Appendix G

Measurement and Verification

Follow these guidelines to prepare an M&V plan for efficiency measures conducted under the Measured Savings approach.

1. Developing an M&V Plan

This section defines SPC/NRR-DR requirements for creating a measurement and verification (M&V) plan to quantify the energy savings and the peak electrical demand reduction resulting from your project's energy efficiency measures. Use this document as a guide in developing measure-specific M&V plans.

Calculated Savings projects do not require full measurement and verification as described in this manual. However, short-term and spot measurements such as described in IPMVP Option A. may be required. **The M&V procedures in this section apply to the Measured Savings approach.** For a general discussion of SPC/NRR-DR options and requirements pertaining to M&V, refer to Sections 1.10 and 1.12 of the *SPC/NRR-DR Procedures Manual.*

1.1 Utility Approval

A measure-specific M&V plan must demonstrate that any metering and analysis will be done in a consistent and logical manner and with a level of accuracy acceptable to all parties. The plan must be submitted by the Project Sponsor as part of the project application and approved by the Utility Administrator prior to the commencement of any M&V activities. Final resolution of M&V and program design issues is left to the discretion of the Utility Administrator.

1.2 Follow 2007 IPMVP

M&V procedures for the SPC/NRR-DR program generally derive from the 2009 International Performance Measurement and Verification Protocol (IPMVP). The IPMVP offers four main options:

- **Option A—Measurement of Key Parameters.** Predicts savings using short-term or continuous measurements of the key operating parameter(s) along with estimated values. Key performance parameters are defined as the factors that affect the energy use of the ECM's system(s) and/or the project's success. Estimated parameters can be based on manufacturer's specifications, historical data, or engineering judgment; however, backup documentation and/or justification of the estimated parameter(s) is required. **This option does not meet the requirements for a Measured Savings project.**
- **Option B—Metered Savings of Equipment or Systems.** Involves short-term or continuous metering of the baseline and reporting periods to determine energy consumption. Measurements are usually taken at the device or system level. This option is preferred for SPC/NRR-DR M&V plans because savings are determined for each efficiency measure. (Because incentive pricing is differentiated by measure category—lighting, HVAC&R, other equipment, and gas—it is important to know how much energy was saved by each category of measure.)
- **Option C—Whole Facility Analysis Using Regression Models.** Involves (1) comparing monthly billing data recorded by a utility meter or sub-meters for the whole facility or sub-facility level, before and after project installation, and (2) analyzing the data to account for any variables, such as weather or occupancy levels. Energy savings can be determined once the variables are recognized and adjusted to match pre-installation conditions.
- **Option D—Computer Simulation.** Involves using software to create a simulated model of a building based on blueprints and site surveys. The model is calibrated by comparing it with end-use monitoring data or billing data. Models of the project are constructed for (1) the existing base case, (2) a base case complying with minimum standards, and (3) a case with the energy measures installed.

Again, only Options B, C and D meet SPC/NRR-DR program requirements, and Option B is preferred.

The remainder of this section offers guidance on creating M&V plans for different types of energy efficiency retrofits, using one or more of Options B, C, or D. Please note that if there is a conflict between the IPMVP and these guidelines, these guidelines take precedence. Should there be a conflict between these guidelines and the SPC/NRR-DR Agreement executed by the Project Sponsor and Utility Administrator, and then the SPC/NRR-DR Agreement will take precedence.

1.3 Supporting Documentation

The 2009 Measured Savings approach is identical to the M&V approach used in the 2001 SPC/NRR-DR program. M&V templates, equipment survey forms, and other M&V materials are detailed below. The exact title of the materials may differ among the utility websites, but the content is the same at all three.

2009 SPC/NRR-DR Manual, Appendix G: Measurement and Verification Requirements
Manual section describing the M&V requirements for the 2009 SPC/NRR-DR program; this is similar to Section 3 of the 2001 manual.

Appendix B: Sample Lighting Table Form (Excel Form)
Contains the lighting equipment survey table in Excel format. Can use workbook to document existing and proposed lighting equipment as well as calculate lighting savings.

These 2009 SPC/NRR-DR program materials are available on the utilities' SPC/NRR-DR websites at the following addresses:

PG&E: http://www.pge.com/mybusiness/energysavingsrebates/

SCE: http://www.sce.com/spc

SDG&E: http://www.sdge.com/business/esc/

2. Lighting Efficiency and Controls

Option B, Method LE-B-01: Monitoring Operating Hours

2.1 Introduction and Key Issues

This section discusses M&V methods for projects that involve the replacement of lighting fixtures or the installation of lighting controls. The projects covered by this M&V method include:

- All replacements of fixtures, lamps, or ballasts with new fixtures, lamps, or ballasts that are more energy efficient
- De-lamping with the use of reflectors
- Installation of control devices on lighting fixtures to reduce the operating hours of the fixtures

Method LE-B-01, presented in this section, is the preferred M&V method for all projects with 70% or more of the direct energy savings resulting from lighting efficiency and controls retrofit measures.

This section offers background on the lighting M&V requirements of the SPC/NRR-DR program and instructions for completing the standard lighting M&V plan (Form L1) to be submitted with the SPC/NRR-DR Application. The following key issues should be noted:

- A lighting audit is required both before and after installation. The audit should identify all fixtures, lamps and ballasts by area.
- The basis for the fixture wattages shall be documented. Fixture wattages from the Table of Standard Fixture Wattages (Appendix B) is the recommended method.
- Monitoring of operating hours of a sample of the fixtures is required.
- Pre- and post- retrofit operating hours are assumed identical for lighting efficiency measures (non-control projects).
- Lighting control measures require both pre- and post-installation monitoring for hours of operation.

A standard lighting M&V plan (Form L1) is included on page G-7. The standard M&V plan, along with the standard lighting audit form (included in Appendix B) provide all the required information for the Utility Administrator's review of a lighting project. While Form L1 and the Lighting Equipment Survey Table are not required, their use is highly encouraged. Many of the savings calculations and the sample selection process have been automated with the use of these forms. This section was written from the viewpoint that the Project Sponsor will use Forms L1 and the Lighting Equipment Survey Table.

If a Project Sponsor wishes to submit an M&V plan or lighting audit that does not use the standard forms, the Project Sponsor must ensure that all of the information in the standard forms is included in the submittal. Providing incomplete information is grounds for the rejection of a submittal.

2.2 Overview of Verification Method

Project Sponsors are required to submit audits of existing (baseline) and proposed (post-installation) fixtures. It is recommended that all fixture wattages in the lighting audits come from the Table of Standard Fixture Wattages provided by the Utility Administrator, or for fixtures that do not appear in the table, from power measurements. Lighting audits may be submitted in one of two formats:

- Using the standard lighting audit form, which contains all the audit information required for this program. Appendix B contains a copy of the Lighting Equipment Survey Table, and an electronic version of this Excel spreadsheet is available on utility websites.
- In a different format, which contains all the information required for this program

2.2.1 Using the Table of Standard Fixture Wattages (Appendix B)

The Table of Standard Fixture Wattages provides codes and wattages for both the pre- and post- installation fixtures. The wattages are an average of many different manufacturers' wattages for each fixture as determined by independent testing laboratories. All fixture wattages in this table meet or exceed minimum federal and state energy efficiency standards. Fixtures that do not meet the minimum efficiency standards do not appear in the table. Some common fixtures that are not eligible under the program are fixtures with 40 W, T-12 lamps, standard magnetic ballasts, and all new fixtures which do not require the use of a tool for removal such as screw-in compact fluorescent fixtures.

If an existing fixture is below the minimum federal and state standards, and therefore not in the Table of Standard Fixture Wattages, a fixture code and wattage for a fixture that is the closest match to the actual fixture should be selected. As an example, assume that a building has existing fixtures with energy saver ballasts and 40 W, T-12 (standard) lamps. The closest fixture code in the Table of Standard Fixture Wattages that represents the same fixture and ballast combination would be a fixture with energy saver ballasts and 34 W, T-12 (energy saver) lamps.

If a fixture is encountered that meets the minimum efficiency requirements but does not appear in the Table, the Project Sponsor must either:

- Complete the Lighting Equipment Survey Table (see Appendix B for a copy of this form) and provide a documented source such as manufacturer's specifications of the fixture wattages for approval by Utility Administrator; or
- Take wattage measurements of a minimum of six fixtures and submit the measurements to the Utility Administrator for approval. The Utility Administrator will then assign a fixture code and wattage for the fixture. New fixture codes and wattages should never be assigned without Utility Administrator approval.

2.2.2 Metering Fixture Wattage

To measure the energy use of a fixture that does not appear in the Table of Standard Fixture Wattages but meets the minimum efficiency requirements, use the following metering protocol:

- Take a 15-minute average, true RMS (root mean squared) wattage measurement from at least six identical fixtures of the type to quantify
- Average all readings to determine the per-fixture wattage values.

Readings must be taken on fixtures that have been operating for at least 100 hours. The meters used for this task must be calibrated and have an accuracy of ±3% or better.

2.2.3 Lighting Audits

An audit of the fixtures that will be retrofitted must be submitted for review and approval with the project application. After installation, an audit of the retrofitted fixtures must be submitted for review and approval in the Installation Report. These audits are the basis of the demand savings for the project. Monitoring of operating hours allows the calculation of energy savings for the project.

The Utility Administrator has provided a Lighting Equipment Survey Table, (Appendix B or Utility web site for electronic version), which lists all the information required for the audit. The use of these forms is encouraged as it simplifies the inspection and evaluation of a project by the Utility Administrator. However, the Utility Administrators recognize that lighting audits are often performed using other formats prior to submitting information for this program. A lighting audit in another format may be submitted if it contains all the information listed in the Lighting Equipment Survey Table.

While all of the information in the Lighting Equipment Survey Table is generally required in a lighting audit, a Project Sponsor may ask the Utility Administrator for permission to omit certain fields from their lighting audit if the information is not applicable to the project. Such a request must be made prior to submitting the Project Application, and the Project Sponsor must submit a sample of the lighting audit for review. A circumstance where this would be acceptable would be omitting the “Pre Operating Hours” and “Controls kWh Saved” information when lighting controls are not being installed on a project.

Lighting audits may be submitted with fixture codes that do not match the fixture codes from the Table of Standard Fixture Wattages. However, all fixture wattages must come from the Table of Standard Fixture Wattages. If a Project Sponsor submits an audit with fixture codes that do not match those in the Table of Standard Fixture Wattages, the Project Sponsor must also submit a look-up table which shows each fixture code in the audit and the corresponding fixture codes in the Table of Standard Fixture Wattages. The Utility Administrator will verify that the fixture types are the same during the pre- and post-installation inspections.

2.2.4 Non-Operating Fixtures

Prior to installing new lighting fixtures, adjustments may need to be made to the baseline demand to account for non-operating fixtures. In addition, adjustments to baseline demand may be required after energy efficiency measure (EEM) installation because of remodeling or changes in occupancy. Any adjustments should be clearly identified on a separate sheet and attached to the M&V plan (Form L1).

All of the existing non-operating fixtures that will be retrofitted or replaced must be identified. Non-operating fixtures are those that are **typically operating,** but that have broken lamps, ballasts, or switches **intended for repair**. A de-lamped fixture is **not** a non-operating fixture, and thus de-lamped fixtures should have their own unique wattage designations. Do not include fixtures that have been disabled or that are broken and not intended for repair in the calculation of baseline demand or energy use. These fixtures should be noted on the equipment survey as the same type and wattage before and after retrofit to avoid confusion.

Calculations of the baseline demand may include fixture wattages for up to 10% of the building’s non-operating fixtures by using values from the Table of Standard Fixture Wattages or from fixture wattage measurements. **The inclusion of non-operating fixtures is limited to 10% of the total fixture count per building.** Therefore, if 10% or fewer of the existing fixtures in the building are non-operating, these fixtures and their functioning wattages should be included on the equipment survey. If more than 10% of the total number of fixtures is non-operating, the baseline demand needs to be adjusted. In this case, the number of fixtures beyond 10% must be incorporated into the equipment survey with a baseline and post-installation fixture wattage of zero.

2.2.5 Monitoring Operating Hours

To determine pre- (for controls measure only) and post-installation hours of operation, a sample of fixtures or rooms needs to be monitored. The monitoring period must be reasonable and must account for any seasonal or other variations. A minimum monitoring period of three weeks per year is required by the SPC/NRR-DR program. Section 2.4.4, Step IV describes the process for determining the monitoring period.

2.2.6 Sampling Approach

The SPC/NRR-DR program requires that the estimate of annual hours of operation for lighting measures be based upon measurements of run time for the affected lighting fixtures. For control measures that reduce operating hours, monitoring must occur in both the pre-installation and post-installation periods. For lighting efficiency measures, monitoring must occur during the post-installation period. Monitoring is required on only a sample of fixtures that are selected by the Utility Administrator. Contact your Utility for more detailed information on the selection of the monitoring sample.

2.3 Lighting M&V Plan

An M&V plan for lighting efficiency and controls measures must be included with the project application. A template of a standard lighting M&V plan (Form L1) is found below in Section 2.4, along with instructions for completing this form. If a Project Sponsor decides to not use Form L1 for the M&V plan, he or she will be responsible for providing all the information contained in Forms L1 and the Lighting Equipment Survey Table in an easily understood format. It is the Project Sponsor's responsibility to submit a complete M&V plan and lighting audit. The submission of incomplete information is grounds for rejection of an SPC/NRR-DR Application and/or Installation Report.

2. 4 The Standard Lighting M&V Plan (Form L1) and How to Complete It

This section contains the lighting efficiency and controls M&V plan (Form L1 on the next page) as well as step-by-step instructions for completing it. Project Sponsors may use a different format; however, all the information in Forms L1 and the Lighting Equipment Survey Table must be provided in the M&V plan. In general, the plan requires the following:

- General information about the Project Sponsor
- General building information
- An audit of the fixtures in the building subject to retrofit
- Identification of the M&V monitoring equipment
- Estimation of operating hours
- Estimation of energy savings

2.4.1 Step I: Project Sponsor Information

The first three lines require input of general project and Project Sponsor information. Enter the following information about the Project Sponsor identified on the SPC/NRR-DR Agreement:

Line 1. Enter the date that the SPC/NRR-DR Application and M&V Plan will be submitted to the Utility Administrator.

Line 2. Enter Project Sponsor's name.

Form L1 – 2009 Standard Lighting M&V Plan

Step I: Project Sponsor Information

1. Date of submittal of this M&V plan:____

2. Name of Project Sponsor:____

Step II: Building Description(s)

3. Name(s) of building(s):____

4. Address(es):____

____

5. Type of buildings (office, retail, school, etc.):________________________________

Step III: Building Audit

6. Attach an audit of the building's fixtures. If not using the Lighting Equipment Survey Table, all the information requested in the lighting table must be included in the audit. Using form the Lighting Equipment Survey Table will automatically produce the savings estimates tables necessary to complete the required forms and documents for the project application. Otherwise, the Project Sponsor must manually calculate the energy savings.

Step IV: Monitoring Period

7. Determine the yearly monitoring period required for this building by referring to Table G-2 in Section 2.4.4. Enter the time period here:____________________________________

Step V: Monitoring Equipment

8. Please list the type of equipment, including manufacturer and model number that will be used to monitor operation of the building's lighting fixtures. Refer to the instructions in Section 2.4.5 on specific requirements for selecting and calibrating monitoring equipment.
Enter type(s) of monitoring equipment:_______________________________________

Step VI: Installation Report

Updated lighting audit and related savings estimates must be submitted with the Installation Report if the actual equipment installed is different from the equipment specified in the project application or other changes have occurred during construction. If a lighting controls measure is included in the retrofit, the pre-installation monitoring results must be provided at this time.

Step VII: Operating Report

Submit an updated lighting audit and related savings estimate with the Operating Report to reflect the results of the post-installation monitoring and any changes in building equipment or operation. Include the following information with your Operating Report submittal:

- A summary of the monitoring results
- A Lighting Equipment Survey Table revised to include monitored post-installation hours
- kW and kWh savings estimates by measure and project in an easy-to-follow table format
- Raw data files for all data loggers

****

2.4.2 Step II: Building Description(s)

Lines 3–5 ask for general information about the building(s) involved in the project. The building is the single structure in which lighting efficiency measure(s) will be installed.

Line 3. Enter a unique name for each building in the format *Company Name, building number*. Examples would include *ABC Grocery #1402* or *Bob's Cadillac #1*.

Line 4. List the complete street address of each building in which the lighting retrofit will be conducted, including the zip code. Do not enter a post office box. Attach extra sheets, if necessary.

