Monitoring interval in units of hours

Since the post-retrofit energy use is being monitored, the savings depend on the baseline value. If the baseline load is constant, this value will be the measured value for the baseline motor. If the baseline load is variable, this value will be calculated from the influencing factors or from the measured RPM for each monitoring interval. The form of the baseline equation is a function of the system the VSD is serving.

Consider the following variable-speed-drive retrofit: A VSD is added to a 75 HP fan motor to replace exit vanes that currently control airflow based on hourly ventilation requirements. Short-term monitoring shows that the baseline motor demand is nearly constant and is not significantly affected by vane position. The variable speed drive replaces the vane control by changing the motor speed to meet the current ventilation requirements.

The baseline motor demand is 50 kW and the VSD kW will be monitored with hourly intervals. At the facility in question, energy is purchased on a time-of-day rate. Table 3-3 shows the measured values and the hourly savings. The sum of the savings is the daily energy savings.

Table 3-2: Load Profile and Savings

Time (Hour ending)	Baseline kW	VSD kW	kW saved	Off-Peak kW Saved	On-Peak kW Saved
0:00	50	2.66	47.34	47.34	
1:00	50	2.66	47.34	47.34	
2:00	50	2.66	47.34	47.34	
3:00	50	2.66	47.34	47.34	
4:00	50	2.66	47.34	47.34	
5:00	50	2.66	47.34	47.34	
6:00	50	2.66	47.34	47.34	
7:00	50	2.66	47.34	47.34	
8:00	50	6.12	43.88	43.88	
9:00	50	16.44	33.56	33.56	
10:00	50	35.81	14.19	14.19	
11:00	50	40.92	9.08	9.08	
12:00	50	40.92	9.08	9.08	
13:00	50	40.92	9.08	9.08	
14:00	50	43.09	6.91	6.91	
15:00	50	46.48	3.52	3.52	
16:00	50	52.50	-2.50	-2.50	
17:00	50	52.50	-2.50	-2.50	
18:00	50	46.48	3.52	3.52	
19:00	50	16.44	33.56	33.56	
20:00	50	9.29	40.71		40.71
21:00	50	4.06	45.94		45.94
22:00	50	2.66	47.34		47.34
23:00	50	2.66	47.34	47.34	
Total	**1,200**	**479**	**721**	**587**	**134**

Figure 7-3 shows the baseline and measured post-retrofit hourly demand profiles. At peak loads, demand exceeds the baseline value because VSDs add some parasitic loss to drive the system. This is to be expected and is not cause for concern — unless the system operates for significant periods at **100%** load.

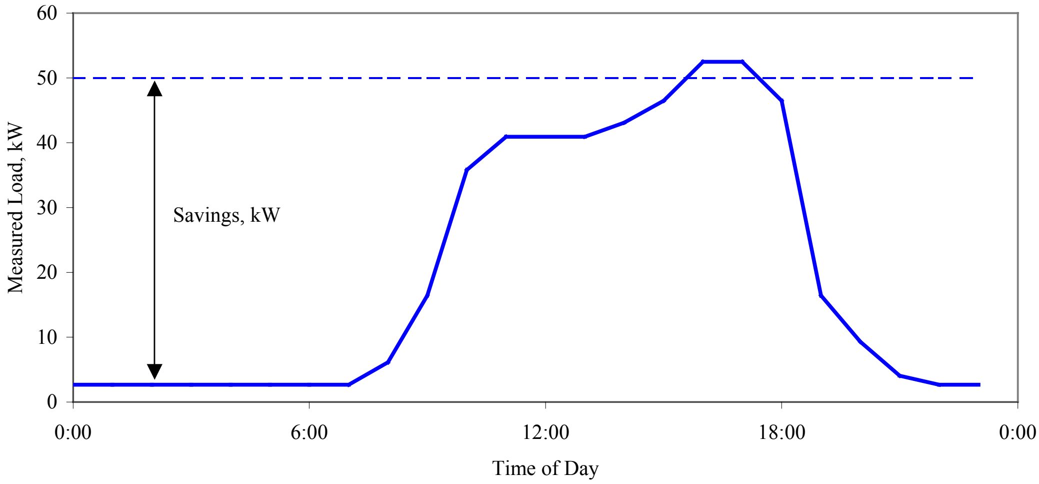

Figure 3-3 Metered Daily Post-Installation Load Profile

Demand

Variable-speed drive projects rarely exhibit demand savings. This is due to the fact that VSD controlled motors are still capable of achieving peak demand and typically do so when the building or facility demand is greatest. The peak demand seen at the meter is therefore not reduced.

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak}$$

Annual Verification Activities

Ongoing VSD power measurements will verify performance of the system. If savings deviate from expected values, a review of the metering information is warranted to determine the reason.

3.6 Boiler and Furnace Upgrades

This sections discusses Method BF-B-01 —Boiler and Furnace Upgrades.

