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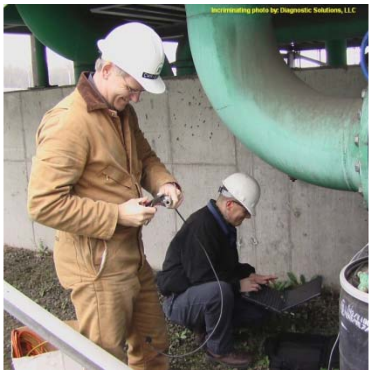

Existing Building Commissioning: An M&V Protocol Application Guide

May 2012

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Prepared for

Bonneville Power Administration

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Contract Number 00044680

Table of Contents

1. Introduction

1.1. Purpose

This document presents *Existing Building Commissioning: An M&V Protocol Application Guide*[1] as a complement to the Measurement and Verification (M&V) protocols used by the Bonneville Power Administration (BPA). The *EBCx Application Guide* assists the engineer in assessing an existing building commissioning (EBCx) project resulting in multiple measures with interactive effects between measures. The protocol also assists the engineer in designing appropriate energy modeling verification plans, while making use of the various common data collection and analysis activities between the M&V and EBCx processes. The protocol is a specific application of BPA's *Verification by Energy Modeling Protocol*[2] and is adherent with *IPMVP Options B* and *C*.

This document is one of many produced by BPA to direct M&V activities. The *Measurement & Verification (M&V) Protocol Selection Guide and Example M&V Plan* provides the region with an overview of all of BPA's M&V protocols, application guides, and reference guides, and gives direction as to the appropriate document for a given energy efficiency project. The document *Glossary for M&V: Reference Guide* defines terms used in the collection of BPA M&V protocols and guides.

Chapter 7 of this protocol provides full citations (and web locations, where applicable) of documents referenced.

1.2. Background

In 2009, BPA contracted with a team led by Research Into Action, Inc. to assist the organization in revising the M&V protocols it uses to assure energy savings for the custom projects it accepts from its customer utilities. The team has conducted two phases of research and protocol development under the contract, Number 00044680.

In the first phase, Research Into Action directed a team comprised of:

- Quantum Energy Services & Technologies, Inc. (QuEST), led by David Jump, Ph.D., PE and assisted by William E. Koran, PE;
- Left Fork Energy, Inc., the firm of Dakers Gowans, PE;
- Warren Energy Engineering, LLC, the firm of Kevin Warren, PE;
- Schiller Consulting, Inc., the firm of Steven Schiller, PE; and

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1 Hereinafter, *EBCx Application Guide.*

2 Hereinafter, *Energy Modeling Protocol.*

- Stetz Consulting, LLC, the firm of Mark Stetz, PE.

In the second phase, Research Into Action directed a team comprised of:

- David Jump, Ph.D., PE, William E. Koran, PE, and David Zankowsky of QuEST;
- Mark Stetz, PE, CMVP, of Stetz Consulting;
- Erik Kolderup, PE, LEED AP, of Kolderup Consulting; and
- Kevin Warren, PE, of Warren Energy Engineering.

The Research Into Action team was led by Jane S. Peters, Ph.D., and Marjorie McRae, Ph.D. Assisting Drs. Peters and McRae were Robert Scholl, Joe Van Clock, Mersiha Spahic, Anna Kim, Alexandra Dunn, Ph.D., and Kathleen Gygi, Ph.D.

For BPA, Todd Amundson, PE, directed the M&V protocol research and development activities. Mr. Amundson was working under the direction of Ryan Fedie, PE, and was assisted by BPA engineers. Mr. Amundson coordinated this work with protocol development work undertaken by the Regional Technical Forum. In addition, Mr. Amundson obtained feedback from regional stakeholders.

David Jump is the primary author of this *EBCx Application Guide*; team members reviewed and provided guidance.

2. Overview of Method

2.1. Description

This *EBCx Application Guide* provides guidance to verify energy savings from existing building commissioning (EBCx) projects in the commercial sector. The commissioning process is a quality assurance process that assures that the building's systems and equipment are performing to the owner's requirements. In recent years, under utility-run energy efficiency programs, the EBCx process has been used to achieve significant energy savings in customer facilities. The EBCx process tests the functionality of building systems and equipment to assure that equipment is in good working order, that system control strategies are working, and that building energy use is as efficient as the installed systems can be. Generally EBCx processes focus on a building's space heating, ventilation, and cooling equipment, and their control systems. However, other building end uses, such as lighting and domestic hot-water systems, may be addressed by the EBCx process. A nationwide study[3] estimated the average commercial building electric energy savings resulting from an EBCx process to be 15% of its annual consumption.