Line 5. Enter the type of building from the following list:

- Retail
- Office
- School
- Hospital
- Industrial
- Manufacturing
- Other (please provide a description of the building)

2.4.3 Step III: Building Audit

Line 6. An audit of the lighting fixtures must be completed before proceeding further with the M&V plan. The Microsoft Excel Lighting Equipment Survey Table may be used for this purpose. The lighting table will automatically supply fixture wattages and calculate energy savings for each line in the audit.

Instructions for the Lighting Equipment Survey Table

The Lighting Equipment Survey Table documents an inventory of the existing lighting equipment and specifies the new equipment to be installed. The information on this form is manually input or automatically calculated by the spreadsheet. The lighting table documents general, pre-installation, post-installation, and savings information for each line item. A line on this form must be created for each unique combination of input parameters such as fixture type, area description/location, use type, and control type.

Following is a description of all the required information for a lighting audit. These are the same fields found in the Lighting Equipment Survey Table:

Line Item. Each line on the form should be numbered consecutively beginning with one.

Building. If there is more than one building in the project, each line should have a unique identifier that designates the building in which the fixtures are located.

Floor. If the building is more than one story, the floor on which the fixtures can be found should be identified.

Area Description/Location. Each line must have a unique identifier for the room or space in the building it represents. These descriptions should be easily understood and intuitive to make it easy for the Utility Administrator to conduct verification inspections. (For example, manager's office, kitchen, sales floor, Room 116, and so on). This information should correspond to any site maps provided.

Use Type. A brief description of the functional use of the space being audited. Table G-1 gives examples of functional uses that are encountered in commercial and industrial facilities.

Table G-1. Example Use Types

Classroom	Loading Dock
Conference Room	Lobby
Detention Area	Medical/Dental Examination Rooms
Dining	Multi-purpose/Auditorium
Equipment/Duplication Room	Office-open
Equipment/Electrical Room	Office-private
Equipment/Mechanical Room	Pharmacy
Equipment/Process Computer Room	Restrooms
Equipment/Process Laboratory	Sales
Equipment/Shop/repair Area	Shower Room
Food Prep Food Display, Sales & Light	Stairway/Hallway
Food Prep Kitchen	Storage- conditioned
Food Prep Lunch Room	Storage- refrigerated
Food Prep Meat Room	Storage- unconditioned
Food Prep Produce Preparation	Swimming Pool
Gymnasium	TV/Radio Studio & Control
Laundry	Unconditioned Attic
Light Industrial/Assembly Area	Unconditioned Parking
Living Areas Patient Rooms	Vacant Space
Living Quarters	

Pre Fixture Number. Each line must show the number of existing fixtures.

Pre Fixture Code. A code identifying the existing fixture type. The code must come from either the Table of Standard Fixture Wattages, or a look-up table must be supplied that shows the corresponding fixture codes in the Table of Standard Fixture Wattages for the Project Sponsor's fixture codes. See Appendix B for a copy of the Table of Standard Fixture Wattages and a legend describing the methodology for assigning the Utility Administrator's fixture code to a specific lamp/ballast combination.

Pre kW/Fixture. The kilowatts per fixture of the existing fixtures taken from the Table of Standard Fixture Wattages. When using the lighting equipment survey table, this field will automatically be filled with the most appropriate wattage from the standard table.

Non-Operating (NOP) Fixtures. The number of non-operating fixtures on the line. Non-operating fixtures are those fixtures that are typically operating but that have broken lamps, ballasts, or switches and are *intended for repair*. The inclusion of non-operating fixtures is limited to 10% of the total fixture count per building.

Pre kW/Space. The total kilowatts of the existing fixtures on the line. This is the result of multiplying the Pre Fixture Number and the Pre kW/Fixture. This calculation is automatically made by the Lighting Equipment Survey Table.

Pre Operating Hours. The estimated operating hours prior to the installation of the retrofit equipment. If a lighting controls measure is included in the project, this field should be updated for the Installation Report submittal to reflect the monitoring results found during the pre-installation monitoring.

Existing Control Type. The type of on/off control for the line, typically a switch, circuit breaker, motion sensor, or photocell. These may be abbreviated.

Post Fixture Number. The proposed number of retrofitted fixtures associated with the line item.

Post Fixture Code. A code identifying the new fixture type. The code must come from either the Table of Standard Fixture Wattages, or a look-up table must be supplied that shows the corresponding fixture codes in the Table of Standard Fixture Wattages for the Project Sponsor's fixture codes.

Post kW/Fixture. The kilowatts per fixture of the new fixture taken from the Table of Standard Fixture Wattages. When using the Lighting Equipment Survey Table, this field will automatically be filled with the most appropriate wattage from the standard table.

Post kW/Space. The total kilowatts for the new fixtures on the line. This is the result of multiplying the Post Fixture Number by the Post kW/Fixture. This calculation is automatically made by the Lighting Equipment Survey Table.

Post Operating Hours. The estimated operating hours after the installation of the retrofit equipment.

Proposed Control Device. The type of on/off control to be installed for the post-installation fixtures on the line, typically a switch, circuit breaker, motion sensor, or photocell. These may be abbreviated.

kW Saved. The result of subtracting the Post kW/Space from the Pre kW/Space for each line. This calculation is automatically made by the Lighting Equipment Survey Table.

Efficiency kWh Saved. The product of multiplying the kW Saved by the post-installation hours on the line. This calculation is automatically made by the Lighting Equipment Survey Table.

Controls kWh Saved. The product of multiplying the post-installation kW by the reduction in hours due to the installation of controls. This calculation is automatically made by the Lighting Equipment Survey Table.

2.4.4 Step IV: Monitoring Period

Line 7. The duration of the monitoring of operating hours needs to be determined. Buildings with variable schedules that change with the season or other factors may require a longer monitoring period than buildings with fixtures that have a constant operating schedule throughout the year. In all cases, the monitoring period should be long enough to capture the operating schedule and any changes in the schedule. In most cases, operating hours need to be monitored for three weeks. Monitoring should not take place during unusual periods, such as vacations, holiday, etc.

For buildings with seasonal schedules (such as schools or seasonal manufacturing), monitoring during all variations of use is necessary. Alternatively, a method may be proposed to quantify the usage of the lower operating season based on the results from the higher monitoring season and any variables that can reflect the decrease in operation of the facility. An example may be for seasonal production. In this case, the operating hours during the period of maximum production would be monitored. Then, the operation of the lights for the minimum production period may be calculated based on the ratio of the production output for the two periods multiplied by the monitoring results.

The recommended monitoring periods for common building types are shown in Table G-2. Enter the monitoring period on Line 8 in Form L1. Contact your Utility Administrator if the facility type in the project is not in the table.

Table G-2. Monitoring Periods for Different Building Types

Building Type	Monitoring Period
Retail	3 weeks
Office	3 weeks
Schools with reduced or no summer occupancy*	4 weeks (2 weeks in session and 2 weeks out of session)
Year-round schools	3 weeks
Hospital	3 weeks
Industries with constant production	3 weeks
Industries with seasonal production*	4-8 weeks (2 weeks each season with a change in operating hours)

* Seasonal variation in operating hours of fixtures

2.4.5 Step V: Monitoring Equipment

Monitoring equipment for recording operating hours of lighting fixtures normally falls under one of the two following categories:

- "Light Loggers," devices that record the operating hours of individual fixtures through the use of photocells. Only light loggers that store information translatable into actual load profiles of on and off times are allowed. This is the preferred equipment.
- Current or power measurements of lighting circuits which, when calibrated to the total connected lighting load on the circuit, can be used to determine how many fixtures were operating in terms of elapsed time or actual time-of-use load profiles.

The monitoring equipment chosen must **measure and record data indicating operating hours in a downloadable electronic format.** The monitoring device must be able to record status at least every 15 minutes. "Raw" as well as "compiled" electronic data from the monitoring devices must be submitted to the Utility Administrator for verification.

Line 8: List the type of equipment, including the manufacturer's name, make, and model number, that will be used to monitor the building's hours of lighting operation.

2.4.6 Step VI: Installation Report

The lighting audit in the Installation Report may need to be updated to reflect the actual equipment installed if the intended retrofit equipment changed. Changes may occur during construction due to design considerations, accessibility problems, and unavailability of planned fixtures. These changes will affect the project's estimated energy savings. The documentation of installed fixtures will be verified by the Utility Administrator during a post-installation inspection. These changes may require updating the Lighting Equipment Survey Table and the M&V plan.

If a lighting controls measure is included in the project, the results from the pre-installation monitoring activity must be submitted with the Installation Report. These results will determine the baseline operating hours for areas/locations that receive a controls retrofit.

2.4.7 Step VII: Operating Report

The lighting audit for the Operating Report may need to be updated to reflect any construction changes (such as a remodel) or non-operating fixtures. These changes will affect the project's estimated energy savings. The following information is required for each Operating Report:

- A summary of the monitoring results
- A lighting audit revised to include monitored post-installation hours
- kW and kWh savings estimates by measure in an easy-to-follow table format
- Raw data files for all data loggers

2.5 Savings Calculation Methodology

This section describes the methodology and equations that are used to estimate the annual savings for both lighting efficiency and controls measures.

2.5.1 Lighting Efficiency

The equation to estimate annual kWh savings for a lighting efficiency measure is:

$$kWh_{saved} = (kW_{base} - kW_{post})OH$$

where:

kWh_{saved}	=	the total annual energy saved [kWh]
kW_{base}	=	the kW demand of the existing fixtures based on the values in the Standard Fixture Wattage Table [kW]
kW_{post}	=	the kW demand of the retrofit fixtures based on the values in the Standard Fixture Wattage Table [kW]
OH	=	the operating hours [hours]

Prior to installation of the retrofit, the operating hours are based on an estimation of time the fixtures are operating. After installation, the operation of the fixtures is defined by the results of the annual monitoring.

The total measure savings is the sum of the kWh saved for each line in the Lighting Equipment Survey Table.

2.5.2 Lighting Controls

The equation to use to estimate annual kWh savings for a lighting controls measure is:

$$kWh_{saved} = (OH_{base} - OH_{post})kW_{post}$$

where:

kWh_{saved}	=	the total annual energy saved [kWh]
OH_{base}	=	the operating hours prior to the installation of the controls [hours]
OH_{post}	=	the operating hours after the installation of the controls [hours]
kW_{post}	=	the kW demand of the fixtures based on the values in the Standard Fixture Wattage Table [kW]

If a project consists of both lighting efficiency and controls measures, the kW_{post} must be the demand of the retrofit fixtures.

The total measure savings is the sum of the kWh saved for each line in the Lighting Equipment Survey Table.

2.6 Things to Consider

Following is a list of common problems associated with lighting monitoring and analysis of data.

Box time. "Box time" refers to the time a logger spends in a box as opposed to monitoring a fixture. There are two kinds of box time: before a logger starts logging and after the logger is removed. The first type is the period between logger initialization and logger installation. Once a logger is initialized, it records "Light Off" until the sensor is properly installed. The second type is the period between logger removal and data downloading. The logger records "Off" when it is waiting for data to be downloaded. Data with significant box time decrease the average on-time and savings estimates. Box times for each logger file should be identified, if they exist.

Malfunctions. If a logger is damaged or malfunctions during the monitoring period, it should be identified as malfunctioning and the data should not be included in the analysis. However, a logger with data significantly different from the average cannot be eliminated as long as both the equipment and the logger are functioning correctly.

In-session and out-of session. Some projects, such as schools, have in-session and out-of-session operating schedules. Sampling requirements are calculated separately for each session. The same methodology on both in-session and out-of-session monitoring results must be followed.

3. Constant-Load Motors

Option B, Method CLM-B-01, Short-Term and Continuous Metering

3.1 Introduction and Key Issues

This section discusses an M&V method applicable to energy efficiency measures involving the replacement of motors that drive a system with constant loading. The M&V method (CLM-B-01) is appropriate only for projects in which:

- Constant-speed motors are replaced with constant-speed, high-efficiency motors with the same capacity rating (horsepower)
- Motors oversized for the load are replaced with smaller-capacity, high-efficiency motors (motor down-sizing)

Examples of motor replacement projects for which this method is appropriate include:

- Constant-speed exhaust, return and supply fans without downstream or upstream dampers or pressure controls
- Constant-load chilled or hot water circulating pumps
- Constant-speed process circulation pumps

Alternative M&V methods must be used for projects in which motor changes are accompanied by the installation of variable-speed control (Section 4) or by system modifications that affect the load on the motor (Section 6). If the pre-installation and post-installation motors will have different operating hours due to the installation of a timer, this method (CLM-B-01) may be used, but will require both pre- and post-installation monitoring of the hours of operation.

The CLM-B-01 M&V method involves a conservative approach to calculating energy savings based on rated efficiencies and short-term or continuous metering. The following key issues should be noted before preparing a measure-specific M&V plan using this method:

- Minimum equipment efficiency standards apply to this type of project.
- Metering of motor electricity consumption or run time is required.
- Only operational motors can be included in the baseline calculations. Motors that are no longer used or are not in operational condition cannot be included in the baseline calculations.
- Changes in operating hours or control systems between the existing and retrofit motors must be treated as a separate measure.

3.2 Baseline Issues

Incentives are paid only for the incremental savings above the minimum equipment efficiency standards; therefore, adherence with applicable energy efficiency standards is required for baseline values. The baseline efficiency for motors is defined by Title 24, which refers to the National Electrical Manufacturers Association (NEMA). For a complete listing of the minimum standards for motors see Appendix C, Table C.1. The baseline efficiency for any motor can be determined if the following characteristics are known:

- Motor horsepower
- Full-load (rated) revolutions per minute (RPM) or number of poles
- Enclosure type: open drip proof (ODP) or totally enclosed fan cooled (TEFC)

3.3 Initial Savings Estimate

Prior to the installation of the retrofit equipment, the initial savings estimate provides the best estimate of the amount of energy the project will save. Thus, these estimates should be based on the best possible data available. Ideally these data will be similar to the data collected during the reporting periods. In most cases, however, much less data are available at the project application stage to generate the initial savings estimates.

For motor efficiency upgrades, the following methods, listed in order of increasing complexity, may be used to generate the initial savings estimates. These methods are:

- Analysis of spot measurements of existing motor. This involves measuring each existing motors' power draw, estimating the operating hours for the entire year, and calculating the post-installation demand with a ratio of the baseline and proposed motors efficiencies.
- Analysis of short-term monitoring data of kW and operating hours for the existing motors. This involves extrapolating the measured motor kW and operating hours to the entire year and calculating the post-installation demand with a ratio of the baseline and proposed motors efficiencies.
- Using the same calculations called for in this M&V method with the use of pre-installation metering or historical data, instead of post-installation data.

The method for developing savings estimates should be selected based on available data for the facility, the savings uncertainty (or risk of achieving savings), the proposed M&V method, and the value of incentive payments. The main point to remember when approaching the savings estimate is that a better estimate results in more realistic expectations.

3.4 Overview of Method CLM-B-01

Using this approach, surveys are required to document existing (baseline) and new (post-installation) motors. Savings are determined using:

- kW spot measurements or short-term metering of existing motors
- Adjustments for minimum motor efficiency standards, if the motor does not meet minimum federal and state standards
- Measurements of post-installation motor kW and operating hours, or kWh

The Project Sponsor must verify that the load on the motors is constant. Section 3.4.4 provides more information about verifying constant loading.

3.4.1 Pre-Installation Equipment Survey

In the pre-installation equipment survey, the equipment to be changed is inventoried. To facilitate the equipment inspection, motor location and corresponding building floor plans should be included with the survey submittal. The surveys must include, in an organized format, the following:

- Motor horsepower
- Motor application or load served (for example, third-floor exhaust fan motors)
- Operating schedule (e.g., 7 a.m. to 6 p.m. weekdays)
- Spot and short-term metering data (true RMS power)
- Location in the subject facility (e.g., Mechanical Room 7)

3.4.2 Establishing Baseline Motor kW

Spot metering is for measuring instantaneous power draw of the motors. For baseline motors, spot metering of power must be recorded. Such measurements must be made using a true RMS meter with an accuracy at or approaching ± 3% of reading. A sample of motors can be spot metered, using the sampling criteria in Section 3.4.6 if a large number of motors are to be replaced within a single facility.

There are three ways to determine baseline motor power draw, kW:

1. If the existing motor's specifications meet or exceed the minimum efficiency standard (Appendix C, Table C.1), then the measured motor power draw defines the baseline kW.
2. If the motor does not meet the minimum energy efficiency standard, but is being replaced with the same size (horsepower) motor, then the baseline kW will be determined by multiplying the post-installation motor kW measurement by the ratio of the applicable minimum standard efficiency to the post-installation motor nameplate efficiency (see Section 3.5.1, second option).
3. If the motor does not meet the minimum energy efficiency standard, and is being replaced by a smaller size (horsepower) motor, then the baseline motor power measurement must be adjusted. This adjustment may be accomplished with a ratio of the minimum standard efficiency and the efficiency of the existing motor taken from nameplate data to estimate the baseline demand for the project.