ECM Definition

Boiler or furnace equipment upgrades involve improving the specific fuel utilization efficiency. Projects covered by this verification plan are as follows:

- Replacement of existing equipment with more energy-efficient boilers or furnaces (including replacing single units with multiple staged units);

- Installation of economizers;
- Installation of automatic controls;
- Boiler or furnace insulation to reduce shell loss;
- Water treatment / blowdown control;
- Flash steam recovery from deaeration tanks; and
- Fuel switching.

These projects reduce the rate of fuel or firewood consumption. The specific fuel consumption and/or the combustion efficiency are measured periodically or continuously.

Overview of Verification Methods

Method BF-B-01 requires periodic or continuous measurement of combustion efficiency and/or load range (fuel input or energy output). It may require tracking external parameters as well, such as production rates and quantities so that specific fuel utilization can be tracked.

Baseline Energy Use

Baseline energy use is a function of equipment performance and operating hours. Baseline performance can often be measured either directly in terms of fuel consumption per unit of output or indirectly using a combustion gas analyzer. If at all possible, these measurements should be taken across a sample of the load range to characterize the equipment. Two different approaches are provided for flexibility:

- Measuring combustion efficiency across a range of loads; and
- Measuring fuel use as a function of production.

In the first approach, the combustion efficiency across a range of loads is measured. This information will be used to establish a model of the baseline performance. This approach is useful for boilers and furnaces operating on fuel oil. However, this may not capture improvements due to blowdown control, dearator tank heat recovery, or boiler insulation as these modifications do not improve combustion efficiency.

In the second approach, efficiency is not measured but fuel utilization in terms of production is (e.g., cubic meters of firewood per 1,000 kg of tea produced or kg of fuel oil per 1,000 kg of steam produced). This approach is useful for wood-fired furnaces where automated measurement of fuel consumption is difficult or for modifications that do not improve combustion efficiency.

Post-Retrofit Energy Use

Post-retrofit efficiency and/or load range (fuel input or energy output) are monitored as they were in the baseline case. The frequency of measurement is periodic (i.e., weekly or monthly) or continuous. Combustion efficiency can be tracked by measuring flue gas temperature and oxygen content through data loggers or an EMCS. Load range (fuel input or energy output) can also be monitored through an EMCS.

Alternatively, weekly or monthly fuel use and relevant production records can be used to track fuel utilization.

Equations for Calculating Energy Savings

If boiler or furnace fuel use can be tracked through data loggers or an EMCS, fuel use and savings can be easily calculated. Baseline efficiency or specific fuel consumption needs to be known and expressed mathematically. To estimate energy savings for boiler or furnace upgrades, use the following equation if the energy *inputs* are known:

$$kJ_{Savings} = \sum [Hours_i][kJ/hr_{input,i,b} - kJ/hr_{input,i,n}]$$

or

$$L_{Savings} = \sum [Hours_i][L/hr_{input,i,b} - L/hr_{input,i,n}]$$

where:

$kJ_{Savings}$, $L_{savings}$	Realized energy savings, kJ or L (liters)
$kJ/hr_{input,i,b}$, $L/hr_{input,i,b}$	Baseline fuel consumption rate for scenario *i* (modeled)
$kJ/hr_{input,i,n}$, $L/hr_{input,i,n}$	New fuel consumption rate for scenario *i* (measured)
$Hours_i$	Hours at a particular mode of operation or output level

If energy inputs are units other than kJ or liters of fuel (e.g., kg of firewood), the equation can be modified accordingly.

To estimate energy savings for boiler or furnace upgrades, use the following equation if the energy *outputs* are known and combustion efficiency was measured:

$$kJ_{Savings} = \sum [Hours_i][kJ/hr_{output,i}]\left[\frac{1}{\eta_{b,i}} - \frac{1}{\eta_{n,i}}\right]$$

where:

$kJ_{Savings}$	Realized energy savings, kJ
$kJ/hr_{output,i}$	Energy output rate for scenario *i* (measured)
$\eta_{b,i}$	Baseline efficiency for scenario *i* (modeled)
$\eta_{n,i}$	New efficiency for scenario *i* (measured)
$Hours_i$	Hours at a particular mode of operation or output level

If output units are measured in different units (e.g., kg of steam), the equation can be modified. It may be necessary to calculate overall system efficiency from measured combustion efficiency to account for shell thermal losses.

If specific fuel utilization is used to determine performance and savings, either simple estimation of the average fuel used per unit of production or a more complex model may be used. The simplest method is to track average specific fuel utilization and compare it to the baseline case. Monthly fuel consumption would be measured in kiloJoules, liters, or cubic meters. Production might be measured in kilograms of tea or rubber, or similar units for the product in question. The energy savings are then calculated as:

$$kJ_{Savings} = (Production)\left[\left(\frac{kJ}{Unit\ of\ Production}\right)_b - \left(\frac{kJ}{Unit\ of\ Production}\right)_n\right]$$

where:

$kJ_{Savings}$	Energy savings in kJ (Can also be l, kg, or m^3)
Production	Monthly production of commodity
$(kJ / \text{Unit of Production})_b$	Baseline energy use per unit of production (Can also be l, kg, or m^3)
$(kJ / \text{Unit of Production})_n$	New energy use per unit of production (Can also be l, kg, or m^3)

In some cases, it may be more accurate to represent energy use as a single or multivariate regression model with different products or commodities and stand-by energy use included. Single-variable models would be appropriate where stand-by energy use is large. Multivariate models would be appropriate where the same system is used to make different products (or grades of products) with varying degrees of energy intensity. Examples of this type of analysis will not be presented here but can be found in standard statistics textbooks.