This *EBCx Application Guide* describes how to apply BPA's *Energy Modeling Protocol* to verify EBCx project savings. It discusses application of important modeling criteria (i.e., selection of measurement boundary, identification of independent variables, and selection of appropriate time intervals for monitoring and collecting data), as well as areas where the EBCx and M&V processes overlap, therefore identifying areas of potential project cost savings. It also discusses reporting requirements and use of energy models for on-going verification of savings. Finally, two examples are given to illustrate how to apply the *Energy Modeling Protocol* methodology to an EBCx project.

2.2. Applicability

This *EBCx Application Guide* is applicable to the following situations:

- EBCx projects where confidence in savings estimates is low due to use of too many assumptions, absence of data in calculations, and questionable analysis methods.
- EBCx projects where the magnitude of savings is high in proportion to the annual energy use of equipment within the measurement boundary (i.e., whole building or building subsystem). Small savings EBCx energy conservation measures (ECMs) scattered in subsystems throughout the building are not good applications of the *Energy Modeling Protocol*.
- Projects in which there is an abundance of baseline energy and independent variable data.

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[3] Mills et al. *The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States.*

- Projects in which building and building subsystem energy use are well described by the energy models in the *Energy Modeling Protocol*.

2.3. Advantages of this Approach for Estimating Savings in EBCx Projects

The use of the *Energy Modeling Protocol* for EBCx projects has several advantages because it:

- Verifies the cumulative savings and accounts for energy interactions of all ECMs installed on equipment or systems within the measurement boundary (measurement boundaries may be defined to include specific building subsystems of interest)
- Leverages the EBCx process of verifying improved system operational performance to meet the same requirement for the M&V process
- Makes use of short-time interval monitoring data to understand energy behavior of buildings and subsystems
- Uses data often collected during the EBCx process to develop energy models for verification purposes
- Enables an estimate of the uncertainty in the resulting savings to be made, which may be important for program evaluation purposes

2.4. Disadvantages of this Approach for Estimating Savings in EBCx Projects

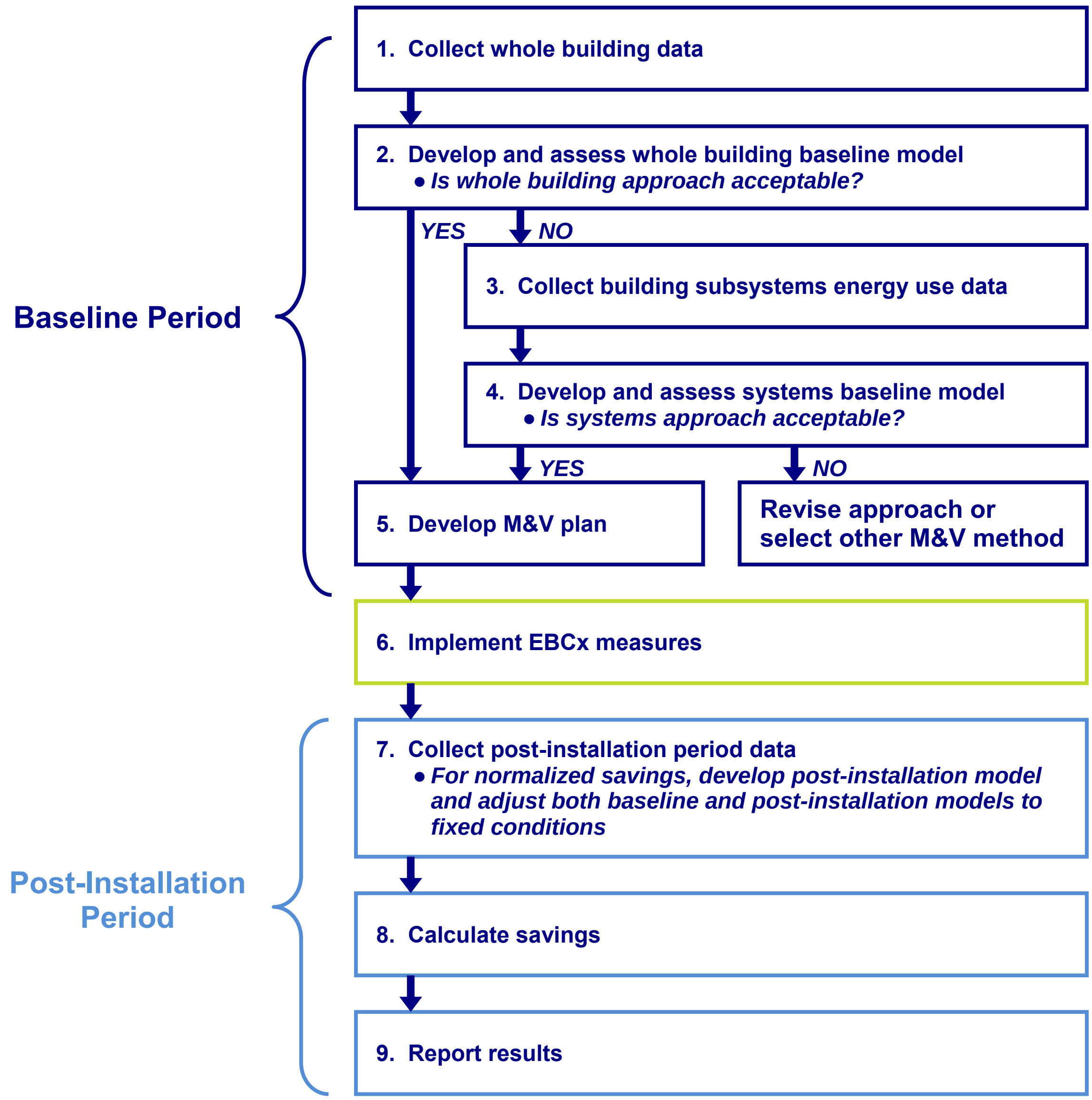
The *Energy Modeling Protocol* is not appropriate for EBCx projects when energy efficiency program requirements require ECM-by-ECM savings verification, or do not allow the cumulative savings to be verified for all systems within a measurement boundary. It is also not appropriate when the energy use cannot be well explained by the selected independent variables or there is too high a degree of uncertainty in the model.