   If the nameplate data are not available, an average efficiency value should be taken from the MotorMaster database for similar horsepower and type (ODP or TEFC) motors. If the MotorMaster database is used, then the values selected will be subject to Utility Administrator approval. (MotorMaster+, Version 4.0.6 or most current, © 2006, written by Washington State University Energy Program, distributed by Motor Challenge Program, U.S. Department of Energy.)

If minimum efficiency values are required from Table C-1, then use a motor with the same horsepower, full-load speed, and enclosure type.

3.4.3 Pre-Installation Short-Term Monitoring

Short-term monitoring, prior to installation of the new motors, may be done for the following reasons:

- Verify that the load on the motors is constant
- Establish the baseline demand for the project
- Generate the initial savings estimates

The required monitoring period is determined by the type of application the motors serve. All short-term monitoring must be for a period of time sufficient to capture the full range of motor operation. Although pre-installation short-term monitoring is not required for all constant-load motor applications, it is recommended to assist in generating a more accurate initial savings estimate.

3.4.4 Verifying Constant Load

There are two methods for verifying that motor loads are constant. These methods are:

1. Short-term metering of the motor (this is the preferred method)
2. Providing written documentation with the project application that the load is constant (this method requires that the Utility Administrator verify the constant-load characteristics of the system during the pre-installation inspection)

Conducting short-term metering

If the constant load cannot be verified through observation during the inspection, short-term metering is required on all baseline motors or a randomly selected sample of motors with the same application or operating hours. Short-term metering should be conducted for a period of time sufficient to capture the full range of operation of the motor and all variances in the load it serves. Sample selection and results of metering for the entire sample should be summarized in a tabulated format.

Short-term metering can be conducted using current transducers and data loggers. The equipment for short-term metering needs to be accurate only within ± 5% of full scale. The short-term metering equipment must be calibrated against the spot-metering equipment by taking spot-metering readings at the same time. Thus, short-term metering equipment must be installed at the same time spot-metering readings are being taken. Data loggers must record readings on intervals of 15 minutes or less.

During the short-term metering, each motor must be tested by modulating the applicable systems over their normal operating range (for example, low cooling load to peak cooling load, economizer operation, minimum output of process product to peak output of process product). Such testing will determine whether motor load remains constant over the full range of normal system operation. The length of metering to verify constant load and the metering protocol must be defined in the measure-specific M&V plan.

After this verification measurement, the following should be determined:

- Number of non-zero observations
- Number of observations within ± 10% of the average amperes or kW determined above
- Percent of observations within ± 10% of the average amperes or kW

To verify that the motor loads are constant, compare the short-term metering period average amps to all hourly non-zero values. A motor load is verified as constant if 90% of all non-zero observations are within ± 10% of the average amps determined above.

If any motor application cannot be verified as constant load, examine the collected data to determine whether the load for the motor varies on a systematic and predictable basis, whether the constant load was changed during the test period, or whether there is some system anomaly.

Providing written documentation to verify constant loads

If it can be determined through observation that the load is constant, written documentation may be submitted with the project application explaining that it is assumed that the load is constant and why. In the written documentation, provide schematics of duct work or piping and state the type of existing controls that are on the motors. In general, this verification method can be utilized for motors that serve exhaust or supply fans. This method may not be used for applications such as process motors.

3.4.5 Post-Installation Short-Term Monitoring

Post-installation short-term metering is required for all constant load motor retrofits. The results from the monitoring are used to determine the:

- kW demand of the retrofit motors
- Operating hours of the proposed motors
- Estimated kWh incentive based savings (through calculations)

The time period for which monitoring is required is determined by the type of application the motors serve. As described in the pre-installation monitoring list, all post-installation short-term monitoring must be of a length of time sufficient to capture the full range of motor operation.

3.4.6 Sampling

The spot-, short-, or long-term metering may only need to be done for a sample of motors from each usage group for determining (a) motor power draw, kW, (b) that the load is constant, and (c) operating hours.

If sampling is used, classify the existing motors with identical operating characteristics and expected operating hours into usage groups. Examples of usage groups include HVAC constant-volume supply fans, cooling water pumps, condenser water pumps, HVAC constant volume return fans, and exhaust fans. For each motor application or usage group at least one motor must be metered.

Sampling plans for motor operating hours across single and multiple project sites must meet a confidence level of 90% and precision level of 20%. Sampling across multiple project sites can be done only if the motors have the same usage groups, ownership, occupancy, and functional use, and energy use patterns. Contact your Utility for information on sampling.

3.4.7 Other Issues

In addition to the requirements generic to all M&V plans, the following issues should be addressed in a measure-specific M&V plan for constant-load motors:

- The basis for setting the baseline motor power draw
- The time period of metering, metering protocol, and reporting format for verifying that the project is a constant load application
- Whether or not operating hours are assumed to be constant before and after measure installation
- How kWh savings will be calculated with or without the use of operating hours monitoring
- The time period for post-installation monitoring of kWh and/or operating hours as well as the metering protocol and reporting format
- The reporting information and format to be used for baseline and post-installation inspections
- How baseline kW values are in adherence, or will be adjusted to comply, with the minimum standard requirement
- Whether slip will be taken into account when calculating savings, and how this will be done

3.5 Calculating Energy Savings

In most cases, the energy savings to be used in determining the incentive payments are established with only the post-installation monitoring results.

3.5.1 Calculating Baseline Consumption

There are three methods to determine the baseline consumption of the motors.

<u>Baseline motor meets minimum efficiency standard</u>

This method uses pre-installation metering results. This method should be used if the existing motor meets or exceeds the minimum standard indicated in Table C-1 of Appendix C. In this case the baseline kW value is an average of the non-zero readings.

<u>Baseline motor does not meet minimum efficiency standard – new motor is same horsepower</u>

The second and more common method is for situations where the efficiency of the existing motor does not meet the minimum standard efficiency. The procedure to calculate the baseline involves the use of post-installation monitoring results and a ratio of the minimum standard motor efficiency (Table C-1) and the efficiency of the retrofit motor with the following equation:

$$kW_{base} = kW_{post} \frac{\eta_{\min - std}}{\eta_{post}}$$

where:

kW_{base} = the demand for the baseline motor

kW_{post} = the average of the metered energy demand for the new motor

$\eta_{min\ std}$ = the efficiency of the baseline motor taken from Table D-1

η_{post} = the efficiency of the new motor taken from its nameplate

<u>Baseline motor does not meet minimum efficiency standard – new motor is different horsepower</u>

The third method is for situations where the efficiency of the existing motor does not meet the minimum standard efficiency and the motor is "down-sized." The procedure to calculate the baseline involves the use of pre-installation metering and a ratio of the minimum standard motor efficiency (Table C-1) and the efficiency of the existing motor with the following equation:

$$kW_{base} = kW_{existing} \frac{\eta_{existing}}{\eta_{\min - s\tan d}}$$

where:

kW_{base} = the demand for the baseline motor

$kW_{existing}$ = the average of the measured energy demand for the existing motor

$\eta_{min\ stand}$ = the efficiency of the baseline motor taken from Table D-1

$\eta_{existing}$ = the efficiency of the existing motor taken from its nameplate or MotorMaster database

3.5.2 Determining Operating Hours

It is assumed that the operating hours are not affected by the motor upgrade. Therefore, the post-installation operating hours, found through monitoring, are equal to the baseline operating hours. Operating hours for the baseline and/or the post-installation periods are determined with short-term or long-term monitoring on at least a sample of motors.

If the control strategy of the motor is changed, the operating hours of the motor may be reduced. Operating hours for the baseline and the post-installation periods are determined with short-term or long-term monitoring on at least a sample of motors.

The method for determining operating hours must be defined in the measure-specific M&V plan. Operating hours can be determined by one of two methods:

- Direct measurement of the hours that the motor is operating
- Measuring the kWh consumption of the motor and dividing by the measured kW draw of the motor. *(Note: this equation is only valid if the load is constant.)*

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

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

The measure-specific M&V plan must specify the period and schedule for monitoring.

3.5.3 Calculating Energy Savings

The equation for calculating the estimated annual kWh savings is:

$$kWh_{saved} = kW_{base}OH_{base} - kW_{post}OH_{post}$$

where:

kWh_{saved} = the estimated annual amount of kilowatt hours of saved

OH_{base} = the pre-installation operating hours

OH_{post} = the post-installation operating hours

In most cases, the retrofit will not affect the operating hours of the system. Therefore, the pre-installation operating hours are equal to the post-installation operating hours. Thus, the equation reduces to:

$$kWh_{saved} = (kW_{base} - kW_{post})OH_{post}$$

Again, this formula is only valid when the load is constant.

3.5.4 Slip Issues

High-efficiency motors may exhibit less slip and thus operate at a higher speed than the baseline motor unless motor-drive systems are modified. Project Sponsors are encouraged to account for slip when selecting motors and preparing initial savings estimates. With Utility Administrator approval, Project Sponsors may document that a change in slip has occurred and adjust the savings to account for the difference in slip; note that on centrifugal loads, changes in speed are governed by the “cube-law.”

4. Variable-Speed Drives

Option B, Method VSD-B-01: Constant Baseline

Option B, Method VSD-B-02: Variable Baseline—Performance Curves with Metering

Option B, Method VSD-B-03: Variable Baseline—Correlating Power to Independent Variable Values

4.1 Introduction and Key Issues

This section discusses M&V methods applicable to energy-efficiency measures involving the installation of a variable-speed drives (VSD) on motors that serve either a constant or variable load. There are three approaches for calculating energy savings:

1. **VSD-B-01,** for constant baseline load applications only. This method uses post-installation monitoring of electricity consumption to determine energy savings. This method is referred to as the ***constant baseline*** approach.
2. **VSD-B-02,** for variable baseline load applications. This method uses part-load performance curves and monitoring of post-installation electricity consumption to determine energy savings. This method is limited to motor applications with professionally recognized and available performance curves, e.g., fan curves. This method is referred to as the ***performance curve*** approach.
3. **VSD-B-03,** for variable baseline load applications. This method employees monitoring of pre- and post-installation energy use as well as any contributing parameters such as flow or production to build a correlation between baseline and post-installation output. This method is referred to as the ***correlation*** approach because correlations are built between baseline and post-installation electricity consumption. This is the most difficult of the three methods.

All of the methods require baseline power spot metering and either short-term or continuous post-installation monitoring. Before beginning, note that minimum equipment efficiency standards apply if a new motor is installed as part of the project. Minimum baseline efficiency ratings are defined by the National Electrical Manufacturers Association (NEMA).

4.2 Efficiency Measure Definition

VSD projects involve the replacement of existing (baseline) motor controllers with VSD motor controllers. These projects cause a reduction in motor demand and energy use but not necessarily a reduction in utility demand charges. VSD retrofits also often include the installation of new, high-efficiency motors. Examples of projects that may use the M&V methods defined in this section include:

- VSDs installed on chilled or hot water circulating pump motors
- Two-speed motors or VSDs installed on ventilation fan motors to replace inlet or outlet vane dampers
- Conversion of a constant volume HVAC system to a VAV system

Another M&V method must be used if the VSD is installed on a chiller (See Section 5, methods CH-B-01 or CH-B-02).

4.3 Baseline Issues

If a new motor is installed as part of a VSD project, the baseline motor energy consumption must be adjusted to account for minimum standard requirements. This correction is needed to encourage the use of new, high-efficiency motors.

Incentives are paid only for the incremental savings above the minimum equipment efficiency standards. The baseline efficiency for motors is defined by the NEMA standard, which is referred to by California's Title 24 (for a complete listing of the minimum standards for motors see Appendix C, Table C-1). The baseline efficiency for any motor can be determined if the following characteristics are known:

- Motor horsepower
- Full-load (rated) RPM or number of poles
- Enclosure type: open drip-proof (ODP) or totally enclosed fan-cooled (TEFC)

If the measure involves downsizing a motor, the baseline motor efficiency should be found by the use of the characteristics of the proposed motor.

4.4 Initial Savings Estimate

While developing the project application, energy savings must be estimated for each measure. Thus, these estimates should be based on the best possible data available. Ideally the savings estimated method should correspond to the energy savings method that will be used during the term of the SPC/NRR-DR Agreement, as defined in the approved M&V plan.

For a VSD retrofit project, the following methods are available for use in developing an initial savings estimate:

- The same calculations and data analyses methods defined in the M&V data—using the data available prior to application submittal
- Computer simulation of the system using a building simulation program (e.g., DOE-2)
- Hourly analysis using system performance curves (e.g., fan curves), estimated or spot measured motor kW readings, and load profile and operating hour estimates
- Computer simulation of a motor and the fan or pump it serves using a VSD simulation program (QuickFan, AC Diskware, etc.)

The method for developing savings estimates should be selected based on available data for the facility, the savings uncertainty (or risk of achieving savings), the proposed M&V method, and the value of incentive payments. The main point to remember when approaching the savings estimate is that a better estimate results in more realistic expectations.

4.5 Overview of Methods

Energy savings are determined by comparing post-installation energy use with what the baseline energy consumption would have been absent the installation of the VSD. For all M&V approaches, surveys are required to document the existing (baseline) and proposed (post-installation) systems (see Section 4.5.1).

The basis for selecting the methodology to calculate savings depends on whether the baseline consumption is constant or variable, and if variable, whether industry-recognized system performance curves for the system are available.

For constant-load baseline systems, use Method VSD-B-01.

For variable-load baseline applications, use Method VSD-B-02 if system performance curve data are available. Acceptable performance curves for some typical HVAC fan systems are presented later in this section. The use of other system performance curves is allowed as long as (a) the curves are endorsed by a nationally recognized association of professionals working in the industry, such as ASHRAE or (b) the curves were obtained from a reliable scientific source (examples include the curves used in DOE-2 developed by the Lawrence Berkeley National Laboratory, or the curves used in BLAST from the US Army Construction Engineering Research Laboratory). In any case, when using the performance curve approach, savings are based on:

- kW spot measurements or short-term metering of existing motors
- System performance curves
- Measurements of post-installation kW, kWh, and/or operating hours

Use method VSD-B-03 for variable-load baseline situations if acceptable performance curves are not available. When using the correlation approach, a regression analysis is performed to develop an equation that defines the relationship between baseline energy use and key factors that determine baseline energy use. For example, with a fan ventilation system the key variable(s) might be airflow, time of day, and/or outdoor temperature. The regression equation must meet certain statistical criteria that indicate the equation is valid. These criteria are described later in this section.

4.5.1 Equipment Surveys

In the pre-installation equipment survey, the equipment affected is inventoried. To facilitate the equipment inspection, include motor location and corresponding building floor plans with the survey submittal. The surveys must include, in an organized format, the following:

- Motor horsepower
- Motor application or load served (e.g., third-floor exhaust fan motors)
- Operating schedule (e.g., 7 a.m. to 6 p.m. weekdays)
- Spot and short-term metering data (true RMS power)
- Location in the subject facility (e.g., Mechanical Room 7)

The spot metering is for measuring instantaneous power draw of the motors. For baseline motors, spot metering (instantaneous measurements) of true RMS power and kW should be recorded. A sample of motors can be spot metered, using the sampling criteria in Section 4.5.2, if a large number of motors are to be replaced within a single facility.

For the post-installation survey, the VSDs should be inventoried with nameplate data. If new motors are installed, their nameplate data should also be reported.

4.5.2 Sampling

If VSDs are installed on a number of motors, the required metering may only need to be performed for a sample of motors. Contact your Utility for information details on sampling and the limitations on its use in this program. The basis for sampling is that similar motors in similar applications are considered to have similar energy use characteristics and savings. Thus, the results from metering of a subset of motors are applied to the entire population of retrofitted motors. With sampling, motors are classified into usage groups with other motors having similar operating characteristics and expected operating hours. Examples of usage groupings for HVAC applications include constant-volume supply fans, cooling water pumps, condenser water pumps, constant volume return fans, and exhaust fans.

In this program, a minimum of three motors per usage group must be monitored. For usage groups with less than three motors, all of the motors must be monitored. Sampling plans must meet a confidence level of 90% and a precision level 20% if a multiple-project-site sampling plan is employed. For single-project-site sampling plans, the confidence level is 80% and the precision level is 20%. A default coefficient of variation equal to 0.5 must be used for the sample design, unless the Utility Administrator approves using a different value. Contact your Utility for more information on sampling, sampling equations, and the requirements in this program.

4.5.3 Adjusting the Baseline Load for Minimum Efficiency Standards

If efficient motors are installed as part of the VSD measure and the existing motors do not meet or exceed the minimum efficiency standards, the baseline energy consumption must be adjusted down to the minimum standard. A list of the minimum efficiency standards is located in Appendix C, Table C-1.