Cost Savings

Fuel cost reductions result from a decrease in fuel use (kJ, liters, m^3). The monthly cost savings is the monthly energy saved multiplied by the appropriate fuel unit cost. The specific energy content (lower heating value) of the fuel being saved needs to be known as well. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. Fuel cost savings are then:

$$Savings, Rs = (Savings, kJ)(Energy\ Content, kJ/l)(Unit\ Cost, Rs/l)$$

Substitute kilograms or cubic meters for liters as necessary.

Annual Verification Activities

With Option B, annual fuel use and/or efficiency measurements demonstrate continued performance. Failure to meet expected efficiency of fuel utilization rates requires investigation and corrective action.

3.7 Chiller Replacement

Two methods for chiller replacement energy savings are described in this section:

- Method CH-B-01— Metering of Chiller kW; and
- 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;
- Existing chillers replaced with those using a different energy source; and
- Changes in chiller controls that improve chiller performance.

For Method CH-B-01, the post-installation chiller energy use is periodically or continuously metered. With Method CH-B-02, the post-installation chiller energy use and the cooling load are periodically or continuously metered.

This option is not recommended for thermal-energy storage (TES) systems. TES shifts energy use and demand to off-peak periods. They save little energy but reduce costs because less expensive electricity is used to provide cooling. An Option C approach is recommended for these systems to verify actual cost reduction.

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; and
- Operating schedules.

Method CH-B-01-Energy Use Metered

Post-installation chiller energy use is continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on:

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

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

Post-installation chiller energy use and cooling loads are continuously measured or measured during set intervals throughout the term of the ESPC. Baseline energy use is based on:

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

Baseline Demand

Establishing the baseline demand involves two steps:

- Conduct a pre-installation equipment survey; and
- 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 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; and
- Equipment locations.

Baseline chiller performance can either be stipulated or measured, but measured is preferred.

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 IPLV (e.g., 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 performance is sensitive to the condenser 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; and
- 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; and
- Chilled water return temperature.

If other features of the cooling plant are also modified by the proposed measures, they will 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.

Measurements of chilled water temperatures (supply and return) should be made using meters with an accuracy at or approaching ±**2%** of reading; power and flow measurements should be made using meters with an accuracy at or approaching ±**5%**. Multiple measurements are made while the cooling system is 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

Chiller energy use and demand profile will be measured either periodically or continuously throughout the term of the contract. 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. The data collected to characterize the performance of the chiller depends on the whether the chiller's efficiency is sensitive to condenser and chilled water temperature. 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 model 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; and
- 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 condenser water supply temperature.

If other features of the cooling plant are also modified by the proposed measures, they must 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.

Measurements of chilled water temperatures (supply and return) should be made using meters with an accuracy at or approaching ±**2%** of reading; power and flow measurements should be made using meters with an accuracy at or approaching ±**5%**. Multiple measurements are made while the cooling systems are operating at different loads so the complete range of chiller performance can be evaluated. Thus, the baseline metering typically requires a time period of at least several weeks during a time when the cooling load is expected to vary over a wide range; often, more time is required.

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:

- Pre-installation metering of cooling loads by the ESCO or customer
- 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); and
- 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

Energy

Calculating the energy and demand savings from the metered data involves comparing the existing chiller performance to the estimated baseline performance. In general, energy savings are the sum of the hourly differences between baseline and new chiller performances:

$$kWh_{Savings} = \sum \left[kW_{b,i} - kW_{n,i} \right]$$

In both CH-B-01 and CH-B-02, new chiller power ($kW_{n,i}$) is measured for every hour *i*. The difference between the two methods is how baseline chiller demand ($kW_{b,i}$) is estimated. In Method CH-B-01, only the new chiller power consumption is monitored. The measured demand is used to estimate the cooling load of the new chiller; this estimated cooling load is then used to estimate the baseline demand of the original chiller:

$$kW_{b,i} = f(Cooling\ Load_i)\ where\ (Cooling\ Load_i) = g(kW_n)$$

The baseline demand for hour *i* is therefore dependent on the accuracy of two models — one for the baseline chiller (*f*) and one for the new chiller (*g*). Both functions *f* and *g* are typically complex multivariate polynomials, although some values may be stipulated for simplicity (e.g., condenser water temperature).