3. Algorithm

3.1. Basic Procedure

The *Energy Modeling Protocol* provides a general procedure for developing energy models as part of an M&V process in compliance with the *International Performance Measurement and Verification Protocol* (IPMVP). Figure 3-1 illustrates the overall process.

Figure 3-1: Process Flowchart



The procedure for energy modeling in an EBCx process is essentially the same as in an M&V process. This approach can be used in determining two types of savings, as appropriate to the program requirements: *avoided energy use* and *normalized savings*.

Avoided energy use is the reduction in energy use that occurs in the reporting period, relative to what would have occurred if the facility had been equipped and operated as it was in the baseline period, but under reporting-period operating conditions. As described in Chapter 3 of the *Energy Modeling Protocol*, the initial steps are the same for determining both types of savings. These steps involve collecting baseline data and developing energy use models. The major difference is that normalized savings calculations adjust baseline and the post-installation models to a fixed set of conditions other than those of the reporting period. The conditions may be those of the baseline period, some other arbitrary period, or a typical, average, or “normal” set of conditions.

The general steps for choosing the energy models are an extension of the process for regression, since this is a regression-based protocol. In most cases, the baseline and post models will be of the same type, using the same independent variable (usually ambient temperature) and the same number of parameters. When normalized savings are used, frequently the fixed conditions basis will be typical meteorological year (TMY) weather conditions, as illustrated in the two examples in Chapter 6. (See the *Energy Modeling Protocol* for sources of weather data.)

The protocol describes how to select appropriate measurement boundaries and time intervals for data collection. It also guides the implementer in identifying the independent and dependent variables that are involved in doing a regression analysis. The companion BPA documents *Regression for M&V: Reference Guide* and *Sampling for M&V: Reference Guide* provide additional guidance for selecting an appropriate model and performing statistical analyses.

In most EBCx projects, a year of monthly energy data is available for both electricity and natural gas (or other heating energy type). While the *Energy Modeling Protocol* describes how to develop models using interval data from hourly or daily time intervals, energy models developed from monthly data are also useful. The protocol discusses the advantages and disadvantages of using short-time monitoring intervals rather than monthly data. For cases when both monthly and interval data are available, the following sequence of model development is recommended:

1. Develop energy models based on *monthly* energy data and corresponding heating or cooling degrees days.
2. Check model sufficiency as described in Section 3.2.
3. If model uncertainty is too large, develop whole-building energy models based on *daily* data.
4. Check model sufficiency.
5. If model sufficiency is too large, develop whole-building energy models based on *hourly* data.
6. Check model sufficiency.
7. If model sufficiency is too large, draw a measurement boundary around an affected building subsystem; develop a system-level energy model based on *daily* data.

8. Check model sufficiency.
9. If model sufficiency is too large, draw a measurement boundary around an affected building subsystem; develop a system-level energy model based on *hourly* data.
10. If model sufficiency is still poor, other BPA M&V protocols should be used. Recommended protocols are:
    a. *Engineering Calculations with Verification Protocol*
    b. *Verification by Equipment or End-Use Metering Protocol*
11. Write an M&V Plan.
12. Install and verify EBCx improvements.
13. Collect post-installation data.
14. Report savings.

3.2. Uncertainty

Selection of an appropriate baseline energy model is dependent on an assessment of the model's uncertainty in comparison with the expected savings of the EBCx measures within the measurement boundary. This issue is termed *sufficiency* and refers to whether the model is sufficiently accurate to verify the expected energy savings.

Determining whether or not the model is sufficient requires calculation and assessment of the *fractional savings uncertainty*, the uncertainty divided by the savings. During the baseline period, this is based on expected savings. During the post period, actual estimated savings can be used. The procedures for determining model uncertainty are described in detail the *Energy Modeling Protocol*. This *EBCx Application Guide* provides guidance on how to determine whether the model is sufficently accurate to verify the expected energy savings.