The procedure to calculate the baseline power consumption involves using the pre-installation monitoring results and a ratio of the minimum motor efficiency standard and the efficiency of the existing motor**. This applies to both constant and variable baseline situations.** The minimum standard baseline power consumption is calculated with the following equation:

$$kW_{base} = kW_{exist} \frac{\eta_{exist}}{\eta_{min\_stand}}$$

where:

kW_{base} = the energy demand for the minimum standard baseline motor (constant or variable)

kW_{exist} = energy demand for the existing motor- either an average for constant load motor applications or a variable for other applications

η_{min_stand} = the efficiency of the baseline motor taken from Title 20 minimum efficiency standards

η_{exist} = the efficiency of the existing motor taken from nameplate data

4.5.4 Current (Amps) Monitoring Option

It is always recommended that true RMS kW measurements be used to determine power and energy consumption both before and after installation of a VSD. However, monitoring true RMS current (amps) may be used to meet the short-term and continuous monitoring requirements. This can be done only if a valid correlation between current and power can be determined using a true RMS meter having an accuracy better than ± 3%. The correlation between current and power must be submitted to the Utility Administrator for review in the project application for a baseline correlation, or in the Installation Report for a post-installation correlation. The Utility Administrator will verify the correlation with spot measurements during the pre- and/or post-installation inspections.

4.5.5 Post-Installation Monitoring

Post-installation monitoring is required for all VSD installation retrofits. The results from the monitoring are used to determine the:

- kW demand of the retrofit motors as well as kWh consumption of the motors
- Operating hours of the proposed motors
- kWh incentive based savings (through calculations)

Upon installation of the proposed equipment, the Utility Administrator will verify the new equipment based on the surveys provided in the Installation Report. After the VSDs are installed, continuous or short-term metering will be conducted for all motors. With this M&V method, one of the following two types of monitoring is required:

- Motor power draw (kW) is metered, typically at 15 minute intervals, continuously or for a set period which can be easily extrapolated to the entire year; or
- Motor energy consumption (kWh) and run time (Hours) are metered continuously or for a set period which can be easily extrapolated to the entire year.

If less than continuous monitoring is used, the monitoring data will be extrapolated to the full year. All short-term monitoring must be of a sufficient length of time to capture the full range of operation of the motors. A minimum monitoring period of one month is recommended for almost all applications. However, the actual time and frequency required will be specific to each project. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to collect data during different times of the year. Examples of monitoring intervals are once a month for each season or one random month during each performance year. The M&V plan submitted with the project application must indicate the timing and length of monitoring.

4.5.6 Calculating Energy Savings

The energy savings calculation process is the same for all three M&V methods described in this section. However, the process does vary depending on whether, after VSD installation, only motor kW is monitored or if motor kWh and operating hours are monitored.

The analysis also depends on whether pre- and post-installation operating hours are assumed to be the same. **The following equations apply only to the situation where operating hours are the same before and after measure installation.** Project-dependent equations must be developed and described in the M&V plan when operating hours are not the same before and after the VSD is installed (see Section 4.9).

Procedure using kW post-installation monitoring—operating hours same pre- and post-installation

To calculate the kWh savings for each post-installation interval, assuming 15-minute time intervals, use the following equations:

$$kWh_{saved} = (0.25\ hrs)(kW_{base} - kW_{post})$$

Once the energy saved per monitoring interval has been determined, total annual kWh savings are calculated by summing up the intervals, using the following equation:

$$kWh_{saved\_annual} = \sum kWh_{saved}$$

where:

kWh_{saved} = energy savings for one 15 minute time interval [kWh]

kW_{base} = the kilowatt demand of the baseline motor, adjusted to meet the minimum efficiency requirements - 15 minute time interval, [kW]

kW_{post} = the average kilowatt demand of the motor with the VSD during the post-installation - 15 minute time interval, [kW]

kWh_{saved_annual} = total annual energy savings, [kWh]

<u>Procedure using kWh and hours post-installation metering—operating hours same pre- and post-installation</u>

To calculate the kWh savings for the monitoring period (e.g., one month), use the following equations:

$$kWh_{saved} = kW_{base} OH - kWh_{post}$$

Once energy saved for the monitoring period has been determined, the total annual kWh savings can be calculated with the use of the following equation:

$$kWh_{saved\_annual} = \sum kWh_{saved}$$

Where:

kWh_{saved} = the energy savings during monitoring period (e.g., one month) [kWh]

kW_{base} = the kilowatt demand of the baseline motor, adjusted to meet the minimum efficiency requirement [kW]

OH = the actual metered on-time hours during the monitoring period [hours]

kWh_{post} = the average kilowatt-hour energy consumption of the motor with the VSD during the post-installation monitoring period [kWh]

kWh_{saved_annual} = annual energy savings [kWh]

4.6 Method VSD-B-01: Constant Baseline

If the baseline energy use or power is a single, constant value while the existing motor is operating, the load is constant. In this case, M&V is simplified as the baseline electrical consumption is always known. The process of determining savings is reduced to monitoring the post-installation power consumption and subtracting it from the baseline (constant) power consumption to obtain the savings for the monitored time interval. No performance curves are required.

In actuality, most constant load systems do have some minor amount of load fluctuation. For the purpose of this program, motor load can be considered constant if 90% of all non-zero meter readings (kW or amps) taken at 15-minute intervals are within 10% of the average while the motor (system) cycles through its full range of operation.

As an option, and at the discretion of the Utility Administrator, Project Sponsors may be allowed to provide written documentation that the load is constant in lieu of short-term metering. To use written documentation, the Utility Administrator must verify the constant-load characteristics of the system during the pre-installation inspection.

4.6.1 Verification of Constant Load

The preferred method of verifying constant load is to conduct short-term metering of either amps or kW on the motor. Short-term metering should be conducted for a sufficient period of time to capture the full range of operation of the motor and all variances in the load it serves. This can take several weeks for many applications. If sampling is used, sample selection and results of metering for the entire sample should be summarized in a tabulated format and submitted with the project application.

During the short-term metering period, it is important to monitor each motor as it modulates through its normal operating range (for example, low cooling load to peak cooling load, economizer operation, and minimum output of process product to peak output of process product). Such monitoring will determine whether or not motor load remains constant over the full range of normal system operation.

To verify that motor loads are constant, compare the short-term metering period average amps or kW to all hourly non-zero values. During this verification measurement, record the following:

- Number of non-zero observations
- Number of observations within ± 10% of the average amperes or kW
- Percent of observations within ± 10% of the average amperes or kW

The length of metering to verify constant load and the metering protocol must be defined in the measure-specific M&V plan.

If it is determined through observation that the load is constant, written documentation may be included with the project application. The written documentation should include schematics of duct-work or piping and should state the type of existing controls that are on the motors. Examples of when this documentation approach can be used are for motors that serve exhaust fans and chilled water pumps serving coils with three-way valves.

4.6.2 Pre-Installation Spot-Measurements

Spot metering is for measuring instantaneous power draw of the motors. For baseline equipment, spot metering (instantaneous measurements) of kW, must be recorded. Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 3% of reading. A sample of motors can be spot metered, if a large number of motors are to be replaced within a single facility and share similar characteristics. If short-term metering is not required, spot kW readings will be the basis for the baseline demand.

Note that if an efficient motor is being installed as part of the measure and the existing motors do not meet the minimum efficiency standard, the baseline power consumption has to be adjusted as shown in Section 4.6.4. For that equation, the baseline kW value is an average of the non-zero readings obtained in the short-term monitoring.

4.6.3 Pre-Installation Short-Term Monitoring

If short-term monitoring is required to verify constant load, the results can be used to:

- Generate the initial savings estimates
- Establish the baseline demand for the project

It is typically assumed that the installation of a VSD does not affect the annual hours of operation of the motor. This simplifies the savings analysis in that post-installation and baseline annual hours of operation are the same and thus only post-installation operating hours need to be monitored. However, if this is not the case, monitoring the baseline hours of operation is required to determine the baseline energy consumption.

The M&V plan submitted with the project application must indicate the timing and length of monitoring.

Short-term monitoring can be conducted using current transducers and data loggers. The equipment for short-term metering needs to be accurate only within ± 5% of full scale, and the metering equipment must have been calibrated within the past two years. Data loggers must record readings on intervals of fifteen minutes or less.

4.6.4 Adjusting Baseline Load for Minimum Efficiency Standards

If the existing motors do not meet or exceed the minimum efficiency standards and they are being replaced with efficient motors as part of the measure, the baseline must be adjusted to the minimum standards. A list of the minimum efficiency standards is located in Table C-1 in Appendix C. See Section 4.5.3 for the equation for adjusting the baseline for minimum efficiency standards.

4.7 Method VSD-B-02, Variable Baseline-Performance Curves with Metering

This method makes use of professionally published and industry accepted performance curves (in the form of equations) for fan and pumping systems to estimate a motor's energy consumption at different system output levels. This method may only be used if the affected system is the same as the system for which a performance curve was developed. That is to say, if a performance curve for a supply fan with inlet vanes is used, the fan cannot have other flow control devices other than inlet vanes. If credible performance curves cannot be used, use Method VSD-B-03 described later in this section.

With this method, a relationship or equation is defined using performance curves (e.g., fan curves) prior to VSD installation. The equation indicates the relationship between baseline energy use and applicable variables for each operating scenario (e.g., kW vs. flow). It is assumed that the installation of the VSD does not change the system requirements (e.g., water or air-flow), and that a common variable (e.g., ambient temperature or system pressure) can be used to relate the post-installation values of the variable(s) to the baseline energy consumption. Much of the discussion describing this method is geared towards VSD applications on HVAC fans. However, these same methods may be used for most pumping systems and other common VSD applications.

4.7.1 Acceptable Performance Curves

Before using this method, the system type must be verified and suitable performance curves (in the form of equations) which relate motor demand to the system's controlling parameters (e.g., ambient temperature) and/or output (e.g., air or water flow). This method may only be used if applicable, industry recognized system performance curves are available. Acceptable sources for performance curves are nationally recognized associations of professionals working in the industry, such as ASHRAE, or reliable scientific sources (examples include the curves used in DOE-2 developed by the Lawrence Berkeley National Laboratory, or the curves used in BLAST from the US Army Construction Engineering Research Laboratory). Before using a performance curve, other than those listed for HVAC fans here, the Project Sponsor should verify with the Utility Administrator that the curve is acceptable.

If the system does not meet the system description for which a curve was developed, the curve cannot be used. In the project application, state the type of system and the curve (equation) that will be employed for estimating energy consumption. The Utility Administrator will verify the system type and the applicability of the curve during the pre-installation inspection.

4.7.2 Methodology Using HVAC Fan Performance Curves

The methodology for determining energy savings using system performance curves is illustrated below along with example HVAC fan system performance curves from ASHRAE Standard 90.1. While different system performance curves may be required for each unique project, the methodology for determining savings will be the same.

ASHRAE Standard 90.1 lists the following equation and coefficients to determine demand (kW) for a given flow rate (CFM) in variable air volume fan systems.

$$kW_{IN}(CFM) = kW_{IN}(CFM_{MAX})\left[A + B\left(\frac{CFM}{CFM_{MAX}}\right) + C\left(\frac{CFM}{CFM_{MAX}}\right)^2\right]$$

where:

$kW_{IN}(CFM)$ = input power at the airflow rate

$kW_{IN}(CFM_{MAX})$ = input power at the maximum scheduled airflow rate, CFM_{MAX}

CFM = air flow rate

CFM_{MAX} = maximum air flow rate

A, B and C = constants from Table 3.4-1

Table G-3. ASHRAE 90.1 Fan Coefficients

Fan Type – Control Type	A	B	C	Minimum Turndown (% CFM)	Minimum Input (% Power)
Air-foil or backward inclined – riding the curve	0.227143	1.178929	-0.410714	45%	68%
Air foil or backward inclined – inlet vanes	0.584345	-0.579167	0.970238	30%	48%
Forward-curved – riding the curve	0.190667	0.310000	0.500000	10%	22%
Forward-curved – inlet vanes	0.339619	-0.848139	1.495671	20%	22%
Vane-axial – variable-pitch blades	0.212048	-0.569286	1.345238	20%	15%
Any – variable-speed drive	0.219762	-0.874784	1.652597	10%	20%

Note that at any level below the minimum turndown, the minimum input power must be used (a constant percent of the maximum power input). If the fan system has outlet dampers, the coefficients denoted as “riding the curve,” in Table G-3 should be used for the applicable fan type. For more information about applying the equation and the coefficients to the system, refer to ASHRAE Standard 90.1.

For the purposes of this program, a derivation of the ASHRAE equation for fan systems will make calculating energy savings simpler:

$$kW_{\%MAX} = A + B(CFM_{\%MAX}) + C(CFM_{\%MAX})^2$$

where:

$kW_{\%MAX}$ = Fraction of the full-load demand (kW)

$CFM_{\%MAX}$ = Fraction of the full-load flow (CFM)

Assuming air flow rates are the same before and after the VSD is installed on the fan motors, energy savings are calculated using the following methodology:

1. Establish the maximum baseline kW demand by recording spot measurements of the baseline motor’s power draw (true RMS kW) at full-load conditions, e.g., the fan is producing its maximum CFM and all vanes or dampers are wide open.
2. After installing the VSD, establish the maximum post-installation kW demand by recording spot measurements of the VSD controlled motor’s power draw (true RMS kW) at full-load conditions, e.g., full speed.

3. With the VSD operating take average demand readings at 15-minute time intervals.
4. The ratio of the 15-minute time interval VSD demand to the post-installation, maximum demand spot reading ($kW_{\%MAX}$) can be input into the ASHARE 90.1 equation using the VSD coefficients. The equation then provides an estimate of the ratio of current, post-installation CFM to maximum CFM ($CFM_{\%MAX}$)—for every fifteen minute interval.
5. Once the CFM ratio is known, the baseline kW can be found by inserting the CFM ratio into the ASHRAE 90.1 equation using the coefficients for the applicable baseline fan system type.
6. The kW savings for the 15-minute interval are found by subtracting the monitored post-installation kW from the baseline kW found with the equation and coefficients.

Figure G-1 shows a graphical representation of each ASHRAE 90.1 system performance curve.

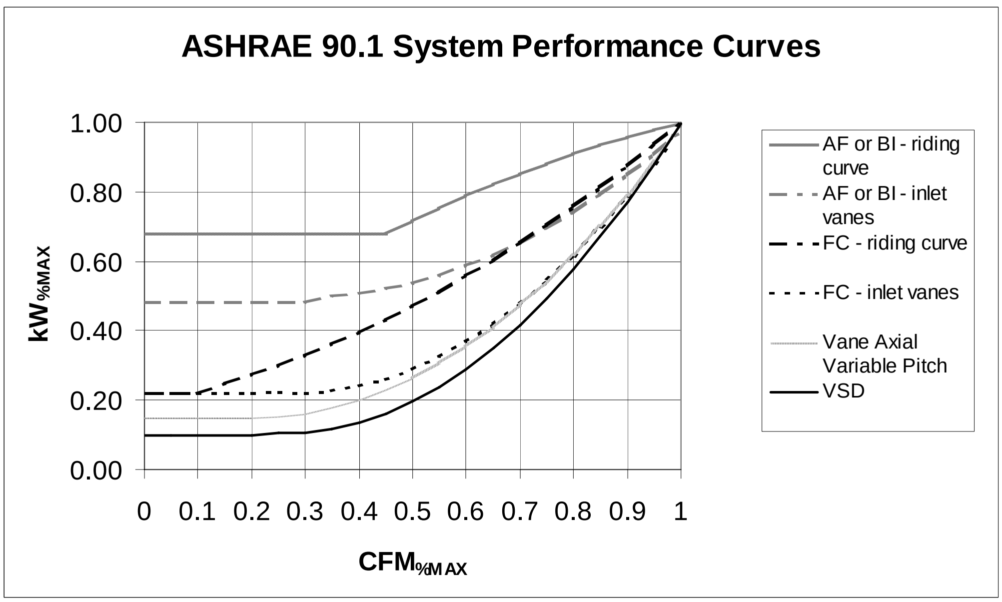

Figure G-1. ASHRAE 90.1 System Performance Curves

4.7.3 Pre-Installation Spot-Measurements

A spot measurement of the full-load kW energy demand is required on the existing motors. It may be necessary to manually adjust control devices to achieve the maximum motor loading, i.e., power draw. In this case one should be careful to adjust all control devices so that the system is at actual full load. Such measurements should be made using a true RMS meter with an accuracy at or approaching ± 3% of reading.

Prior to finalizing the M&V plan, the Project Sponsor should test the analysis method by using sample data to see if the results and calculation methodology result in consistent and logical results.