Method CH-B-02 eliminates the characterization of the new chiller by measuring the cooling load directly. This eliminates the uncertainty introduced by model *g* but increases the measurement complexity and cost required. The baseline chiller demand ($kW_{b,i}$) is then:

$$kW_{b,i} = f(\dot{m}, T_{CHWR}, T_{CHWS}, T_{CWR})$$

where:

$kW_{b,i}$	Estimated demand of baseline chiller at hour *i*
$f(m, T_{CHWR}, T_{CHWS}, T_{CWR})$	A complex function of four variables
m	Chilled water flow rate
T_{CHWR}	Chilled water return temperature (from building)
T_{CHWS}	Chilled water supply temperature (to building)
T_{CWR}	Condenser water return temperature (from tower)

There are many forms of the function *f* that defines chiller demand. These can be located in references published by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and the Air-Conditioning and Refrigeration Institute.

If the function *f* can be defined solely by load (e.g., performance = 0.7 kW/ton), load can be calculated from measured flow and temperature as:

$$Load_i = (1.189)(T_{CHWS,i} - T_{CHWR,i})(\dot{m}_i)$$

where:

$Load_i$	Chiller load in tons (12,000 BTU/hr) for hour *i*
m_i	Chilled water flow rate for hour *i*, l/s
$T_{CHWR,i}$	Chilled water return temperature for hour *i*, ^oC
$T_{CHWS,i}$	Chilled water supply temperature for hour *i*, ^oC

Load is calculated in the American units of tons cooling (12,000 BTU/hr) because chiller performance and chiller equations are often expressed as tons.

Demand

Chiller demand is often the dominant electrical demand in many buildings. Therefore, reducing chiller demand results in a direct decrease in utility demand. The demand reduction seen at the meter is typically the chiller demand reduction when chiller load or demand is greatest:

$$kVA_{Savings} = \text{Max}\left[\frac{kW_{b,i}}{PF_b} - \frac{kW_{n,i}}{PF_n}\right]$$

where:

$kVA_{Savings}$	Reduction in monthly billed demand
PF_b, PF_n	Power factor of the different chillers at full load
Max	The maximum value function applied to the whole month
$kW_{b,i}$	Baseline chiller load at hour *i*
$kW_{n,i}$	New chiller load at hour *i*

Measurement Considerations

Characterizing chiller performance is neither trivial nor inexpensive. Power measurements between 100 and 1,000 kW need to be made on a continuous basis; water flow should be measured with a non-intrusive (i.e., ultrasonic) flow meter; temperatures need to be measured with great precision (±**2%** or better). Measurements need to be made hourly, which requires data collection equipment. This equipment is costly and requires periodic calibration.

The advantage of direct measurement is the reduced uncertainty in the savings calculations and the assured long-term performance of the chiller project. This information can be used for troubleshooting and diagnostics as well. Equipment costs may be reduced if the data collection is performed by an existing EMCS.

The decision to use either of the Option B approaches or an Option A approach is a function of the expected savings, the measurement cost, and the customer's risk tolerance. Typically, the larger the chiller, the greater the savings and the greater the risk.

Cost Savings

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

With either of the Option B methods, annual measurements will demonstrate the continued performance of the new chiller.

3.8 Heat Recovery Applications

This section describes Method HR-B-01—Heat Recovery Applications.

ECM Definition

A heat recovery system installation or upgrade recovers heat (or cold) from a process or effluent stream that would otherwise be lost. Recovering heat (or cold) reduces the heating or cooling energy required for the process stream. Projects covered by this verification plan include:

- Recovering heat from a process effluent stream;
- Recovering heat (or cool) from an exhaust air stream; and
- Exchange of heat between process streams.

These projects reduce energy demand either in terms of fuel use and/or electrical power required. Temperatures of relevant process streams are measured and engineering equations used to calculate the heat recovered. Continuous monitoring allows verification of long-term performance that would not be revealed if measurements were not made.

Overview of Verification Methods

Method HR-B-01 requires periodic or continuous temperature measurements at baseline and post-installation conditions. For most accurate results, flow needs to be measured as well. An energy or enthalpy balance needs to be performed to determine the heat recovered in the baseline case (if heat recovery exists at all) and in the post-retrofit case.

Calculation of Demand and Energy Savings

Baseline and Post-Retrofit Energy Use

Baseline and post-installation performances are based on measured temperatures and flows (and relative humidity if applicable). The throughput pattern in the pre- and post-retrofit periods and the hours of operation are measured. The relevant temperatures are the input and output temperatures across the heat (cool) recovery system. This recovered energy directly displaces heating or cooling energy from the primary source.