Two issues should be considered in assessing model sufficiency:

1. **Whether the model will potentially have correlated or uncorrelated residuals**. Generally, models developed from monthly data have uncorrelated residuals, while models built from daily or hourly data have correlated residuals due to their shorter time intervals. The calculation of the fractional savings uncertainty is slightly different for each of these cases.

2. **The acceptable fractional savings uncertainty for the project**. The savings uncertainty should ideally be much smaller than the savings. However, the acceptable range of uncertainty should be assessed by the project sponsors. For example, a 50% fractional savings uncertainty (at any confidence interval) for a savings of 100,000 kWh, means that the acceptable range of savings is 100,000, ±25,000 kWh , or that the actual savings is between 75,000 kWh and 125,000 kWh, at the specified confidence level.

Other parameters needed for this analysis are given in Table 3-1. The equations and details of calculating fractional savings are given in the *Energy Modeling Protocol*.

Table 3-1: Additional Parameters Needed for the Analysis

Parameter	Description / Source
t	*Student's t-statistic:* identified from a lookup table based on the selection of the confidence interval
CV(RMSE)	*Coefficient of variation of the root mean square error:* indicates variability in the regression model (see the *Energy Modeling Protocol*)
F	*Savings fraction:* $E_{save}/E_{baseline}$
n	*Number of data points in the baseline period:* for example, n=12 for one year of monthly energy data
m	*Number of data points in the post-installation period:* for example, m=61 for a daily model with data from June 1 through July 31 (unsegregated by any weekday/weekend/holiday categories)
p	*Number of model parameters:* a linear model has two parameters (intercept and slope), a 3P model has three parameters (intercept, change-point, and slope), etc.
r	*Autocorrelation coefficient:* describes the degree to which the data is self-correlated (see the *Energy Modeling Protocol*)

The *Energy Modeling Protocol* describes how to develop the best-fit regression models to the energy and selected independent variable data. After the best fit model is determined, the model parameters described above are used to determine model sufficiency. The simple test for model sufficiency is as follows:

1. Estimate the fraction (*F*) of savings expected from the EBCx project within the measurement boundary. For example, if the measurement boundary is the whole building, then estimate the savings as a fraction of the baseline whole building energy use. If the boundary includes the entire HVAC system, estimate the savings as a fraction of the baseline HVAC system use.

2. Following the procedure in the *Energy Modeling Protocol*, determine the model's fractional savings uncertainty over *m* post-installation modeling intervals ($\Delta Esave,m$ / $Esave,m$), based on whether the data has monthly, daily, or hourly analysis time intervals.

3. Compare the fractional savings uncertainty with the estimated savings fraction for the project. If it is sufficiently smaller than the estimated savings fraction (at the specified confidence level), the model from which it was built meets the sufficiency requirement. The degree of *sufficiency* is determined by the project team. If not, several actions may be taken to develop a better fitting model:

    a. Extend the baseline or post-installation modeling period to obtain more data points.

    b. Shorten the analysis time interval. This requires that data be monitored in short time intervals.

    c. Identify and incorporate other independent variables into the energy model.

    d. Select a lower confidence interval (i.e., 90% in place of 95%).

The following chapter considers how to incorporate these M&V procedures into an EBCx project. It begins by identifying the overlap in the EBCx and M&V processes, including the types of data collected and how savings are estimated, then focuses on the baseline period.

4. Issues Specific to Application of Energy Modeling to an EBCx Process

4.1. Overlap of EBCx and M&V Processes

The EBCx process is essentially a quality assurance process to assure the building and its systems are meeting the owner's requirements. When the EBCx process is used to eliminate energy waste and save energy, the M&V process provides the quality assurance that the estimated energy savings are realized. The EBCx and M&V processes share some important activities. Table 4-1 shows both processes so that the common activities among them are identified.

Table 4-1: EBCx and M&V Processes

EBCx Process	M&V Process
Planning Phase • Establish building requirements • Review available information • Visit site / interview operators • Develop EBCx plan • Document operation conditions **Investigation Phase** • Identify current building needs • Perform facility performance analysis – Diagnostic monitoring – System testing • Create list of findings • Estimate energy savings • Estimate costs • Recommend improvements	**Baseline Period** • Define scope of M&V activity • Identify affected systems • Select Approach – System – Whole building • Collect data – Energy measurements – Independent variables – Frequency & duration • Document the baseline – Equipment inventory – Operations – Energy baseline and adjustments – Assess uncertainty • Finalize and document the M&V Plan
Implementation Phase • Prioritize recommendations • Install / implement recommendations • Functionally test recommendations • Document improved performance	**Implementation Phase** • Verify proper performance
Turnover Phase • Update building documentation • Develop final report • Update systems manual • Plan ongoing commissioning • Provide training	**Post-Installation Period** • Collect post-installation data • Calculate savings for reporting period • Estimate annual savings • Develop savings report(s)