4.7.4 Post-Installation Monitoring

Post-installation monitoring is required for all VSD installation retrofits. With this M&V method, monitor motor power draw (kW) at 15-minute intervals continuously or for a set period which can be easily extrapolated to the entire year.

If less than continuous monitoring is used, the monitored data will be extrapolated to the full year. A minimum monitoring period of one month is recommended. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to collect data during different times of the year. Examples of set monitoring or metering intervals are once a month for each season or one random month during each performance year.

4.8 Method VSD-B-03: Variable Load-Correlating Power to Independent Variable Values

With this method, a regression based equation is established between the baseline and post-installation energy consumption and all applicable and significant variables (flow, number of widgets produced, etc.). Values for both the baseline demand (kW) and the applicable variables are established prior to VSD installation. These data are used to develop a regression based equation that defines the relationship between baseline demand and the applicable variables. Then after VSD installation, demand and operating hour data are collected and the same applicable variables (flow, number of widgets produced, etc.) defined for the baseline equation are monitored.

Using the baseline equation, with the values of the applicable variables in the post-installation phase, the baseline kW values are determined. Thus, demand savings are calculated for each post-installation time interval. Data collected on operating hours are also collected after the VSDs are installed in order to determine what baseline energy use would have been and thus the kWh savings.

4.8.1 Pre-Installation Short-Term Monitoring

Baseline monitoring, probably at 15-minute intervals, is required of (1) true RMS kW and (2) all applicable variables. This information is used to establish a relationship between kW and the variables prior to installation of the VSD. The applicable variable can be time, so baseline short-term monitoring is conducted to:

- Develop a schedule of motor kW (for example, 4,380 hours per year at 40 kW and 4,380 hours per year at 20 kW); or
- Define the relationship between motor kW and the appropriate independent variables (for example, outdoor air temperature or system pressure for a variable air volume system).

All short-term monitoring must be of a sufficient length of time to capture the full range of operation of the motors. In general, the monitoring period should be between two and four weeks; however, the actual time and frequency required will be specific to the project.

Once the short-term monitoring is collected, the relationship between baseline kW and the applicable variables must be developed and presented in the project application.

The statistical validity of the regression model will need to demonstrate that::

- The model makes intuitive sense (e.g., the explanatory variables are reasonable and the coefficients have the expected sign [positive or negative] and are within an expected range [magnitude]).
- The modeled data represent the population.
- The number of coefficients is appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations).
- The T-statistic for all key parameters in the model is at least two (95% confidence that the coefficient is not zero). R2 values are at least 80%.
- The model is tested for possible statistical problems and, if present, appropriate statistical techniques are used to correct for them.

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

The regression models or equations will be verified by the Utility Administrator during the pre-installation inspection and the review of the application submittal.

4.8.2 Post-Installation Monitoring

Two post-installation monitoring approaches are possible:

- Monitor motor (with VSD) kW, kWh, operating hours, and the relevant variables defined in the baseline model or equations
- Monitor just motor (with VSD) kW, kWh, and operating hours

If just motor kW, kWh, and operating hours are monitored, the values for the relevant variables defined in the baseline model or equations must be calculated. This requires short-term monitoring of the variables and the motor kW (or kWh) for period of time after the VSD are installed. Then, similar to the baseline model development, the post-installation monitoring data are used to develop a model or equation defining the relationship between the post-installation kW and the applicable variables. These models or equations are presented in the Operating Report.

Regression relationships between applicable variables and motor kW developed for the baseline and post-installation motor power consumption should have R^2 values of at least 80%, with absolute values for t-statistics of explanatory variables greater than 2. The relationships will be verified by the Utility Administrator.

4.8.3 Calculating Baseline Energy Use with Post-Installation Data

After having developed the baseline regression model or equations, savings can be calculated using one of two different methods, depending on what data are collected after the VSD(s) are installed:

- **If just post-installation power consumption is monitored.** Insert the post-installation power consumption data into the post-installation regression model or equations, to determine the value of the applicable variables. Then insert the value of the applicable variables into the baseline model or equations to determine the baseline energy consumption given the same values of the applicable variables.
- **If post-installation power consumption and the applicable variables are monitored.** Inserting the values of the applicable variables into the baseline model or equations, determine what the baseline power consumption would have been, absent the installation of the VSDs.

4.9 Monitoring for Operating Hours

If the operating hours of the motors will change as a result of the project, the baseline and post-installation operating hours must be established separately with short-term (baseline) or long-term (post-installation) monitoring on at least a sample of motors.

Operating hours will be established for different operating scenarios. Examples include:

- For a baseline motor: 4,000 hours per year at 50 kW (control valve open), and 4,760 hours per year at 40 kW (control valve closed)
- For a motor with a VSD: 2,000 hours per year at 15 kW (50% speed), 2,000 hours at 30 kW (75% speed), and 4,760 hours at 50 kW (100% speed)

Conduct the short-term monitoring for a period of time specified in the measurement and verification plan. Project Sponsors should propose a time period for Utility Administrator approval. The time period should be long enough to establish the annual operating hours at different loads and cover the full range of operating scenarios.

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

If operating hours change as the result of the retrofit, calculate energy savings using the following equation:

$$kWh_{saved} = kW_{base} OH_{base} - kW_{post} OH_{post}$$

where:

kWh_{saved} = the estimated annual amount of kilowatt hours of saved

kW_{base} = the pre-installation average kW

kW_{post} = the post-installation average kW

OH_{base} = the pre-installation operating hours

OH_{post} = the post-installation operating hours

4.10 Other Issues

The following is a list of issues that should be addressed in a measure-specific M&V plan for variable speed drive projects:

- Whether the existing equipment meets minimum standards (if the motor is being replaced)
- Whether the baseline is a constant or variable value and whether operating hours are assumed to be constant before and after measure installation
- Identification of the independent variables that determine baseline and post-installation power draw, how they impact power draw, and the range of values that they are anticipated to have
- How baseline kWh will be calculated after VSD installation (if variable)
- The time period of metering, metering protocol, and reporting format for documenting baseline and post-installation energy use and their relationships to independent variables
- The time period for post-installation monitoring of kWh, independent variables, and/or operating hours as well as the metering protocol and reporting format
- The reporting information and format to be used for baseline and post-installation inspections

5. Chiller Replacement

Option B, Method CH-B-01: Metering Chiller kW

Option B, Method CH-B-02: Metering Chiller kW and Cooling Load

5.1 Introduction and Key Issues

The methods discussed in this section pertain to projects that involve the replacement of water cooling packages (chillers). There are two approaches to conducting M&V: a simple, conservative approach based on rated equipment efficiencies and a more complex approach that captures variations in equipment performance.

Examples of energy efficiency measures for which these M&V methods would apply include:

- Replacing existing chillers used for space conditioning with high-efficiency chillers
- Replacing existing chillers used for process cooling, such as reducing the temperature of products on a production line, with high-efficiency chillers.

If the cooling load changes as result of the project, these methods do not apply. For these situations, consider using Method GVL-B-01 or the calibrated simulation method.

The following key issues should be noted:

- Minimum baseline, chiller efficiency standards apply to these types of projects—whether they are for space conditioning or process applications.
- Post-installation metering of chiller electricity consumption is required.

5.2 Overview of Methods

The two M&V methods described in this section are:

- CH-B-01, monitoring post-installation chiller electricity use. This method is limited to estimating savings based on changes to efficiency only. This is referred to as the **simple** approach.
- CH-B-02, monitoring post-installation chiller energy use as well as the cooling load and state points. Estimates energy savings for both efficiency improvements and changes in performance characteristics such as efficient unloading using a VSD on the compressor. This is referred to as the **complex** approach.

For both methods, the baseline efficiency is defined by California's Title 24 minimum efficiency standards and only requires post-installation monitoring. See Appendix D for baseline standards information.

3.5.3 Baseline Issues

A chiller replacement project will only receive incentive payments for the energy saved due to increases in chiller efficiency above the minimum efficiency standard. For a listing of minimum efficiencies of cooling equipment, please see Appendix C. The baseline efficiency for any chiller can be determined if the following characteristics are known for the proposed chiller:

- Condenser type, such as air-cooled or water-cooled
- Capacity in full-load tons as rated by the American Refrigeration Institute (ARI)

Under Title 24, chiller standards are indicated with IPLVs (Integrated Part-Load Values) and COPs (ARI full-load-rated Coefficient of Performance). As indicated in Appendix C, for this program **use the COP values.**

The application of each of the efficiency standards for the simple and complex M&V approaches is discussed in Sections 5.5.2 and 5.5.3.

Title 24 also specifies performance characteristics to predict unit performance under non-standard conditions. Method CH-B-02 involves the use of these performance characteristics and requires additional monitoring of supply temperature, entering condenser water temperature, and cooling load. Adjustments needed to use these performance characteristics include:

- Capacity adjustment
- Adjustment to efficiency reflecting part-load conditions
- Adjustment to efficiency to reflect actual supply and condenser temperatures

5.4 Initial Savings Estimate

An initial savings estimate, which will later be compared with the M&V results, must be prepared as part of the project application submittal. This estimate should be based on the best possible data available. Ideally these data will be similar to the data collected during the performance period of the SPC/NRR-DR Agreement. In most cases, however, much fewer data are available at the application stage to generate the initial savings estimates.

For chiller projects, the following methods may be used to generate the initial savings estimates:

- Computer simulation or bin analysis of the chiller system(s)
- Analysis of spot measurements or short-term monitoring data of the existing chiller. This involves extrapolating the measured chiller(s) kW and operating hours to the entire year and calculating the post-installation demand with a ratio of the baseline and proposed chiller efficiencies. This can be full-load hourly analysis using existing or estimated chiller run time.
- Using the same calculations called for in the selected M&V method with the use of pre-installation metering or historical data, instead of post-installation data

The method for developing savings estimates should be selected based on available data for the facility, the savings uncertainty (or risk of achieving savings), the proposed M&V method, and the value of incentive payments. The main point to remember when approaching the savings estimate is that a better estimate results in more realistic expectations.

5.5 Approach to M&V

Project savings may be determined through either the simple or the complex M&V approaches.

The simple approach is based on the post-installation electrical consumption of the new chiller. Savings are estimated by simply applying the ratio of baseline efficiency to proposed efficiency. This method assumes that the baseline chiller operates identically to the proposed chiller, just more efficiently. Select this method for minimum data collection and a conservative estimate of savings.

The complex approach involves using post-installation data representing the cooling load and operating conditions to model the baseline with Title-24 minimum equipment curves provided by the California Energy Commission (CEC). This method takes a detailed approach to computing how the baseline chiller would have performed if operated under the conditions observed with the proposed chiller. This method should be selected in order to claim an incentive for increased part-load performance, but requires extensive data collection and analysis.

5.5.1 Method Selection

When considering what approach to use for M&V, the primary considerations are:

- Chiller unloading capability
  - VSD-driven compressors
  - VAV boxes
  - Dual-speed air handler fans
- Existing controls and instrumentation

Chiller unloading capability refers to how the chiller operates at part-load or non-standard conditions. In order to take "credit" for the savings from improved part-load operation associated with the proposed chiller, the baseline chiller will need to be modeled using CEC-based performance characteristics and post-installation temperature and flow data. Note that the collection of accurate temperature and flow data can be expensive, and the benefit of intensive analysis needs to be carefully weighed against the cost of data collection. However, if the existing chiller has been outfitted with controls and instrumentation to monitor flow rates and temperatures, it may be advantageous to model baseline performance.

5.5.2 Determining Energy Savings: Simple Method

The following activities must be accomplished in order to demonstrate savings:

- Determine baseline, minimum standard, efficiency (COP)
- Determine new chiller efficiency (COP)
- Measure post-installation chiller energy use (kWh)
- Calculate savings

To estimate baseline load, first compute the ratio of baseline full-load efficiency (minimum standard or existing, whichever is higher) to the rated full-load manufacturer rated efficiency of the new chiller. This ratio is then used to scale the monitored, post-installation chiller energy use data to represent baseline energy use. The key assumption that allows this type of calculation is that the proposed and baseline chillers have identical operating characteristics. That is, the only difference between the proposed and baseline chillers is the rated efficiency.

Since the only difference between the two chillers is rated efficiency, the baseline usage can be estimated with the energy use data from the new chiller and the ratio of efficiencies of the chillers. Using the efficiencies, the ratio is computed as the baseline efficiency divided by the proposed efficiency. Given this assumption, the baseline usage can be estimated as:

$$kWh_{Baseline} = kWh_{proposed}\ x \left(\frac{Eff_{Baseline}}{Eff_{New}} \right)$$

where the efficiency (Eff) is stated in terms of kW/ton. The above equation can be interpreted as saying that the baseline chiller will consume a fixed percentage above the proposed chiller. Savings are estimated by subtracting the post-installation load data from the estimated baseline load as:

$$kWh_{Savings} = kWh_{Baseline} - kWh_{New}$$

or this calculation can be made directly as:

$$kWh_{Savings} = kWh_{new} \left(\frac{Eff_{Baseline}}{Eff_{new}} - 1 \right)$$

This calculation must be completed for a data set that can represent an entire year's worth of chiller energy usage. Monitoring of post-installation energy use can be done continuously throughout the term of the SPC/NRR-DR Agreement or during set intervals during the term of the Agreement. Whatever period is selected must be representative of the entire year. The monitoring period must be defined, for Utility Administrator approval, in the measure-specific M&V plan.

Note that this method, intrinsically, uses actual load (weather, occupancy, etc.) data versus typical values.

5.5.3 Determining Energy Savings: Complex Method

In the complex savings verification approach, the performance of the baseline chiller must be modeled using the operating characteristics defined by the CEC. The steps needed to model the chiller's performance are:

1. Calculate the current (post-installation) cooling load in tons.
2. Calculate the current chiller capacity.
3. Calculate the current part-load ratio (PLR).
4. Calculate the correction to input power for the PLR.
5. Calculate the correction to input power for current chilled water supply and condenser water return temperatures.
6. Calculate the electrical demand for the current time period.
7. Calculate the annual electricity savings.

Each of these steps is described in detail below. Following is a description of notation used:

$Tons_i$	Current cooling output from chiller
CHWF	Chilled water flow (gallons per minute)
ECHWT	Entering chilled water temperature (return temperature, °F)
LCHWT	Leaving chilled water temperature (supply temperature, °F)
CWT	Condenser water temperature (°F)
500	Conversion from GPM to pounds per hour (Eqn. 1)
1	Btu per pound-degree Fahrenheit (Eqn. 1)
12,000	Conversion from Btuh to tons (Eqn. 1)
CAP_{nom}	Nominal capacity of chiller
kW_{nom}	Nominal or full-load chiller demand (kW)
$LCHWT_{nom}$	Leaving chilled water temperature (supply temp. °F) at nominal rating conditions
CWT_{nom}	Condenser water temperature (°F) at nominal rating conditions
CAP_{ref}	Reference capacity of chiller for a given curve
kW_{ref}	Reference full-load chiller demand (kW) for a given curve
CAP_i	Current capacity of chiller
PLR_i	Current part-load ratio
kW_i	Current chiller demand (kW)
PLR_{Adj}	Adjustment to input power due to part load
$Temp_{Adj}$	Adjustment to input power due to chilled and condenser water temperatures

Step 1

Calculate current cooling load based on the flow and temperature data collected with stand-alone instrumentation or, if possible, an energy management system (EMS). In the event that a Btu meter is used, this step will be simplified in that no conversion to tons will be required. Use Equation 1 below to compute the tons of cooling currently being provided by the chiller.

Equation 1:

$$Tons_i = \frac{(CHWF)(500)(ECHWT - LCHWT)(1)}{12{,}000}$$

Step 2

Calculate the reference capacity and power for the chiller based on a nominal rating and the curve coefficients. The equation used is bi-quadratic, with the coefficients defined by the CEC.

Equation 2:

$$CAPFT(LCHWT_{nom}, CWT_{nom}) = a + b(LCHWT_{nom}) + c(LCHWT_{nom})^2 + d(CWT_{nom}) + e(CWT_{nom})^2 + f(LCHWT_{nom})(CWT_{nom})$$

Equation 3:

$$EIRFT(LCHWT_{nom}, CWT_{nom}) = a + b(LCHWT_{nom}) + c(LCHWT_{nom})^2 + d(CWT_{nom}) + e(CWT_{nom})^2 + f(LCHWT_{nom})(CWT_{nom})$$

Equation 4:

$$EIRFPLR(1.0) = a + b + c$$

Equation 5:

$$CAP_{ref} = \frac{CAP_{nom}}{CAPFT(LCHWT_{nom}, CWT_{nom})}$$

Equation 6:

$$KW_{ref} = \frac{KW_{nom}}{CAPFT(LCHWT_{nom}, CWT_{nom}) \times EIRFT(LCHWT_{nom}, CWT_{nom}) \times EIRFPLR(1.0)}$$

Step 3

Calculate current capacity. Since the capacity of the chiller will vary from the rated capacity depending on the actual supply and condenser water temperatures, a capacity adjustment must be calculated. The current capacity of any chiller is a function of the nominal capacity and the current chilled water and condenser water temperatures. The equation used is bi-quadratic, with the coefficients defined by the CEC.

