9 Measurement and Verification Using Calibrated Simulation Analysis

9.1 Overview

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

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

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

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

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

1. Work with CenterPoint Energy and its contractor to define a strategy for creating a calibrated building simulation model in the project-specific M&V plan.

- Collect the required data from utility bill records, architectural drawings, site surveys, and direct measurements of specific equipment installed in the building.
- Adapt the data and enter them into the program's input files.
- Run the simulation program for the "base" building model. The base building is the existing building without the installed EEMs. The base building should comply with minimum state and federal energy standards.
- Calibrate the base model by comparing its output with measured data. The weather data for the base model should be the actual weather occurring during the metering period. Refine the base building model until the program's output is within acceptable tolerances of the measured data.
- Run the calibrated base model using typical weather data to normalize the results.

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

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

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

9.2 Baseline and Post-Retrofit Data Requirements

9.2.1 Simulation Software

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

9.2.2 Weather Data

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

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

9.3 Calculation of Energy Savings

9.3.1 Develop a Calibrated Simulation Strategy

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

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

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

9.3.2 Building Data Collection

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

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

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

9.3.3 Base Building Simulation Models

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

9.3.3.1 Minimum Energy Standards

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

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

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

9.3.3.2 Calibration

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

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

9.3.3.3 Hourly Data Calibration

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

Equation 9.1: Monthly mean bias error

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

Where:

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

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

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

Where:

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

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

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

Table 9.1: Acceptable tolerances for hourly data calibration

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

9.3.3.4 Monthly Data Calibration

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

Equation 9.3: Error in monthly energy consumption

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

Where:

M_{month} = the measured kWh for the month

S_{month} = the simulated kWh for the month

Equation 9.4: Error in annual energy consumption

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

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

Table 9.2: Acceptable tolerances for monthly data calibration

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

9.3.4 Post-Installation Models

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

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

The above mentioned post-installation model calibration mechanisms are not necessarily mutually exclusive. If the first two mechanisms are used the model can be calibrated soon after measure installation. If the last mechanism is used then the model can only be calibrated after sufficient (e.g., 12 months) billing data are available.
In some instances the post-installation model should be the only model calibrated. This can occur when the baseline project site cannot be easily modeled due to significant changes during the 12 months prior to the new measures being installed and thus the recent billing data are not representative.

9.3.5 Detailed Energy Savings Calculations

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

Equation 9.5: Energy savings calculation

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

Where:

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

9.4 Project-Specific M&V Issues

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

- Which version of DOE-2 will be used, the supplier of the program, and what if any pre- and post-processors will be used?

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