Continued

EBCx Process	M&V Process
Persistence Phase	**Persistence Phase**
• Monitor and track energy use • Monitor and track non-energy metrics • Trend key system parameters • Document changes • Implement persistence strategies	• Verify continued equipment performance • Monitor energy use • Calculate savings • Provide periodic savings reports

4.1.1. Shared Data

In the EBCx process, whole building and system energy data, as well as system operational data, are collected and analyzed to understand how well the building systems are meeting their operational requirements. This data is analyzed, functional testing of systems and equipment is performed, and the results are used to identify needed repairs and operational performance deficiencies. The whole building energy use data, as well as any system sub-metered energy data, are obviously data that may be used to develop energy models. In addition, system-level operational data, such as constant or variable equipment feedback status signal, may be converted into proxy energy variables. This is accomplished through the use of independent energy measurements. For constant loads, a spot measurement of equipment power when it is operating will provide a multiplication factor to convert the status signal into an energy variable. For variable load equipment, the equipment power may be logged as the equipment ranges through its series of operations. A simple regression between the logged power data and the corresponding variable feedback status signal trend data will develop a suitable relationship between feedback status signal and power.

4.1.2. Engineering Savings Estimates

For EBCx processes used in energy efficiency programs, an estimate of the energy savings and costs are required prior to implementation of the EBCx improvements. These savings estimates are also needed for M&V purposes. They help with the selection of the measurement boundary and they provide a reference point to test the sufficiency of the energy model.

4.1.3. Operational Verification

IPMVP-adherent M&V processes require two kinds of verification: *energy savings verification* and *operational verification*. While the energy modeling method provides the energy verification component, operational verification assures that the equipment is operating in a more efficient manner as a result of the installed EBCx measures.

The EBCx process requirement to conduct trend analysis or functionally-test equipment operations after installation corresponds to the operational verification requirement for the M&V process. Often the data collected during the EBCx process may be used in the post-installation M&V analysis.

4.2. Baseline Period

4.2.1. Measurement Boundary

The *Energy Modeling Protocol* describes the concept of the measurement boundary. Generally there are two levels: *whole building* and *systems*. A measurement boundary around a whole building includes all energy-consuming equipment in the building. Energy use data is obtained from the main meter, for both electricity and natural gas (or other heating energy source). A measurement boundary for a building subsystem delineates all systems affected by the EBCx improvements. System measurement boundaries may be defined to include the entire HVAC system or may be limited to a subsystem, such as the air handling system, chilled water system, or industrial process load. Data sources for the equipment within the system boundary must be identified. Data collection instruments may exist on a building energy-management system or they may be installed to measure the required data over the required time period.

EBCx projects in a commercial building generally focus on a building’s HVAC and control systems, and sometimes on domestic water and lighting systems. Depending on the EBCx project focus and the location of systems in the building, the affected systems may be local to one area or distributed throughout the building. This is one factor that affects the decision of where to draw the measurement boundary.

Another important factor in the selection of measurement boundary is the magnitude of expected savings from the implemented EBCx improvements. When following the procedures in the *Energy Modeling Protocol*, the regression models developed from the data will have an amount of uncertainty due to different sources, including random error in the dependent and independent variables, and inability of the selected independent variables to fully explain the dependent variable behavior. When the expected savings from the installed EBCx improvements (expressed as a percentage of the annual energy use of the equipment inside the measurement boundary) is the same or less than the energy model’s uncertainty (expressed as a percentage of the annual energy use), the selected measurement boundary may be too large. For example, if the measurement boundary includes the whole building, then it may need to be redrawn around only the affected systems (i.e., HVAC, chilled water, or air handling systems, industrial process, etc.).

There are many aspects to this selection process. A key aspect is the model’s ability to explain the energy use within the measurement boundary. Poor models will have a higher amount of uncertainty, better models a lower amount. This aspect may be less important if the expected savings is large. If not, then the energy model may be improved using the techniques identified in the *Energy Modeling Protocol*. These techniques include: developing energy models based on a larger data set, identifying additional independent variables, and selecting a different analysis time interval. The latter two techniques are discussed in the following sections.

4.2.2. Independent Variables

Energy use in commercial and industrial buildings is driven by many factors. Some principal factors include: ambient conditions, number of occupants in the building, equipment operation hours, building occupancy, lighting loads, and other heat loads in the building. When developing energy models, it is a good practice to identify and use only the main quantifiable independent variables that affect energy use in the building. This is most often the ambient temperature, as data is generally easy to obtain and it explains most of the energy use variation in a building or in the HVAC systems that are subject to the EBCx process. When only ambient temperature is used as the independent variable, adequate energy models may be developed using different model forms (i.e., 2P, 3P, or 4P models) and different time granularity.