Equation 7:

$$CAP_i = CAP_{ref} [\ a + b(LCHWT) + c(LCHWT)^2 + d(CWT) + e(CWT)^2 + f(LCHWT)(CWT)]$$

where the coefficients "a" through "f" are defined by the CEC based on the chiller capacity and condenser type. Coefficients for all chiller types can be found in Appendix D.

Step 4

Calculate the current part-load ratio: simply the ratio of current tons to current capacity, the two quantities that are calculated with equations 1 and 2.

Equation 8:

$$PLR_i = \frac{Ton_i}{Cap_i\left(CAPFT\left(LCWT_i, CWT\right)_i\right)}$$

where CAPFT is calculated using the actual measured temperature and the formula from Equation 2 above.

Step 5

Calculate the part-load adjustment to the nominal chiller kW. This adjustment is accounting for both the change in performance due to off peak loading as well as the off peak loading itself. The result of this equation is a multiplier to be used with the baseline chillers' nominal, full-load demand, to estimate consumption at the given part load.

Equation 9:

$$PLR_{AdJ} = a + b(PLR_i) + c(PLR_i)^2$$

Again, the coefficients are defined by the CEC and reproduced in Appendix D.

Step 6

Calculate the ambient adjustment to the nominal chiller kW. Similar to the part-load adjustment, this adjustment factor accounts for the change in nominal chiller performance as a function of condenser and supply water temperatures.

Equation 10:

$$Temp_{Adj} = a + b(LCHW) + c(LCHW)^2 + d(CWT) + e(CWT)^2 + f(CHWT)(CWT)$$

Step 7

Calculate the current baseline chiller kW. Using the part-load and temperature adjustment factors that have just been developed, calculate the current chiller demand as the product of nominal chiller demand, PLR_{Adj}, and $Temp_{Adj}$.

Equation 11:

$$kW_i = kW_{ref}\left(PLR_{Adj}\right)\left(Temp_{Adj}\right)\left(CAPFT\left(LCHW_i, CWT_i\right)\right)$$

Note that the above equation produces the average baseline kW for the interval associated with the data collected. Given that data are logged during a 15-minute time interval, the average kW estimated will need to be multiplied by 0.25 hours to convert from kW to kWh. For M&V purposes, average hourly values for temperatures and flows will be computed summing the four 15-minute data points contributing to each hour's worth of data.

Step 8

The calculations described below will be performed each year of the SPC/NRR-DR Agreement. The results will be reported in the Operating Report and will form the basis of incentive payments.

Energy savings for each time interval (hour) will be calculated by determining the power reduction for that time interval and multiplying by the time interval, using the following equations:

$$kWh\ Savings = (kW\ Savings) \times (1\ hour)$$

$$kWh\ Savings_{annual} = Sum(kWh\ Savings\ for\ all\ time\ intervals\ in\ the\ year)$$

where:

$kWh\ Savings_{annual}$ = annual energy savings [kWh]

kW Savings = ($kW_{baseline}$ - kW_{post}), the demand savings during a given metering time interval

$kW_{baseline}$ = kilowatt demand the baseline chiller would have required if the new chiller had not been installed, as calculated by the procedure presented above

kW_{post} = kilowatt demand of the new chiller during the post-installation time interval [kW] as recorded by the EMS, or data collection system

5.6 Other Issues

The following is a list of issues that should be addressed in the measure-specific M&V plan for chiller projects:

- Which M&V method will be used and why
- Whether the capacity of the new chiller(s) are different than the existing chiller(s); if different, explain why and how this might impact the M&V results
- Whether the existing chiller(s) meets minimum standards
- The source and values for baseline and new chiller efficiencies
- Which chiller performance curve and constants will be used if method CH-B-02 is being applied (describe the source of chiller load and temperature data that will be input into the performance curves)
- The time period for post-installation monitoring of kWh, independent variables, and/or operating hours as well as the metering protocol(s) and reporting format(s)

6. Generic Variable-Load M&V Guidelines

Option B, Method GVL-B-01: Continuous Post-Installation Metering

6.1 Introduction and Key Issues

This section discusses M&V methods applicable to projects that improve the efficiency of end uses that exhibit variable energy demand or operating hours. Examples of such projects include:

- Replacing gas-fueled boilers with high-efficiency boilers
- Upgrading building automation systems
- Installing new industrial process equipment or systems
- Comprehensive chiller plant modifications, including chillers, cooling towers, pumps, etc.

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

6.2 Overview of Method

The use of continuous post-installation metering normally involves four steps:

1. Auditing of the pre-installation system(s). As with all M&V methods, the Project Sponsor must audit existing systems to document relevant components (e.g., piping and ductwork diagrams, control sequences, and operating parameters).
2. Establishing a baseline model (e.g., an equation that determines energy use when key independent variables are known). All, or a representative sample, of the existing systems should be metered to establish regression-based equations or curves for defining baseline system energy use as a function of appropriate variables (e.g., weather or cooling load). Adjustments may be required for the models to comply with minimum energy efficiency standards.
3. Post-installation monitoring of energy use and/or independent variables such as weather. Monitoring can be done continuously throughout the term of the SPC/NRR-DR Agreement or during representative periods of time during each performance year.
4. Subtracting the post-installation energy use from the baseline energy use (as indicated in the baseline model). This difference represents the system savings.

There are two general approaches for determining savings:

- Continuously measuring post-installation energy use and the appropriate independent variables. Post-installation independent variable data are used with the baseline model to calculate baseline energy use.
- Continuously measuring only the appropriate independent variables during the post-installation period. The post-installation variable data are used with baseline and post-installation models to calculate baseline and post-installation energy use, respectively. With this approach, metering is required after the project is installed to determine the post-installation relationship between energy use and the independent variables.

6.3 Pre-Installation M&V Activities

Before installing any energy-efficiency modifications, this M&V method requires (a) an audit of all existing equipment affected by the proposed measure(s) and (b) development of a baseline energy consumption model based on metered system data.

6.3.1 Auditing the Baseline System

When auditing the affected systems document all relevant components, such as motors, fans, pumps, boilers, and controls. For each piece of equipment, document the manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, mmBTu/hr), nominal efficiency, the load served, and any independent variables that affect system energy consumption.

6.3.2 Establishing the Baseline Model

Measurements

Before making any efficiency modifications to existing equipment, the following variables must be monitored simultaneously:

- Independent variables that affect energy use. Examples of such data are ambient temperature, control outputs, flow rate, cooling tons, and building occupancy.
- System energy consumption. Meter energy use (e.g., kWh and therms) of the equipment to be affected by the efficiency measure over a representative time period before any efficiency modifications are made. The duration of this metering must be sufficient to document the full range of system operation. The M&V plan should propose an appropriate metering duration, which will be subject to the Utility Administrator's approval.

Typically, metering observations should be made in 15-minute intervals, unless it can be demonstrated that longer intervals are sufficient and such intervals are approved by the Utility Administrator.

If multiple, identical equipment components or systems are to be modified (e.g., multiple heating boilers), the measure-specific M&V plan may (subject to Utility Administrator approval) specify metering of only a sampling of the equipment. Contact your Utility for sampling information.

In some cases, a dependent variable may serve as an accurate proxy for energy use and may be monitored in lieu of energy metering. Examples of dependent variables that can be used (subject to Utility Administrator approval) as a proxy for energy include amperes and rotating equipment speed. If proxy variables are used, the Project Sponsor must provide evidence that the proxy variable is representative of the actual energy use.

Baseline Model Development

The energy use of most projects will be influenced by independent variables. For such projects, a model must be developed (typically using regression techniques) that links independent-variable data to energy use. The methodologies for creating such a model must be included in the measure-specific M&V plan prepared for Utility Administrator approval.

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

Criteria for establishing statistical validity are:

- The model makes intuitive sense; e.g., the explanatory variables are reasonable, and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- The modeled data represent the population.
- The model's form conforms to standard statistical practice and modeling techniques for the system in question.
- The number of coefficients is appropriate for the number of observations.
- The T-statistic for all key parameters in the model is at least two (95% confidence that the coefficient is not zero). The R2 is at least 80%.
- All data entered into the model are thoroughly documented and model limits (range of independent variables for which the model is valid) are specified.

Raw data used in model development must be submitted with an SPC/NRR-DR Application or Installation Report. The Utility Administrator will make a final determination on the validity of models and monitoring plans and may request additional documentation, analysis, or metering as necessary.

6.3.3 Baseline Standards

The baseline model must comply with all applicable minimum energy standards and codes, as defined in Appendix C. If any existing equipment that will be part of the project does not meet the applicable standards, the measure-specific M&V plan must document how the baseline model will be adjusted to account for the standards. It is possible that two baseline models will be developed—an existing system baseline model and a minimum-standard system baseline model. See Appendix C for more information on minimum equipment efficiency standards.

6.4 Post-Installation Metering and Savings Calculations

There are two approaches defined in this section for calculating savings:

1. Continuously measuring post-installation energy use and the independent variables used in the pre-installation model. Post-installation variable data are used with the baseline model to calculate baseline energy use.
2. Continuously measuring appropriate post-installation variables. Post-installation variable data are used with the baseline and post-installation models to calculate baseline and post-installation energy use.

6.4.1 First Approach: Metering Post-Installation Energy Use and Variables

After installing the measure, metering and monitoring will be conducted in the same way as the metering and monitoring performed to collect data for development of the System Baseline Model(s).

For this option, the post-installation metered input energy will be used directly in the savings calculation and the monitored independent variables will be used in the System Baseline Model(s) to calculate pre-installation energy input.

Calculate energy savings over the course of a single observation interval using the following equation (assuming an electricity measure):

$$\text{Energy Savings}_i = (kW_b - kW_m) * T_i$$

$$\text{Annual Energy Savings} = \sum \text{Energy Savings}_i$$

where:

kW_b = baseline kW calculated from System Baseline Model and corresponding to same time interval, system output, weather, etc., conditions as kW_m

kW_m =Measured kW obtained through continuous, or representative period, post-installation metering

T_i = Length of time interval

6.4.2 Second Approach: Metering Post-Installation Variables

The first step is to develop a Post-Installation System Model for use as a proxy for direct energy use measurement (conditional upon Utility Administrator approval). Then, monitor the relevant independent variables and then use the data to estimate post-installation energy use. If a Post-Installation System Model is to be used, the model development will be subject to the same requirements outlined for development of the Baseline System Model.

Once the post-installation energy use is estimated, calculation savings proceed as outlined in the preceding section “Metering Post-Installation Energy Use and Variables.”

The energy savings for each observation interval should be calculated using the following equation (assuming an electricity measure):

$$\text{Energy Savings}_i = (kW_b – kW_p) * T_i$$

where:

KW_b = baseline kW calculated from System Baseline Model and corresponding to same time interval, system output, weather, etc., conditions as kW_m

kW_p = post-installation kW calculated from Post-Installation Model and corresponding to the measured time interval, measured system output, measured weather variables, etc. in the post-installation period

T_i = length of time interval

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

6.5 Actual or Typical Data

To determine savings using dependent or independent variables, either use (a) the actual measured values as they occur during the term of the SPC/NRR-DR Agreement or (b) typical values for calculating savings. For example, with respect to weather data, it may be more appropriate to use typical year data versus actual weather data. Selection of actual or typical data is made on a project-by-project basis and requires Utility Administrator approval.

6.6 Measure-Specific M&V Plan

Specific M&V issues that need to be addressed and that are related to these types of generic variable-load projects include:

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

7. Billing Analysis Using Regression Models

Option C, Method GVL-C-01: Analyzing Billing Data Using Regression Analysis

7.1 Introduction and Key Issues

Option C for the SPC/NRR-DR program uses utility interval billing data to develop regression-based models to calculate energy savings. Utility billing analysis is limited to situations where the Utility Administrator indicates that Options B and D are not viable and that an accurate billing analysis model can be developed. This is considered the option of last resort and is the least-preferred M&V option.

Option C methods are the least preferred because:

- Twenty-four months of historical billing data and independent variable data are typically required to establish the baseline.
- It is necessary to use at least 9 and preferably 12 months of post-installation billing data and independent variable data prior to calculating first-year savings.
- The following tasks are often difficult or cannot be done accurately:

  --Adjustment of the analyses so the baseline meets minimum energy standards.

  --Allocation of savings to different measure categories for incentive level differentiation by measure type.

  --Removal of interactive savings from measures (e.g., cooling savings resulting from lighting projects) not counted for incentive payments under the SPC/NRR-DR program.

  --Adjustments of energy savings due to changes in facility operation or occupancy during the year-long M&V period.

  --Obtaining accurate data for the relevant independent variables that affect energy use and savings.
- The proper use of billing analysis requires experienced staff familiar with statistical concepts and data analysis.

However, billing regression analysis may be appropriate for projects in which the affected measure equipment has a dedicated utility meter, where equipment is not subject to state/federal baseline criteria, incentive levels are the same for all measures, and/or there are not many (one or two) relevant independent variables.

Billing regression analysis should not be used for lighting projects or projects in which the affected equipment shares a utility meter with several other end uses that also are affected by the same independent variables.

7.2 Overview of Method

M&V of measures using utility billing analysis requires a good deal of caution and is not a viable option in many cases. If billing data regression analysis is being considered, contact the Utility Administrator before preparing an M&V plan.

Multivariate regression is a technique that can be used to adjust baseline and, in some cases, post-installation energy consumption estimates for non-retrofit-related factors. If the necessary data on explanatory (or independent) variables, such as weather, occupancy, and operating schedules are available, the technique will result in more accurate and reliable savings estimates than a simple comparison of pre-and post-installation consumption—a practice that is not allowed in this SPC/NRR-DR program.

Use of the multivariate regression approach depends on, and is limited by, the availability of data. The decision to use a regression analysis technique must be based, in part, on the availability of appropriate information. Thus, on a facility-specific basis, it is critical to investigate the systems that affect and are affected by the project and select all independent variables that have relationships to energy use. Data must be collected for the dependent and explanatory variables in a suitable format over at least 12 and preferably 24 months prior to project installation.

Option C encompasses whole-facility or main-meter verification procedures that provide retrofit performance verification for those projects where whole-facility baseline and post-installation data are available. Option C involves:

- Collecting historical whole-facility baseline energy use data and continuously measuring whole-facility energy use after measure installation.
- Baseline and periodic equipment inspections
- Development of baseline and, in some cases, post-installation regression models of whole-facility energy consumption

7.3 Baseline Standards

The baseline (existing) equipment must comply with all applicable minimum energy standards and codes (see Appendix C for more information). If any existing equipment that will be part of the project does not meet these standards, the measure-specific M&V plan must document how the regression model will be adjusted so that this equipment's energy use value will comply with all minimum standards. This adjustment may be extremely difficult or require adjustments outside of the billing analysis. The Utility Administrator should be contacted if the existing equipment does not meet the minimum standards given in Appendix C of this manual.

7.4 Data Collection

Data collection, validation, and proper handling to ensure alignment of start and end dates are important elements of billing analysis.

7.4.1 Types of Data

Billing data serves as the dependent variable (the value to be estimated) for regression models for estimation of both baseline and, in some cases, post-installation energy use. Non-energy site data (such as outside air conditions) serve as independent variables that affect energy use and can be used to account for changes in energy use not associated with measure installation. These data elements are discussed below.

<u>Interval Demand Billing Data</u>

Interval billing data records the average demand (or energy use) for a given interval (e.g., 1 hour, 15 minutes, etc.) associated with the billing period. Note that monthly billing information often does not provide an adequate number of pre-installation or post-installation data points for sufficiently accurate analyses.

Non-Energy Site Data

Site data provide the information necessary to account for usage of, or changes in, energy consumption not associated with the retrofit equipment. Typical site data that can be incorporated in regression models include weather parameters, occupancy, facility square footage, and changes in operating hours. These data are typically used to help define the independent variables that explain energy consumption or change not associated with the measures.

7.4.2 Duration of Data Collection

Billing data to be used in the regression analysis, including the time period covered by the data, must be documented in the M&V plan. The following are some guidelines.

Baseline Energy Consumption

The regression analysis typically requires at least 12 to 24 months' worth of data prior to installation.

Post-Installation Energy Consumption

Regression analysis requires at least 9 and preferably 12 months of data after installation to determine savings for the first year. If post-installation billing analysis models are used, they should be updated until at least 12 months of post-installation data have been used to determine the independent variable coefficients.

