6 Measurement and Verification Using Calibrated Simulation Analysis

6.1 Overview

This section outlines the use of computer simulation analysis for measurement and verification of new construction energy savings. Computer simulation analysis should be used when the energy impacts of the energy efficiency measures are too complex[1] or too costly to analyze with traditional M&V methods. Computer-based building energy simulations are appropriate for constructions in which

- A building energy management or control system is specified
- The degree of interaction among multiple measures is either unknown or too difficult or costly to measure.
- The measures involve improvements that primarily affect building load—e.g., thermal insulation, low-emissivity windows

Conducting simulation analysis is often a time-consuming and expensive task, and the costs associated with this approach may be prohibitive in some instances. Also, building simulation software programs are not always capable of modeling every type or combination of energy efficiency measures.

The approach described here is based, in part, on Option D of the 2001 International Performance Measurement and Verification Protocol (IPMVP). More information on computer simulation analysis can be found in the IPMVP.

This approach requires that the Project Sponsor

1. Work with CenterPoint Energy to define a strategy for creating a calibrated building simulation model in the project-specific M&V plan.
2. Collect the required data from architectural drawings, mechanical plans, equipment schedules, and equipment submittals.
3. Adapt the data and enter them into the program's input files.
4. Run the simulation program for the "as-built" high-performance building model. The "as-built" building is the newly constructed building with all energy efficiency measures installed.

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

5. Calibrate the model by comparing its output with measured data. The weather data for the model should be the actual weather occurring during the metering period. Refine the model until the program's output is within acceptable tolerances of the measured data.
6. Run the calibrated as-built model using typical weather data to normalize the results.
7. Repeat the process for the baseline building model. The baseline building model is the newly constructed building with specifications that reflect applicable minimum performance values (from ASHRAE 90.1 1999 or from the minimum state and federal energy standards, whichever are more efficient).
8. Calculate the savings by subtracting the as-built results from the baseline results. CenterPoint Energy reviews and verifies the savings estimates and simulation results.

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

6.2 Software Selection

CenterPoint Energy recommends that the Project Sponsor use the most current version available of the DOE-2.1E hourly building simulation program. For projects with small projected incentive payments, the Project Sponsor may use another program, provided that the program can be shown to adequately model the building, the system or equipment installations can be calibrated to a high level of accuracy, and the calibration can be documented.

6.3 Developing a Calibrated Simulation Strategy

A sound approach to measuring and verifying your savings using computer simulation analysis must include the activities listed below. The Project Sponsor and CenterPoint Energy should confer on the best approach to each activity.

- 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 an experienced modeler can save a significant amount of time.
- Define the baseline building. In general, the baseline building represents the building, as it would have been built, had minimum standard equipment been installed instead of the high-efficiency equipment.
- Define the as-built building, which represents the building as it was constructed, with all the installed high-efficiency equipment and systems.
- Define the calibration interval. The as-built model should be calibrated using hourly, daily, or monthly data. Calibrations to hourly or daily data are preferred because there are more data points to compare. If monthly billing data are used, then spot or short-term data measurements 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.

6.4 Data Collection

The volume of data required for simulating a real building is significant. The Project Sponsor needs to collect data from the following sources:

- **As-built building plans**. The Project Sponsor should work with the building owner to gather as-built building plans.
- **Utility bills**. The Project Sponsor should collect utility bills for a *minimum* of twelve consecutive months following construction. The billing data should include monthly consumption (kWh) and peak electric demand (kW), preferably in fifteen-minute or hourly intervals (for optimal calibration). If interval data are not available, the Project Sponsor may need to arrange for the installation of metering equipment to collect the necessary data. Also, the Project Sponsor should determine if building systems are sub-metered, and collect these data if available.
- **Conduct on-site surveys and reviews of mechanical plans.** CenterPoint Energy helps the Project Sponsor establish which data must be collected. The Project Sponsor should visit the site to verify the accuracy of the mechanical plan data. CenterPoint Energy may accompany the Project Sponsor during this survey. Depending on the project, the Project Sponsor should collect data for
    - primary HVAC equipment (e.g. chillers and boilers): capacity, number, model and serial numbers, operation schedules
    - secondary HVAC equipment (e.g., air handling units, terminal boxes): fan sizes and types, motor sizes and efficiencies, design flow rates and static pressures, duct system types, economizer operation and control
    - HVAC controls, including the 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
    - lighting systems: number and types of lamps, with nameplate data for lamps and ballasts, lighting schedules
    - plug loads: summarize major and typical plug loads for assigning values per zone
    - occupancy: 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 can also inform on any deviation in the intended operation of equipment.
- **Make spot measurements.** To determine the actual power draw of operating equipment, the Project Sponsor may find it necessary to meter certain circuits (lighting, plug load, HVAC equipment).
- **Conduct short-term measurements**. Data-logging equipment may be set up to record system data as they vary over time. These measurements may involve lighting systems, HVAC systems, and motors. The period of measurement should be from one to several weeks.
- **Obtain weather data.** Calibrating a computer simulation of a real building for a specific year requires the use of actual weather data 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. In the M&V plan, the Project Sponsor 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).