Often, the ambient temperature alone is inadequate to develop sufficient energy models. Buildings and building systems operate in different modes throughout the day and week. Sometimes there are seasonal changes to the operating schedule. Energy use in the building is also dependent on whether equipment is operating or not. Another important independent variable is equipment operation status. This is a categorical variable, and is defined by the building operation schedule (for hourly analysis time interval data) or daytype (for daily analysis time interval data). Categorical variables are used to group all data in the same category and then develop energy models for that category. For hourly data, energy models are developed separately for occupied and unoccupied times, then recombined using the categorical variable, usually expressed using a “1” or a “0” coefficient. For daily data, models are developed for weekdays, weekends, and holidays as appropriate, and recombined using the daytype categorical variable.

Data for the preceding two independent variables is most straightforward to obtain. Other independent variables are more difficult. These include occupancy rate and other heat loads in a building. For some systems, data that characterizes the load served by the system, such as chilled or hot water tons, or air handler Btus, may be available. Quantifying load in this way accounts for all loads seen by the equipment. However, these data points must also be available for post-installation analysis.

4.2.3. Analysis Time Interval

The *Energy Modeling Protocol* discusses two principal analysis time intervals: *hourly* and *daily*. For the same duration of monitoring, hourly data will produce more data points upon which to develop a regression model. *Short time interval* refers to the actual frequency that the data is recorded, which is typically 5 minutes (for building automation system – BAS – data) or 15 minutes (for utility TOU meters). They are aggregated to an hour or to a day (energy in kWh is summed, temperature is averaged) for analysis. There is also an *analysis time interval* that refers to the aggregated data. Hourly kWh and temperatures each day undergo a broad range of variation, and better regression models are developed when the data covers the broadest range of its variation. In general, the more data used, the less uncertainty in the model.

However, because the hourly data over successive days repeats a similar pattern, there is less uniqueness in the data and therefore less capability of the data to explain the energy use. This effect is attributed to *autocorrelation* in the data. Autocorrelation is described by the coefficient ρ in the *Energy Modeling Protocol*.

Often, buildings and system energy models developed from hourly data have a high degree of uncertainty. This may be due to the absence of important independent variables or other unexplained operational modes within the measurement boundary. In these cases, daily data may be more advantageous, despite the need for a longer monitoring duration. Energy use is totaled for each day and a representative ambient temperature may be used, such as an average over the day, or the day’s peak temperature. Use of daily data serves to smooth over the variability in the data.

5. Minimum Reporting Requirements

5.1. Measurement and Verification Plan

5.1.1. Essential Elements of the Measurement and Verification Plan

Proper savings verification requires planning and preparation. The IPMVP lists several requirements for a fully adherent M&V plan.[4] The *EBCx Application Guide* describes methods for verifying savings from the commissioning of existing buildings. This application guide describes planning requirements, as well as specific measurement and analysis activities in the baseline and in the post-installation periods. Documenting in an M&V Plan how these requirements will be met is important so that others who subsequently become involved in the project can obtain a full understanding of the project's history and progress. The following are the essential items in documenting a savings verification plan.

- **Measurement Boundary:** Define the measurement boundary to encompass the building or system within which the savings will be verified. This boundary can be a whole building, all equipment connected to one of multiple meters in a building, systems connected to a building sub meter, or a specific system within the building. Systems may be defined as one of the major energy consuming systems within the building, or by their function, such as air handling or chilled water system. In industrial applications, systems may also be defined by their process.

- **Baseline Equipment and Conditions:** Document the baseline systems, equipment configurations, and operational characteristics of the building or facility. This includes equipment inventories, sizes, types, and condition. Describe any significant problems with the equipment. This information may be provided in an EBCx investigation report.

- **Energy and Independent Variable Data:** Identify the independent variables to be used in the analysis. Describe the sources of the energy and independent variable data and the time interval at which they are monitored. Describe any needed corrections to the data. Define the duration of monitoring for both the baseline and post-installation periods. Define the analysis time interval (i.e., hourly or daily).

- **Reporting Period:** Describe the length of the reporting period and the activities that will be conducted, including data collection and sources.

- **Analysis Procedure:** Describe how the baseline and post-installation energy use or demand will be adjusted to a common set of conditions. Describe the procedures used to prepare the data. Describe the procedures used for analyzing the data and determining savings. Describe any extrapolations of energy use or savings beyond the reporting period. Describe how savings uncertainty (if required) will be estimated. Document all assumptions.

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[4] *Chapter 5, IPMVP Volume I – 2010.*

- **Option A Requirements:** For each non-key parameter, specify the basis for the estimated values used. Describe their source or sources. Describe the impact of any significant variation in the values used and what otherwise would be measured on the calculated savings.
- **Savings Verification Reports:** Describe what results will be included in the savings reports. Describe what data and calculations will be provided. Describe when savings will be reported for the project. Indicate the reporting format to be used. See the section below regarding the *Savings Verification Report* for the minimum requirements.