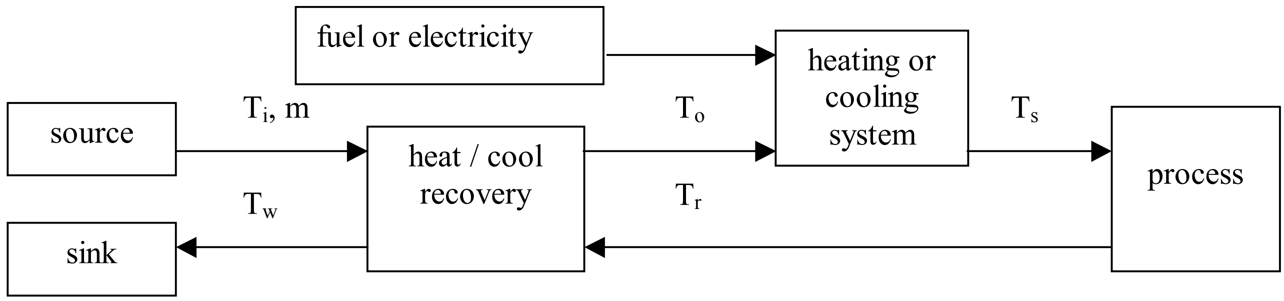

Figure 3-4: Heat and Cool Recovery System

Equations for Calculating Energy and Demand Savings

Energy

If an energy-recovery system is being installed where none previously existed, the savings are the total energy captured by the system. If an existing system is being upgraded or improved, the savings are the incremental energy captured by the new system relative to the old.

The effectiveness *e* of the heat recovery system can be defined as the fraction of available energy recovered. Assuming that the mass flow on the supply and return sides are identical, the effectiveness of the heat recovery system can be defined as:

$$e = \frac{T_i - T_o}{T_i - T_r} = \frac{\text{recovered energy}}{\text{available energy}}$$

where:

T_i	Temperature of input stream
T_o	Temperature of output stream
T_r	Temperature of return stream

Over time, the effectiveness of a heat recovery system may degrade due to scaling or fouling of the heat exchange surface. As the effectiveness decreases, the recovered energy decreases.

For all energy recovery systems, the efficiency of the heating plant or the performance of the cooling plant needs to be taken into account. Since it is often difficult or impossible to know the specific efficiency or performance of heating and cooling systems at specific times, the average efficiency or performance should be used instead.

Using this Option B method, it is expected that temperatures of the supply and return stream will be monitored continuously in time intervals relevant to the process. If the process flow rate is constant, it should be measured once. If the process flow rate varies, it should be measured along with temperature. For heat recovery applications where a boiler or furnace acts as the heating source, use the following equation:

$$kJ_{Saved} = \sum \frac{\Delta t \dot{m} c_p (T_o - T_i)}{\eta}$$

where:

kJ_{Saved}	Total reduction in thermal energy use
Δt	Time interval of measurement (e.g., one hour)
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg ^oC
T_o, T_i	Measured supply and return temperatures of stream, ^oC
η	Average heating system efficiency

If an existing heat recovery system is being upgraded, the previous equation needs to be modified to account for the increase in heat recovery. In this situation, the output temperature T_o is expected to be greater than in the baseline case. Comparing a new heat recovery system to the old reduces to the following:

$$kJ_{Saved} = \frac{\Delta t \dot{m} c_p (T_{o,n} - T_{o,b})}{\eta}$$

where:

kJ_{Saved}	Total reduction in thermal energy use
Δt	Time interval of measurement (e.g., one hour)
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg ^oC
$T_{o,b}$	Measured baseline supply temperatures of stream, ^oC
$T_{o,b}$	Measured new supply temperatures of stream, ^oC
η	Average heating system efficiency

The savings in kiloJoules need to be converted to units of fuel. To do this, the specific energy content (lower heating value) of the fuel being saved needs to be known. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. If electric heat is being displaced, the conversion factor is 3,600 kJ per kWh.

For applications where cooling energy is being displaced, use the following equation:

$$kWh_{Saved} = \sum \frac{\Delta t \dot{m} c_p (T_i - T_o)}{3{,}600\ COP} = \sum \frac{\Delta t \dot{m} c_p (T_i - T_o)}{12{,}648} (kW / ton)$$

where:

kWh_{Saved}	Total reduction in electrical chiller energy use
Δt	Time interval of measurement (e.g., one hour)
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg °C
T_o, T_i	Measured supply and return temperatures of stream, °C
COP	Average chiller coefficient of performance (dimensionless)
kW/ton	Average chiller performance, kW per ton (12,000 BTU/h) of cooling provided.

The previous equation assumes that an electric-driven chiller is being used to provide cooling. The equation is given in two forms depending on what chiller information is available: COP and kW/ton (common units for American-made chillers).