7.5 Data Analysis Protocols

The criteria used for identifying and eliminating outliers need to be documented in the measure-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 because it is beyond the expected range of values. Before a point is eliminated, an explanation for the unexpected data should be sought, and if there is reason to believe that the data are abnormal because of specific mitigating factors, then the data point may 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 based on sound engineering judgement as well as common statistical practice. Outliers may be defined in terms of consumption changes and actual consumption levels.

7.6. Overview of the Regression Approach

A regression model should be developed that describes changes between pre- and post-installation energy use for the affected facility, taking into account all substantive explanatory variables. Any differences, after adjusting for non-retrofit-related factors, are then defined as the gross load impacts of the project.

For affected utility electric billing meters with time-of-use data, the regression model should estimate savings by hour or critical time-of-use period. For meters with only monthly consumption data, it may be sufficient for the models to predict monthly savings. The regression equations should be specified to yield as much information as possible about savings impacts.

A list of explanatory variables that affect energy consumption needs to be specified in the measure-specific M&V plan. Critical variables may include weather, occupancy patterns, and operating schedules. If the energy savings model incorporates weather in the form of heating degree-days (HDD) and cooling degree-days (CDD), the relationship between temperature and energy use, which tends to vary depending upon the time of year, must be considered. For example, a temperature of 55°F in January often has a different implication for HVAC energy use than the same temperature in August. Thus, seasonality may need to be addressed in the model. Use of building balance point temperatures is recommended for models that address HVAC energy use.

7.7 Testing Statistical Validity of Model(s)

The statistical validity of the regression model must be demonstrated. In addition to documenting that the model conforms to standard statistical practice it must also be shown that:

- The model makes intuitive sense—e.g., the explanatory variables are reasonable and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- The modeled data represent the population.
- The number of coefficients are appropriate for the number of observations
- The T-statistic for all key parameters in the model and the R2, for the model as a whole, are reasonable. The standards for reasonableness can be set in the measure-specific M&V plan for Utility Administrator review and approval.
- The model is tested for possible statistical problems and, if present, appropriate statistical techniques are used to correct for them.
- All data input to the model are thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.

7.8 Calculating Savings

Savings calculation details depend on issues such as:

- Use of hourly versus monthly utility meter billing data
- The data's format (e.g., corresponding to same time interval as the billing data and availability of all relevant data for explanatory variables)
- Amount of available energy consumption data
- Whether actual or typical data are used to calculate savings
- How energy standards and interactive savings are accounted for in the baseline.

7.9 Other Issues

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

- The experience and capability of the individual(s) that will conduct the analyses
- The availability of energy use and independent variable data
- How the baseline will be adjusted to have it meet minimum energy standards (see Appendix C)
- How the analyses will differentiate savings for measures with different incentive rates. To address this issue, using the billing analyses to estimate total facility energy savings may be considered and another M&V method used to estimate the percent savings from each measure category.
- How the analyses will account for interactive savings

8. Calibrated Computer Simulation Analysis

Option D, Method GVL-D-01: Computer Simulation

8.1 Introduction and Key Issues

Use of the calibrated computer simulation M&V method is appropriate for complex projects in buildings where multiple measures will be installed or where tracking complex building operation conditions is necessary. Because a computer simulation allows a user to model the complex interactions that govern a building'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, modeling a building and calibrating that model is a time-intensive activity and should be performed by an accomplished building simulation specialist. Calibrated simulation is an expensive M&V procedure, and should only be used for projects that generate enough savings to justify its use.

In general, projects for which the calibrated computer simulation method is an appropriate method include:

- The installation of multiple measures for which the savings are too difficult to determine independently and which may be paid at different incentive rates.
- Projects with measures that have energy usage dependent heavily on the weather and/or other building operation conditions such as occupancy and equipment operation schedules.

Specific project examples include:

- A lighting upgrade plus a variable air volume conversion project, because savings from the lighting and VAV measures must be calculated separately
- A project that includes both a chiller efficiency upgrade and the installation of a VSD on the cooling tower fan
- Improvements to the building shell, such as improving the windows or adding insulation to the walls or roof
- An addition of a control system which reduces equipment operation hours
- A project in which there have been major changes to the existing building (such as building additions or major renovations) within the past 12 months, or where it is known that changes are planned during the post-installation period

Situations for which calibrated simulation M&V is not appropriate include buildings or measures that cannot be modeled by the building simulation software program. Examples include:

- Building structures that cannot be modeled. Large atria, attached greenhouses, odd-shaped rooms, and other architectural features are building spaces that cannot be modeled by most common building simulation programs. These spaces are generally too large, or have complex heat circulation patterns, which the simulation program is not designed to model.
- Building systems that cannot be modeled. The simulation program lacks the capability to model certain equipment or control algorithms that are important for comparing baseline and post-installation scenarios. An example is adding optimum start/stop to the building energy management control system (EMCS). This measure requires the control system to "learn" a building's optimal operation cycles and adjust the starting and stopping of equipment based on this knowledge. Most building simulation software cannot model this ability of an EMCS.
- Building models that cannot be adequately calibrated due to a lack of utility or end-use meter data.

- Lighting-only projects. All lighting-only projects must use the lighting M&V procedures described in Section 2.

8.1.1 Cost Considerations

Calibrated simulation M&V requires extensive data collection for model definition and specification of operating conditions, and is generally an expensive procedure. It is not recommended for projects that will generate 200,000 kWh savings or less.

8.1.2 Allowable Simulation Software

The most frequently used type of building simulation program for energy analyses is the whole facility, fixed-schematic hourly simulation program.[1] Such programs are the most versatile, allowing the accurate modeling of most buildings through input data. Two of the most common public domain programs of this type are DOE-2 and BLAST.

For M&V plans using calibrated computer simulation models, only eQUEST 3.6 or more current DOE-2 versions are allowed. For small projects with small projected incentive payments, the Utility Administrator may consider allowing the use of other models if the:

- Program is commercially available, supported and documented;
- Model can be shown to adequately model the project site and the measures;
- Model can be calibrated to a level of accuracy approved by the Utility Administrator; and
- Calibration can be documented.

Fixed-schematic programs require extensive input data to describe a building. Merely writing all the necessary data into a program's input file can consume a significant part of the project budget. Recently, user interfaces have been developed that simplify the input process with easy-to-use graphical formats. More extensive libraries of building components, materials, and systems have been added to facilitate model development. Upon pre-approval by the Utility Administrator, the use of certain program model interfaces may be allowed.

8.1.3 Weather Data

Calibrating a computer simulation of a real building for a specific year necessarily requires that actual weather data be used. Programs that only allow use of average weather files or weather from only a few "representative" periods per month or season are not suitable for the calibration techniques described in this section. The measure-specific M&V plan must specify which weather data sources will be used. Both the source of the data and the physical location of the weather station need to be specified. One example of an acceptable weather data source is the National Oceanographic Atmospheric Association (NOAA). The location of the source of data is significant, because some NOAA city data are from weather stations at remote airports, well-removed from a downtown location.

1 Ayers, J.M. and E. Stamper, "Historical Development of Building Energy Calculations," *ASHRAE Transactions,* Vol. 101, Part 1, 1995.

8.1.4 Monitoring of Building Subsystems

Depending on the project size, the Utility Administrator requires that calibration of building models also include calibration to measured data from specific building sub-systems in addition to calibration to whole facility utility bill data. This requires that monitoring of building sub-systems be included in M&V activities (usually in the post-installation period). The specific sub-systems selected for monitoring are in most cases the installed measures. However, some measures, such as windows or insulation, cannot be monitored. In this case, the Project Sponsor must indicate which sub-systems will be monitored. Also, to improve the model calibration, it is recommended that the energy end uses for which the least information is available be monitored.

The Project Sponsor should propose the number of sub-systems to be monitored, and the number of variables, the duration, and the data collection interval for each specific sub-system. The Utility Administrator will review all sub-monitoring plans and accept or recommend changes to the plans.

8.1.5 Calculation of Project Savings

All measure savings will be determined by the difference in annual measure usage predicted by the baseline building model and that predicted by the post-installation building model. This means that annual usage of each measure must be obtained from each building model in order to make the calculation. Total project savings is determined by the sum of individual measure savings. The same rule applies in calculating the initial project savings estimate as well as the verified savings.

8.2 Definitions

This M&V method description uses various definitions of building models and concepts. Below are the key definitions used in describing this procedure:

Existing Building Model. The existing building model is a model of the building as-is. All data collected for the existing building will be used to construct the existing building model. These data include the building geometry and materials of construction, building orientation and solar shading, inventories and descriptions of all active building systems, which include the heating and cooling plant, HVAC and lighting systems, plug loads, occupancy rates, and building operation schedules, and so on. The existing building model is used as a basis for developing the baseline building model and the post-installation building model. In some cases, the existing building model and the baseline building model are the same.

Baseline Building Model. The baseline building model is a model of the building with equipment (chillers, HVAC, lighting, etc.) efficiencies that comply with California State Energy Standards (Title 24). This model is developed from the existing building model. Only the equipment efficiencies (such as lighting kW per lumen, motor efficiency, or chiller kW per ton) of equipment or systems that will be replaced by the measures of the project must be changed from those in the existing building model. In addition, this equipment efficiency adjustment is only needed for existing building equipment that does not comply with current California Title 24 regulations. For example, if an measure will upgrade a building’s chiller and the existing building’s chiller efficiency does not meet current Title 24 regulations, the baseline building model must include chiller efficiency specifications which meet current Title 24 regulations. Note that the efficiency specifications of the proposed chiller will be used in the post-installation model.

Post-Installation Building Model. The post-installation model is a model of the building with all of the proposed equipment efficiency specifications included. It differs from the existing building model and the baseline building model only in the efficiencies of the proposed measures. It uses the same descriptions of the building and the same building operation conditions as the existing and baseline building models to determine the post-installation energy usage.

Calibrated Model. A building model is considered to be calibrated if its predictions of whole facility energy usage and, when included in the M&V plan, its predictions of individual measure energy usage are in agreement with measured data. Demonstration of this agreement is done using the statistical comparison techniques described in Section 3.8.6.

Initial Savings Estimation. The initial savings estimate is required in the Application and may be determined from the predictions of uncalibrated models. However, the models must be "tuned" using the best available data, such as whole facility usage data from the building's previous 12 to 24 months of utility bills. If other data are available, such as trend logs of specific equipment energy usage from the building's EMCS, then it may also be used to develop the initial savings estimation. The initial savings estimation for each measure is determined from the difference in annual energy usage between the post-installation model prediction and the baseline model prediction. The procedure used to develop the initial savings estimation should be documented for approval by the Utility Administrator.

Verified Savings. Verified savings for each measure are determined from calibrated models after each post-installation year. Annual energy usage for each measure is determined from the difference in annual energy usage between the calibrated post-installation model prediction and the baseline model prediction. Total verified savings for each measure must be reported to the Utility Administrator in each Operating Report. The procedure used to determine the verified savings should be documented for approval by the Utility Administrator.

8.3 Overview of Method

The M&V method described here is based, in part, on materials in the 2009 International Performance Measurement and Verification Protocol (IPMVP). Information on the IPMVP may be found at www.ipmvp.org.

The standard approach to performing a calibrated simulation M&V plan is outlined below. The Project Sponsor may propose an alternate procedure, subject to approval by the Utility Administrator.

1. Model the existing building as-is.
2. Tune the existing building model to the best available data. For example, adjust the model inputs to obtain reasonable agreement between the model whole facility monthly usage and the previous 12 to 24 months of utility billing data. Similarly, obtain agreement between the model and data from trend logs for specific building subsystems.
3. Change the efficiencies of the affected equipment to the minimum state standard values to obtain the baseline building model.
4. Change the efficiencies of the affected equipment to that of the proposed equipment to obtain the post-installation model.
5. Determine the initial savings estimate of the project by subtracting the annual measure usage prediction of the post-installation model from the annual measure usage prediction of the baseline model. Repeat the procedure for each measure. Determine the total initial savings estimate from each savings category. Report the procedure and results in the project application.
6. Obtain SPC/NRR-DR Application approval and install the measures.

7. Perform any building sub-system spot measurements or short-term monitoring required for use in calibrating the post-installation model.
8. Calibrate the post-installation model using the collected data and actual weather data. Calibration requirements are described in Section 3.8.6. One of the following three model calibration approaches must be selected:
   - Calibration of whole facility usage to monthly utility bill data
   - Calibration of whole facility usage to monthly utility bill data in combination with calibration of specific sub-system usage to measured hourly data
   - Calibration of whole facility usage to hourly utility bill data
9. Substitute the baseline building equipment efficiencies into the calibrated post-installation model to obtain the calibrated baseline building model.
10. Determine the verified savings of each measure from the difference in the measure's annual usage predicted by the calibrated baseline model and the measure's annual usage predicted by the calibrated post-installation model. Determine the total verified savings from each incentive category. Determine the total incentive payment from each category's total savings and respective incentive rates. Report the procedure and results in the Operating Report.

8.4 Common Issues in Developing the M&V Plan

Many issues must be considered and addressed in developing the measure-specific M&V plan. Some of the more common issues are discussed below.

8.4.1 Use an Experienced Building Modeling Professional

Although new simulation software packages make much of the process easier, a program's capabilities and real data requirements cannot be fully understood by inexperienced users. Using inexperienced staff for building modeling will result in inefficient use of time in data processing, and in checking and understanding simulation results.

8.4.2 Availability of Hourly Utility Bill Data

Calibrations to hourly data are generally more accurate than calibrations to monthly data because there are more points to compare. However, hourly whole facility usage data are generally available only for a utility's largest customers. Determine whether hourly or monthly billing data are available and whether meters can be installed to collect hourly data. If only monthly billing data are available, be prepared to use additional short-term monitoring of building sub-systems to improve the accuracy of the model.

8.4.3 Specify Spot-Measurements and Short-Term Monitoring

These measurements augment the whole facility data and more accurately characterize building systems. It is recommended that the end-use be monitored over a period which captures the full range of the equipment's operation. The data must also be collected in a way which facilitates comparison to the building model's end-use prediction of the same quantity. Careful selection of spot measurements and short-term monitoring is necessary, because it may add significant cost and time to the project.

8.4.4 Use of the Simulation Program's HVAC System Library

Many software packages have libraries of HVAC systems that may seem to be a good match with the real system. Be cautious and investigate the library HVAC description to be sure it is a good representation of the real system.

8.4.5 Controls

Thoroughness is required to obtain close-to-exact sequencing of building controls. Sequencing of building controls is difficult to interpret from interviews, site surveys, manufacturer's data, and measurements. Be aware that the program's input capability may limit data input for control systems.

8.4.6 Use of California Title 24 Standard Equipment Efficiencies

The baseline model must comply with minimum energy standards with respect to the following:

- Baseline equipment/systems models must not include devices (e.g., lamps and ballasts) that are not allowed to be installed under current regulations.
- Baseline equipment models must meet prescriptive efficiency standards requirements for affected equipment. See Appendix C for minimum standard information.
- Baseline calculations do not have to comply with performance adherence methods that require the project site to meet an energy budget.
- Energy savings may be claimed for mandatory measures required for all construction.

8.5 Building Simulation Procedure

8.5.1 Collect Data

The amount of data required for simulating a real building is voluminous. The main categories of data to collect for the building and proposed measures are described below:

- Obtain building plans. Use as-built building plans; if not available, define alternative sources for Utility Administrator approval.
- Collect at least 12 (and preferably 24) consecutive months, with applicable dates, of utility bills for the months immediately prior to installation of the measures. The billing data should include monthly kWh consumption, peak electric demand for the month, and monthly heating fuel use (e.g., natural gas)[2]. Fifteen-minute or hourly data are also desired for calibration. Determine if building systems are sub-metered. Collect these data if available.
- If hourly data are required to calibrate the simulation, but none are available, consider installing metering equipment to acquire them.
- Determine what data to collect from the building using the software's user manual as a guide. Develop data-collection forms to facilitate a site survey and keep records of building data. Prepare summary tables to easily check program input.
- Conduct on-site surveys. Visit the building site and collect the requisite data identified in the preceding step. Data that may be collected include:
    - HVAC systems - primary equipment (e.g., chillers and boilers): capacity, number, model and serial numbers, age, condition, operating schedules, etc.
    - HVAC systems - secondary equipment (e.g., air-handling units, terminal boxes): characteristics, fan sizes and types, motor sizes and efficiencies, design-flow rates and static pressures, duct-system types, economizer operation, and control
    - HVAC system-controls: including location of zones, temperature set-points, control set-points and schedules, and any special control features

---

2 The SPC/NRR-DR program provides incentives for electric and natural gas savings in the PG&E and SDG&E service territories. No gas savings incentives are paid in the SCE service territory.