6.5 Building Simulation Models

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

6.5.1 Calibration

After the as-built model is created and debugged, the modeler should make a comparison of the energy flows and demand projected by the model to that of the 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 modeler should document the calibration process 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.

6.5.1.1 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 (C_V(RMSE))[2]. Equation 6.1 is used to calculate MBE, and Equation 6.2 is used to calculate. C_V(RMSE).

Equation 6.1 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

Acceptable tolerance of for hourly data calibration is ± 10%.

Equation 6.2 ef d 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

Acceptable tolerance for hourly data calibration is ± 30%

6.5.1.2 Monthly Data Calibration

Comparing simulated energy use to monthly utility bills is straightforward. First, the model is developed and run using weather data that correspond to the monthly

[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.

utility billing periods. Next, monthly simulated energy consumption and monthly measured data are plotted against each other for every month in the data set. Equation 6.3 and Equation 6.4 are used to calculate the error in the monthly and annual energy consumption, respectively.

Equation 6.3 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

Acceptable tolerance for monthly data calibration = ± 25%

Equation 6.4 Error in annual energy consumption

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

Acceptable tolerance for monthly data calibration = ± 15%

6.5.1.3 Baseline Models

After calibrated simulation of the as-built model, the baseline model can be prepared. The baseline model is usually the as-built model with the substitution of minimum energy standards for equipment and systems. This new baseline model should also be documented.

6.5.1.4 Minimum Energy Standards

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

- Baseline equipment/systems should not include devices (such as lamps and ballasts) that are not allowed under current regulations.

- Baseline equipment models should meet *prescriptive* efficiency standards for affected equipment. These requirements are found in either ASHRAE 90.1 1999 or local/federal energy codes. The applicable standard requiring the highest efficiency should be used.
- Baseline calculations *do not* have to comply with *performance compliance* methods that require the project site to meet an energy budget.

6.5.1.5 Detailed Energy Savings Calculations

Energy savings are determined from the difference between the outputs of the baseline and as-built models. Savings are determined with both models using the same conditions (weather, occupancy schedules, etc.). To calculate savings, the energy consumption projected by the as-built model is subtracted from energy consumption projected by the baseline model. Equation 6.5 is used to calculate energy savings.

Equation 6.5 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 as-built building.
$kWh_{As\text{-}Built}$	=	The kilowatt-hour consumption of the as-built building operating under the same conditions (weather, operation and occupancy schedules, etc.) as the baseline building.

6.5.1.6 Detailed Peak Demand Savings Calculations

Peak demand savings are determined from the difference between the outputs of the baseline and as-built models. Savings are determined with both models using the same conditions (weather, occupancy schedules, etc.). To calculate savings, the peak demand occurring during the summer peak period projected by the as-built model is subtracted from peak demand projected by the baseline model. Equation 6.5 is used to calculate peak demand savings.

Equation 6.5 Peak demand savings calculation		
$kW_{saved} = kW_{baseline} - kW_{post}$		
Where:		
$kW_{savings}$	=	The peak kilowatt demand savings occurring during the summer peak period.
$kW_{baseline}$	=	The peak kilowatt demand of the baseline building operating under the same conditions (weather, operation and occupancy schedules, etc.) as the as-built building.
$kW_{As\text{-}Built}$	=	The peak kilowatt demand of the as-built building operating under the same conditions (weather, operation and occupancy schedules, etc.) as the baseline building.

6.6 Project-Specific M&V Issues

Project Sponsors who are using the computer simulation analysis approach must include the following in their project-specific M&V plans:

- Identification of which version of DOE-2 is will be used, who will supply the program, and what, if any, pre- and post-processors will be used.
- As-built building description (age square footage, location, etc.) including a description of building systems that have been upgraded to high-efficiency.
- Description of any building operation conditions (set-points, schedules, etc.) that are affected by the energy efficiency specifications.
- Documentation of incorporation of state and federal standards in the baseline model.
- Documentation of the calibrated simulation strategy and project procedure, including differences in calibration parameters between the baseline and as-built 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 who will perform the simulation analysis and calibration.
- Specification of format for documentation.