Demand

Demand savings are applicable only to electric cooling applications. Demand savings are equivalent to the maximum demand reduction available, provided that the demand reduction occurs at a time coincident with the building or facility peak demand.

$$kVA_{Saved} = \frac{1}{PF}\,\mathrm{Max}\left[\frac{\dot{m}c_p(T_i - T_o)}{3{,}600\,COP}\right] = \frac{1}{PF}\,\mathrm{Max}\left[\frac{\dot{m}c_p(T_i - T_o)}{12{,}648}\left(kW/ton\right)\right]$$

where:

kVA_{Saved}	Monthly demand reduction
m	Mass flow rate of stream where energy is being recovered, kg/hr
c_p	Specific heat of stream, kJ/kg °C
T_o, T_i	Measured supply and return temperatures of stream, °C
COP	Average chiller coefficient of performance (dimensionless)
kW/ton	Average chiller performance, kW per ton (12,000 BTU/h) of cooling provided
PF	Chiller power factor at full load

Cost Savings

Fuel cost reductions result from a decrease in fuel use (kJ, liters, m^3). The monthly cost savings is the monthly energy saved multiplied by the appropriate fuel unit cost. The specific energy content (lower heating value) of the fuel being saved needs to be known as well. For example, light fuel oil has an approximate specific energy content of 40,000 kJ/l. Fuel cost savings are then:

$$Savings, Rs = (Savings, kJ)(Energy\ Content, kJ/l)(Unit\ Cost, Rs/l)$$

Substitute kilograms or cubic meters for liters as necessary.

Electricity cost reductions result from a decrease in energy use (kWh) and a reduction in peak demand (kVA). For flat rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate plus the demand reduction multiplied by the appropriate demand rate. For time-of-day rates, energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. In equation form,

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs / kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs / kWh)_{Off-Peak} + (Demand\ Savings, kVA)(Demand\ Charge, Rs / kVA)$$

Annual Verification Activities

With this Option B method, annual measurements will demonstrate the continued performance of the new system. Periodic calibration of temperature and flow sensors should be performed to ensure the validity of the measurements. Changes in the temperature difference across the heat recovery system will indicate problems that need to be addressed.

3.9 Control System Upgrades

This section described CS-B-01—Measured Performance and Measured Hours for Different Load Conditions.

ECM Definition

Automated controls are used in both building and industrial applications to control temperatures, flows, and equipment operations. Adding, repairing, or upgrading controls systems to buildings and plants has the potential to decrease energy use while improving the performance (e.g., comfort, throughput) of the building or plant. Modern EMCS also have the ability to record measurements for later analysis. This M&V method is applicable to any EMCS addition or upgrade provided that the EMCS can record and store data for later use.

Overview of Verification Methods

Determining the performance of and savings from an EMCS requires establishing what parameters are to be affected and how they will influence energy use. There is no single defining equation that can be used to characterize an EMCS; the defining equations are derived from an engineering analysis of the affected systems. Data collected from the EMCS will serve as an input to the savings calculations.

Calculation of Demand and Energy Savings

Baseline Energy Use

In the pre-installation equipment survey, the equipment to be changed and the replacement equipment to be installed are inventoried. Schematic diagrams of the affected systems are developed to help understand how the EMCS will affect the energy-using systems. Relevant static and dynamic parameters (e.g., space or process temperature, air or water flow rates) and equipment performance (e.g., boiler efficiency, chiller kW/ton) are measured or estimated. This information is used to develop mathematical models that describe energy and will serve as the baseline scenario.

Post-Retrofit Energy Use

Performance of installed or upgraded equipment (e.g., boiler efficiency, chiller kW/ton) is measured to verify performance. The EMCS will record relevant static and dynamic parameters (e.g., space or process temperature, air or water flow rates). This information will be used in conjunction with the baseline models to determine performance and energy savings.

Equations for Calculating Energy Savings

Energy savings (both electrical and fuel) are determined by comparing current energy use to the baseline model for every hour of recorded data. Summing the hourly savings over the relevant period (daily, monthly or annually) will provide the total savings.

$$kWh_{Savings} = \sum \left[kW_{b,i} - kW_{n,i} \right]$$

and

$$kJ_{Savings} = \sum \left[kJ_{b,i} - kJ_{n,i} \right]$$

where:

$kWh_{Savings}$	Total electrical energy savings
$kW_{b,I}$	Baseline demand for hour *i*, estimated
$kW_{n,I}$	New demand for hour *i,* measured
$kJ_{Savings}$	Total fuel energy savings (could also be l,kg, m^3)
$kJ_{b,I}$	Baseline energy use for hour *i,* estimated (could also be l,kg, m^3)
$kJ_{n,I}$	New energy use for hour *i,* measured (could also be l,kg, m^3)

Cost Savings

Electricity cost reductions result from a decrease in electrical energy (kWh) and fuel (kJ) use. For flat electrical rates, the monthly cost savings is the monthly energy saved multiplied by the appropriate rate. For time-of-day rates, electrical energy savings must be divided into peak and off-peak periods and the energy savings for each period multiplied by the appropriate rate. Fuel cost savings are added to the electrical energy savings. In equation form:

$$Savings, Rs = (Savings, kWh)(Unit\ Cost, Rs / kWh) + (Fuel\ Savings, kJ)(Fuel\ Unit\ Cost, Rs / kJ)$$

or

$$Savings, Rs = (Savings, kWh)_{Peak}(Unit\ Cost, Rs/kWh)_{Peak} + (Savings, kWh)_{Off-Peak}(Unit\ Cost, Rs/kWh)_{Off-Peak} + (Fuel\ Savings, kJ)(Fuel\ Unit\ Cost, Rs/kJ)$$

Annual Verification Activities

With this Option B method, annual measurements will demonstrate the continued performance of the new system. Periodic calibration of temperature and flow sensors should be performed to ensure the validity of the measurements.