5.1.2. M&V Plan Additional Elements

The IPMVP describes several other elements of a good M&V plan. These items are good practice in general, but not necessary for every project. Many of them are provided here for reference and consideration for inclusion in M&V Plans written under this application guide.

- **Energy Prices:** Document the relevant energy prices to be used to value the savings. This can be a blended electric rate or a schedule of rates based on time-of-use. Note that the latter will add significant complexity to the calculations.
- **Measurement Instrument Specifications:** Document the instruments used to obtain the data used in the calculations, including their rated accuracy and range. Identify the last instrument calibration date.
- **Budget:** Estimate the budget required for the savings verification activity. Estimate labor and material (e.g., meters and instruments, associated safety equipment, etc.) costs and provide an approximate schedule for when activities will occur.
- **Quality Assurance:** Describe any quality assurance activities that will be conducted as part of this M&V project. This may include how data is validated, how *IPMVP Option A* estimates are checked, identifying other parties who will review the work, and so on.

5.1.3. Documentation for BPA Database

The documentation should also include the following information to support review and inclusion of the project and measure in the BPA *Energy Efficiency Central* database (*EE Central*):

- Utility name
- Utility program
- Sector (commercial/industrial/residential)
- Existing building or new construction
- Site address (this will be used to establish the climate zone)
- Building type (examples: office, school, hospital)
- Building size, square feet

- ➡ Affected end uses (examples: HVAC, interior lights, exterior lights, receptacle plugs, DHW)
- ➡ Affected system (examples under HVAC: cooling plant, heating plant, HVAC fans, terminal units, controls)
- ➡ Affected equipment type (examples under cooling plant: chiller, packaged unit, cooling tower, pumps)
- ➡ Measure type (broad category)
- ➡ Measure name (specific category)

5.2. Savings Verification Report

5.2.1. General Verification Report Requirements Based on IPMVP

After the M&V calculations have been completed, the savings and actual M&V process used need to be documented.

Per the IPMVP, the *Savings Verification Report* should follow the savings verification report requirements described in the project's M&V Plan. Any deviations from the M&V Plan must be clearly described. If the M&V method followed the M&V Plan, then the information in the M&V Plan does not need to be repeated, but can just reference the Plan. However, deviations from the planned method, measurement boundary, baseline characteristics, etc. necessitate new descriptions.

IPMVP Chapter 6, M&V Reporting, generally requires the following:

- ➡ Report both energy and cost savings.
- ➡ Report the data relevant to the reporting period, including the measurement period and the associated energy data and independent variables. Any changes to the observed data must be described and justified.
- ➡ Describe any non-routine baseline adjustments, including the details of how the adjustments were calculated.
- ➡ Report the energy prices or rates used in the cost-savings calculations.

In addition, actual data for baseline and post-period energy use should both be reported.

5.2.2. Additional Savings Verification Report Requirements

Load and Schedule Relationships

In the basic procedure for the *Verification by Equipment or End-Use Metering Protocol*, one of the numbered items states, "Determine the relationships between load and hours-of-use terms in the energy savings equation and other parameters, such as temperature, air or water flow, pressure, and so on." This includes the relationships of daytypes and seasons to load and hours-of-use.

These relationships are important for all protocols, not just the *End-Use Metering Protocol*. In general, if the power or energy varies with respect to ambient temperature or another independent variable, then a relationship (e.g., regression) must be developed. Schedule variations require similar considerations.

The *Energy Modeling Protocol* is obviously built on these relationships, and energy indexing uses the ratio between energy and some independent driving variable – another relationship. Similarly, spreadsheet-based engineering calculations should use relationships (also described as correlations) to describe the load.

The savings verification report should clearly define loads and schedules, and their relationship to other variables:

- ➡ **For a constant load**, the load value and units should be provided, as well as how the load value was obtained. If any proxies are used to define the load, the proxies should be justified and their development described.
- ➡ **For variable load**, the load frequency distribution should be provided, along with a description of how it was obtained. For loads that can be any value, they should generally be grouped into 5 to 10 bins, but this is dependent upon how much the load varies. For example, if the load varies from 0% to 100%, 10 bins might be appropriate, but if the load only varies from 80% to 100%, then 2 to 4 bins might be appropriate.
- ➡ **For a timed schedule**, report the source for the schedule and the total annual hours.
- ➡ **For a variable schedule**, report the source for the estimate of the hours during the measurement period and the total annual hours.

Variable load information, energy models, and load correlations for engineering calculations are all similar and should be shown graphically in an x-y (scatter chart), as well as an equation or table. Load frequency distributions should be shown in both a bar chart and a table.

Savings Verification Report Information

The report should include the following information. It may be organized in this order with a separate section for each of these items, or in another order or organization that makes sense for a particular program or project. However it is reported, all of this information should be included in most cases:

1. The data for the baseline period, including the time period, monitoring intervals, and data points should be described.
2. The load and schedule for the baseline period, and any relationships associated with variable loads or schedules, should be clearly defined.
3. The impact of the ECM on the load or hours-of-use in the reporting period should be described.