- Building envelope and thermal mass: dimensions and type of interior and exterior walls, properties of windows, and building orientation and shading from nearby objects
- Lighting systems: number and types of lamps, with nameplate data for lamps and ballasts, lighting schedules, etc.
- Plug loads: summarize major and typical plug loads for assigning values per zone
- Building occupants: population counts, occupation schedules in different zones
- Other major energy-consuming loads: type (industrial process, air compressors, water heaters, elevators), energy consumption, schedules of operation

▪ Interview operators. Building operators can provide much of the above listed information and also any deviation in the intended operation of building equipment. It is critical to note changes in building occupancies that will effect energy use and thus the calibration process.

▪ Make spot measurements. Record power draw on lighting plug load, HVAC equipment, etc., circuits to determine actual equipment operation power.

▪ Conduct short-term monitoring. Data-logging monitoring equipment is set up to record system data as it varies over time. These data reveal how variable-load data change with building operating conditions such as weather, occupancy, daily schedules, etc. These measurements may include lighting systems, HVAC systems, and motors. The measurement period may be from one to several weeks. These data may be required if particular subsystems, e.g., the chiller plant in a building, need to be accurately modeled in order to determine savings.

▪ Collect weather data. For calibration purposes, representative site weather data are required. These data may be measured on-site or obtained for a nearby site from the National Climatic Data Center (NCDC).[3] Solar radiation data is not generally available in these data sets, but many programs have modules that simulate solar radiation from the cloud cover values in the NCDC data.

  Model calibration is most effective when the weather files contain real data for the same dates covered by the billing records. After the model is calibrated, the building's energy use may be normalized using average-year weather. Average weather data may be obtained from ASHRAE (WYEC2) and the National Renewable Energy Laboratory (TMY2).

▪ Document all collected information and inputs in a format that allows due-diligence review. Inadequate or disorganized documentation can be the basis for rejecting a submittal.

8.5.2 Input Data and Run Model

Consult the simulation program's user guide to determine how to properly input the collected data into the model. From the volume of data collected, many decisions must be made to best represent the data in the simulation program's input file. This can be done most cost-effectively by an experienced building modeling specialist.

After inputting data, run a few simulations to debug the model. Check the model output files to verify that there are no errors in running the program and that the model predictions are reasonable.

3 The National Climatic Data Center is located at 37 Battery Park Avenue, Federal Building, Asheville, NC 28801, 704-271-4800.

8.5.3 Compare Outputs to Measured Data

Using the procedures described in Section 8.6, compare the energy usage and demand projected by the model to that of the measured utility data. This step may require some post-processing to view the comparison. All utility billing data should be used in the analysis, electric as well as heating fuels such as natural gas.

The calibration process must be documented to show the results from initial runs and what changes were made to bring the model into calibration. This information, as well as the actual calibration results, needs to be provided in post-installation submittals and annual reports.

8.5.4 Refine Model

If the statistical indices calculated during the previous step indicate that the model is not sufficiently calibrated, revise the model inputs, run the model, and compare its predictions to the measured data again. There are graphical and statistical techniques described in Section 8.6 that hint at where the greatest errors in the model can be found. Pay particular attention to the model's predictions of usage by the project measures. These results can be plotted and compared with short-term measured data and scheduling information to check for sources of error.

8.6 Calibrating the Building Model

Selecting an approach to calibrating a building model depends on many factors. Among these are the availability of hourly utility bill data and the amount of project savings. After consideration of these and other factors, the Project Sponsor must select one of the following three approaches to calibrating the building models:

- Calibration at the whole facility level, comparing model monthly usage predictions to monthly utility bill data
- Calibration at the whole facility level, comparing model monthly usage predictions to monthly utility bill data in combination with calibration at the subsystem level, i.e., comparing model sub-system usage predictions to measured hourly data
- Calibration at the whole facility level, comparing model hourly usage predictions to hourly utility bill data

The following three sections describe the required tolerances for model calibration at the whole facility level using monthly data, at the sub-system level using hourly data, and at the whole facility level using hourly data. Note that for second approach, calibration at the whole facility level using monthly data combined with calibration at the sub-system level using hourly data, then the calibration tolerances prescribed in Sections 8.6.1 and 8.6.2 both apply.

8.6.1 Whole Facility Level Calibration with Monthly Data

Comparing energy use projected by the building model to monthly utility bills is straightforward. First, the model is developed and run using weather data that corresponds to the monthly utility billing periods. Next, monthly simulated energy consumption and monthly measured data are plotted against each other for every month in the data set, as shown in Figure G-2. Be sure to sum the model's whole facility energy usage over the same calendar days as for each month's utility bill. The error in the monthly and annual energy consumption is calculated by the following equations:

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

$$ERR_{year} = \sum_{year} \frac{ERR_{month}}{N_{month}}$$

where M indicates the measured kWh or fuel consumption and S the simulated kWh or fuel consumption. N_{month} is the number of utility bills in the year.

Note that monthly differences in measured and simulated energy consumption may cancel each other, resulting in a smaller annual ERR. To ensure against cancellation of monthly errors, the coefficient of variation of the root-mean-squared monthly errors must also be checked.

The root-mean-squared monthly error is calculated by the following equation:

$$RMSE = \sqrt{\frac{\sum_{month} (M - S)_{month}{}^{2}}{N_{month}}} \ ,$$

The mean of the monthly utility bills is:

$$A_{month} = \frac{\sum_{year} M_{month}}{N_{month}}$$

The CV(RMSE) for the monthly billing data is:

$$CV(RMSE_{month}) = \frac{RMSE_{month}}{A_{month}} \times 100$$

The combination of ERR and the CV(RMSE) can determine how well model predicts whole facility energy usage. The lower the ERR and CV(RMSE), the better the calibration. Table G-4 below specifies the acceptable tolerances for monthly and yearly values of ERR for monthly data calibration.

Table G-4. Acceptable Tolerances for Monthly Data Calibration

Index	**Value**
ERRmonth	± 15%
ERRyear	± 10%
CV(RMSEmonth)	± 10%

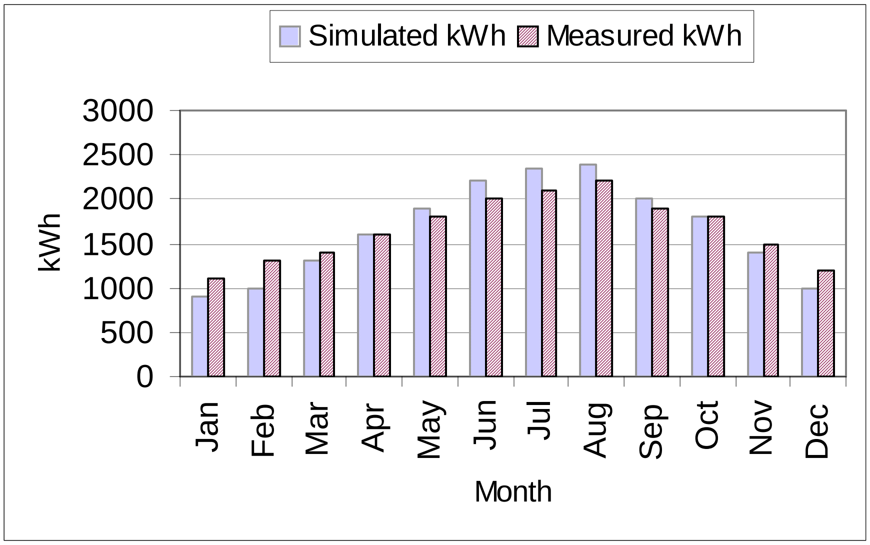

Figure G-2. Comparison of Measured and Simulated Results.
For this example, EERyear = 2.5% and CV(RMSEmonth) = 10.3%.

8.6.2 Sub-system-Level Calibration with Monitored Data

Calibration of a building model's sub-systems to measured data may be required to enhance the accuracy of the model. The model's hourly predicted energy usage (kWh, therms, or Btu) is compared to measured hourly energy usage for the monitored building sub-systems (the sub-systems are to be specified in the M&V plan). Compare the measured and modeled data using the mean bias error (MBE) and the coefficient of variation of the root-mean-squared error [CV(RMSE)] to determine whether the model accurately predicts subsystem level usage. In this case, the MBE is defined as:

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

where M_{hr} is the measured hourly sub-system average usage and S_{hr} is the hourly average predicted usage from the building simulation.

eQUEST 3.6 can output most sub-system usage values in hourly intervals, therefore measured data must be averaged over each hour. For example, if a chiller is monitored for exactly four weeks beginning Wednesday, June 23, 1999 at 12 noon, then the monitoring period consists of all 672 hours from then until 12 noon on July 21, 1999. The monitoring period should be sufficient to capture the entire range of operation of the sub-system.

The RMSE is obtained by squaring the difference between paired hourly data points, summing the squared differences over each monitoring period, and then dividing by the number of points in the monitoring period. The square root of this quantity yields the root mean squared error. The CV(RMSE) is obtained by dividing the RMSE by the mean of the measured data for the monitoring period.

The root mean square error for the monitoring period is:

$$RMSE_{period} = \sqrt{\frac{\sum_{period}(M-S)_{hr}^{2}}{N_{hr}}} \text{ ,}$$

where N_{hr} are the number of hours in the monitoring period. The mean of the measured data for the period is:

$$A_{period} = \frac{\sum_{period} M_{hr}}{N_{hr}}$$

The CV(RSME) is:

$$CV(RMSE_{period}) = \frac{RMSE_{period}}{A_{period}} \times 100$$

The combination of MBE and CV(RMSE) can determine how well the model of the building sub-system fits the monitored data. The lower the MBE and CV(RMSE), the better the calibration. Table G-5 below specifies the acceptable tolerances for MBE and CV(RMSE).

Table G-5. Acceptable Tolerances for Hourly Data Calibration for Building Sub-Systems

Index	**Value**
MBEperiod	± 7%
CV(RMSEperiod)	± 15%

8.6.3 Whole Facility-Level Calibration with Hourly Data

If hourly data are available and calibration to hourly data will be used, two statistical indices are required to declare a model "calibrated." These are the monthly mean bias error (MBE) and the coefficient of variation of the root mean squared error (CV(RMSE)).[4]

The mean bias error is calculated by subtracting the simulated energy consumption from the measured energy consumption for all the hours over a given time period, usually a month or equivalent billing period. The differences are summed and then divided by the sum of the measured energy consumption over the same time period. MBE is expressed as:

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

where M indicates the measured kWh or fuel consumption and S the simulated kWh or fuel consumption.

4 Kreider, J. and J. Haberl, "Predicting Hourly Building Energy Usage: The Great Energy Predictor Shootout: Overview and Discussion of Results," *ASHRAE Transactions* Technical Paper, Vol. 100, pt. 2, June 1994.

Kreider, J. and J. Haberl, "Predicting Hourly Building Energy Usage: The Results of the 1993 Great Energy Predictor Shootout to Identify the Most Accurate Method for Making Hourly Energy Use Predictions," *ASHRAE Journal,* pp. 72-81, March 1994.

Haberl, J. and S. Thamilseran, "Predicting Hourly Building Energy Use: The Great Energy Predictor Shootout II, Measuring Retrofit Savings – Overview and Discussion of Results, *ASHRAE Transactions,* June 1996.

The MBE indicates how well the energy consumption is predicted by the model as compared to the measured data. However, it is subject to cancellation errors, where the combination of positive and negative values for (M-S)hr serve to reduce MBE. To account for cancellation errors, the CV(RMSE) is also needed.[5]

The CV(RSME) is a normalized measure of variability between two sets of data. For calibrated simulation purposes, it is obtained by squaring the difference between paired hourly data points, summing the squared differences over each month or billing period, and then dividing by the number of points, which yields the mean squared error. The square root of this quantity yields the root mean squared error. The CV(RMSE), is obtained by dividing the RMSE by the mean of the measured data for the month or billing period.

The root mean square error for the month is:

$$RMSE_{month} = \sqrt{\frac{\sum_{month} \left(M - S \right)_{hr}^{2}}{N_{hr}}} ,$$

where N_{hr} are the number of hours in the month. The mean of the measured data for the month is:

$$A_{month} = \frac{\sum_{month} M_{hr}}{N_{hr}}$$

The CV(RSME) is:

$$CV(RMSE_{month}) = \frac{RMSE_{month}}{A_{month}} \times 100$$

The combination of MBE and CV(RMSE) allows one to determine how well a model fits the data: the lower the two values, the better the calibration. These indices may be calculated for the entire period, or for weekdays, weekends, and holidays separately (Bou-Saada and Haberl, 1995). Table G-6 below specifies the acceptable tolerances for MBE and CV(RMSE).

Table G-6. Acceptable Tolerances for Hourly Data Calibration

Index	Value
MBEmonth	± 10%
CV(RMSEmonth)	± 25%

8.6.4 Graphical Comparison Techniques

Any or all of four graphical comparison techniques summarized in Bou-Saada and Haberl, 1995, may be used to compare a simulation's output with real data. Some of these techniques require significant post-processing of data. These are:

- Hourly load profiles, which compare measured and simulated power for different day-types and seasons. These plots show where the simulation may be under- or overestimating building power.

5 Bou-Saada, T.E. and J.S. Haberl, "An Improved Procedure for Developing Calibrated Hourly Simulation Models," International Building Performance Simulation Association, Report No. ESL-PA-95/08-01, 1995.

- Binned interquartile analysis using box-whisker-mean plots, which show both measured and simulated energy use by temperature bins. Such plots allow the statistical characterization of dense collections of points in temperature bins. These plots show how well the simulation is performing in different temperature ranges, as well as the variability in both the measured data and simulation results.
- Weather day-type 24-hour profile plots are also box-whisker-mean plots that show whole facility electricity use versus the hour-of-the-day for both measured and simulated data for different weather day-types. These plots show ambient temperature influences and how well the simulation performs for the different weather periods chosen.
- Three-dimensional surfaces, which are plots of day, hour-of-day, and differences (positive only) between measured and simulated results (negative-only differences are plotted separately). These plots show the modeler when gross differences occur, that may be caused by modeling errors, which can then be checked and corrected, or by building operating conditions that were not accounted for in the data-collection phase of the project. Three-dimensional color plots may be used instead of surface plots. The advantage of color plots is that the plot may be easier to interpret or easier to recognize than time-of-year occurrences of peculiar data.

8.7 Calculation of Energy Savings

Verified energy savings are determined from the calibrated post-installation building model and the calibrated baseline building model. Once these two models have been developed, the energy savings for each measure must be determined. This is a straightforward procedure:

1. Determine the annual energy usage for each measure included in the project from the calibrated post-installation building model.
2. Determine the annual energy usage for the building equipment replaced by the measure from the calibrated baseline building model.
3. Determine the energy savings for each measure by subtracting the post-installation annual usage from the baseline annual usage.
4. Repeat for each measure.
5. Categorize the individual measure savings into the proper incentive categories (lighting, air-conditioning and refrigeration, other/motors, and gas).
6. Determine the total project incentive payment by multiplying the total measure savings in each category by the category’s incentive rate and adding the results.

8.8 Calibrated Simulation M&V Plan Documentation Requirements

Specific issues that need to be addressed in the measure-specific M&V plan include:

- Documentation of the project procedure, describing how the initial savings estimate was determined and how the verified savings will be determined
- Explicit descriptions of data that will be used to calibrate the model; this includes selection of the whole facility data (monthly or hourly), and data from specific subsystems that will be collected, including the duration and season of monitoring, and the monitoring interval
- Which version of DOE-2 will be used, the supplier of the program, and what, if any, pre- and post-processors will be used
- Existing building description (age, square footage, location, orientation, etc.), including a description of building systems to be replaced by the measures of the proposed project

- Description of any building operation conditions (set-points, schedules, etc.) affected by the measures
- Documentation that the baseline model complies with minimum standards
- A description of the building data to be collected and their sources (e.g., site surveys, drawings, etc.)
- Identification of spot measurements and short-term monitoring of specific building equipment to be made
- Identification and source of weather data used (on-site, local weather station, or typical weather data)
- Identification of the statistical calibration tolerances and graphical techniques to be used to demonstrate calibration of the model
- Indication of who will provide the simulation analysis documentation to the Utility Administrator

---

Equation 6: $Capi = Cap_{ref} [a + b(LCHWT) + c(LCHWT)^2 + d(CWT) + e(CWT)^2 + f(LCHWT)(CWT)]$

Equation 8: $PLR_{AdJ} = a + b(PLR_i) + c(PLR_i)^2$

Equation 9:

$$Temp_{Adj} = a + b(LCHW) + c(LCHW)^2 + d(CWT) + e(CWT)^2 + f(CHWT)(CWT)$$