Option C approaches use regression models and utility billing data (e.g., kWh, kVA, l, kg, and m3) to calculate annual energy savings. In general, Option C can be used with complex equipment replacement and controls projects for which predicted savings are relatively large—i.e., greater than **10-20%** of the site's energy use, on a monthly basis. Option C can also be used for power factor correction projects where kVA reduction is expected to be **10-20%** of current kVA demand.

Utility bill analysis using regression models is applicable for measurement and verification when project effects 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 greater than **10-20%** of the monthly utility bill;
- There is a high degree of interaction between measures;
- 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;
- Power factor correction is implemented; and
- Other approaches are too expensive.

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; and

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

Energy consumption under Option C is calculated by developing statistically representative models of whole-facility energy consumption (i.e., kWh, l, m^3). The types of models depend on the number of independent variables that affect energy use and the complexity of the interrelationships. The types of models that may be used include:

- One-parameter models;
- Two-parameter models;
- Change-point models; and
- Multivariate models.

The best model is one that is simple and yet produces accurate and repeatable savings estimates. Finding the best model often requires testing 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.

Three approaches to calculating savings can be used:

- Defining a baseline model using regression analysis and comparing it to actual post-installation meter readings;
- Proposing separate models that define baseline and post-retrofit energy use with savings equal to the difference between the two; and

- Generating a single "savings" model that includes both baseline and post-installation factors.

Baseline Energy Consumption

Regression analysis requires information that spans the full range of normal values for the independent variables. For weather-dependent measures, 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 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; creating extra utility billing data points is generally not acceptable.

Post-Retrofit Energy Consumption (First Year)

Regression analysis requires at least 9, and preferably 12, months of data collected after the date of installation to determine energy use for the first year.

Post-Retrofit Energy Consumption (Second and Subsequent Years)

The billing analysis models should be updated until at least 18 to 24 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.

Outliers

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). However, the elimination of outliers must be explained; it is not sufficient to eliminate a data point simply because it is beyond the expected range of values. Data points found to be abnormal because of specific mitigating factors 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 Method

Multivariate regression is an effective technique that controls for 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 energy use.

Using 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(s) 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 energy use and savings. For example, with hourly data, it should be possible to estimate savings 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.

The standard form of a monthly weather-dependent multivariate regression model is:

$$Q_i = B_1 + B_2(T_i \;\; T_{i\text{-}1}) + B_3HDD_i + B_4CDD_i + B_5X_i + B_6Y_i + B_7Z_i \ldots$$

where:

Q_i	Energy use in relevant units for month *i*
i	Month
B_n	Coefficients
T_i	Average temperature for month *i*
HDD_i	Heating degree-days for month *i*
CDD_i	Cooling degree-days for month *i*
X_i, Y_i, Z_i	Other explanatory variables for month *i*

Number and Type of Explanatory Variables

A list of explanatory variables that affect energy consumption as well as any interactive terms (i.e., combination of variables) needs to be specified. The most common variable is outdoor temperature for many measures. Other examples of variables are building occupancy, commodity production, and time of day.

The amount of data available directly affects the number of coefficients that the model can contain. It is impossible to develop a model with more coefficients than the number of observations available. In general, a minimum of three to four observations are need for each coefficient desired. If only a year's worth of monthly data is available, that limits the number of model coefficients to three or four. In practice, it may take six or more observations per coefficient to develop a statistically valid model.

Model Limits

Models are generally valid only for the range of independent variables that are used to determine the regression model. For example, if a regression model was developed using ambient temperature data between 25° and 35° C, the model should be used only for that range. If a situation arises in which energy use or savings must be calculated when the ambient temperature is 40 °C the model may or may not be valid. Model limits should always be specified in conjunction with a definition of the regression model(s).

Independent Variable Ranges

It is important that the data collected on each independent variable span as large a range as possible. For example, if production during the 24 months before a retrofit varied only between **65%** and **75%**, the model coefficient for production will not be very meaningful. Not until production varies significantly from **65%** or **75%** will it become apparent that the model cannot account for such a variation. As a rule of thumb, a prospective independent variable should span a range of at least 2 to 1, i.e., its highest value should be at least twice the lowest value for the related coefficient to be reliable.

Weather Data

If the energy-savings model incorporates weather in the form of heating degree-days and cooling degree-days, the following issues should be considered:

- The building temperature balance point should be used in defining degree days rather than an arbitrary degree day temperature base; and.
- The relationship between temperature and energy use that tends to vary depending upon the time of year.

For example, a temperature of 25°C in January has a different implication for energy usage than the same temperature in August. Thus, seasonality should be addressed in the model. Given the relatively constant climate in Sri Lanka, temperature-related variables may not be the only consideration.

Relationships Between Variables

Independent variables must be truly independent of each other for regression models to be reliable. Lack of independence is referred to as auto-colinearity. Adding variables that are not independent can result in no new information in the model and unstable results, if the standard statistical T-test (see below) does not indicate a problem.

Testing Statistical Validity of Model(s)

To be statistically valid, the final regression model will need to meet the following requirements:

- 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, i.e., the model limits (range of independent variables for which the model is valid) are reasonable.
- 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 is tested for possible statistical problems (e.g., auto-colinearity), and if they are found, appropriate statistical techniques are used to correct for them.
- All data input to the model are thoroughly documented, and model limits are specified.

In addition to these tests, the Standard Error of the Estimate (SEE) needs to be compared to the expected values. If the SEE exceeds the expected savings, the model is unusable.

Calculating Savings

The details of the savings calculations are dependent on:

- The use of hourly versus monthly utility meter billing data;
- The format of the data (e.g., corresponding to the same time interval as the billing data) and availability of *all* relevant data for explanatory variables;
- The amount of available energy consumption data; and
- Whether actual or typical data are used to calculate savings

Project-Specific M&V Issues

When Option C is used, the project-specific M&V plan must address the following in addition to other topics generic to all M&V methods:

- The model type and format that will be used to define baseline, and, possibly, post-installation energy use as well as energy savings;
- The explanatory (independent) variables that will be evaluated for inclusion in the model(s) and what the expected limits for these variables are;
- The source and time frame of data that will be used to determine model coefficients;
- The statistical tests that will be used to test the validity of the models;
- The baseline modifications that the model(s) will capture and the frequency in which the model(s) will be updated; and
- The manner in which outlier data will be identified and treated.

Chapter 5: Computer Simulations-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 it 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:

- Document the strategy for calculating savings in the site-specific M&V plan;
- Collect required data from Electricity Board bill records, architectural drawings, site surveys, and 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; and
- Refine the existing model until the program's output is within acceptable tolerances of the measured data.

Those interested in obtaining more information are encouraged to obtain Guideline 14 from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Guideline 14 can be purchased for US$ 74 from:

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
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As of this writing, the IPMVP New Construction Guidelines have not been formally adopted or published. A draft copy may be downloaded from http://www.ipmvp.org. For more information, contact Satish Kumar at skumar@lbl.gov or +1-202-646-7953.

Appendix A: Ceylon Electricity Board Tariff[10]

Table A-1: Residential Tariff

Domestic	Units (kWh)	Unit Charge, Rs/kWh
Fixed Charge	month	30.00
Block 1	0-30	3.00
Block 2	31-60	3.70
Block 3	61-90	4.10
Block 4	91-180	10.60
Block 5	greater than 180	15.80

Table A-2: Religious Purpose Tariff

Religious	Units (kWh)	Unit Charge, Rs/kWh
Fixed Charge	month	30.00
Block 1	0-30	2.50
Block 2	31-90	2.70
Block 3	91-180	4.00
Block 4	greater than 180	7.20

Table A-3: Street Lighting

Street Lighting	Rs. 7.80/kWh

Table A-4: Small Commercial and Industrial Use

Supply at 400/230 V Contract Demand < 42 kVA	General Purpose	Industrial	Industrial, Time-of-Day	Hotel	Hotel, Time-of-Day
Unit Charge (Rs/kWh)	10.90	7.50		10.90	
Unit Charge, Peak, (Rs/kWh)			15.00		
Unit Charge, Off-Peak, (Rs/kWh)			6.90		
Fixed Charge (Rs/kVA/month)					
≤ 10 kVA	30.00	30.00	30.00	30.00	
> 10 kVA	230.00	230.00	230.00	230.00	

[10] Effective August 1, 2002.

Table A-5: Medium Commercial and Industrial Use

Supply at 400/230 V **Contract Demand ≥ 42 kVA**	**General Purpose**	**Industrial**	**Industrial, Time-of-Day**	**Hotel**	**Hotel, Time-of-Day**
Unit Charge (Rs/kWh)	10.80	7.10		7.10	
Unit Charge, Peak, (Rs/kWh)			14.70		14.70
Unit Charge, Off-Peak, (Rs/kWh)			6.50		6.50
Demand Charge (Rs/kVA)	480.00	400.00	380.00	400.00	380.00
Fixed Charge (Rs/month)	800.00	800.00	800.00	800.00	800.00

Table A-6: Large Commercial and Industrial Use

Supply at 11/33/132 kV	**General Purpose**	**Industrial**	**Industrial, Time-of-Day**	**Hotel**	**Hotel, Time-of-Day**
Unit Charge (Rs/kWh)	10.70	7.00		7.00	
Unit Charge, Peak, (Rs/kWh)			14.00		14.00
Unit Charge, Off-Peak, (Rs/kWh)			6.10		6.10
Demand Charge (Rs/kVA)	460.00	380.00	360.00	380.00	360.00
Fixed Charge (Rs/month)	800.00	800.00	800.00	800.00	800.00

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