4. The data for the reporting period, including the time period, monitoring intervals, and data points should be described.
5. The load and schedule, and any relationships associated with variable loads or schedules, should be clearly defined for the reporting period.
6. The equations used to estimate baseline consumption, reporting period consumption, and savings should be listed and explained.
7. Report consumption (and where relevant, demand), as well as savings, since this facilitates review and reasonableness checks.
8. As required by IPMVP, report the energy prices or rates used in the cost savings calculations.
9. Also, as required by IPMVP, report both energy and cost savings.
10. Provide verification of potential to generate savings.

Post Installation Verification of Potential to Generate Savings

IPMVP Section 4.3 requires that, "After the ECM is installed, inspect the installed equipment and revised operating procedures to ensure that they conform to the design intent of the ECM." Therefore, an IPMVP-adherent process requires evidence that the efficiency measures have the potential to generate savings. BPA may require short-term monitoring, spot measurements, production data, or other forms of verification to confirm potential.

Verification includes notation of any changes to the project subsequent to the M&V plan. If the project changed, the energy and demand savings should be recalculated based on as-installed conditions. Data and analysis from metering performed before or after installation should be included with the calculations.

In general, verification of potential to generate savings can take either of two forms:

- ➡ Installation verification
- ➡ Operational verification

Installation Verification

Installation verification is the less rigorous of the two verification methods. It demonstrates the measures were installed as planned. This demonstration may vary by measure. Project developers are required to describe the evidence and documentation they plan to provide to demonstrate that the measures were installed, and this evidence and documentation belongs in the savings verification report.

Examples of installation verification include:

- ➡ Photographs of new equipment
- ➡ Photographs of new control set-points

- Screen captures from EMCS
- Invoices from service contractors (invoices should not be the sole form of evidence, but may supplement other verification documentation).

Operational Verification

Operational verification demonstrates that in the post-installation period, the system is operating (or not operating) as modeled in the calculations. It is based on visualization of *operational* data (as opposed to *energy* data) collected during one or more site visits after the measures have been installed.

Operational verification is in addition to installation verification and documentation should include the same types of evidence as for installation verification. In addition, the data logging, control system trending, or functional tests used to establish baseline shall be repeated to demonstrate that operations have been improved. Documentation of the commissioning of the new systems or equipment can be used for operational verification.

If the collected post-installation data, test results, and/or commissioning indicate less than predicted performance, or that the measures were not installed as assumed in the savings calculations (for example, due to incorrect or partial installation, or other circumstance), either:

- Take action to help the customer fully install the measure properly and then re-verify it using these procedures; or
- Use the same calculation methodology with the post-installation data to calculate a revised measure savings estimate.

Choice of Verification Method

Common, well-known measures, measures with low expected savings, and measures whose savings estimates have considerable certainty, may need only *installation verification*. Measures with large savings and measures with less certain savings (whose savings can vary greatly dependent upon application) typically require *operational verification*.

Thus, there is no hard-and-fast rule for this choice. The analyst should recommend a verification method and the evidence expected to be presented for verification when submitting calculations or simulations. The final choice of verification method and evidence will be made by the reviewer.

6. Examples

The following examples illustrate how to apply the *Energy Modeling Protocol* framework in the context of an EBCx project. The first example involves a whole building approach (*IPMVP Option C*); the second example focuses on the HVAC systems within a building (*IPMVP Option B*). Both examples calculate normalized savings adjusted to TMY conditions.

6.1. Example 1 – Whole-Building Approach

6.1.1. Overview

University Library is a four-floor undergraduate library with a basement; it is used by students for study and research. The library was originally built in the 1930s. Successive wings have been added over the years until it achieved its current footprint of a rectangle, oriented with its long axis along the east-west direction. The library has an outside courtyard in its center. Its heating, ventilation, and air conditioning (HVAC) systems operate continuously throughout the year to minimize thermal stress on its books. The library has 400,072 square feet of conditioned space.

The library is served by the campus chilled water and steam loops. There are two connections into the building from each of the chilled water and steam loops. The steam connections serve three heating hot-water heat exchangers. There are two chilled-water and three hot-water meters serving the building. The library also has eleven air handling systems: two are single-duct variable air volume with terminal reheat, and nine are constant air volume systems. The west wing is the newest addition to the building and houses the two largest variable volume fans.

An EBCx project was undertaken in this library to find and correct faults in system operations and implement improved control strategies, with a goal to save energy and reduce operation costs. Several measures were identified, and are summarized in Table 6-1. Energy savings estimates for these measures were not required. Because a full year of monitoring before and after the measures are installed is not possible, both baseline and post-installation models will be developed and normalized to a TMY dataset to determine savings.

Table 6-1: Summary of Implemented Measures

System	Description of Deficiencies Findings
AC01 & AC02	• Excessive fan speed due to failure to meet static pressure set-point • Economizer malfunction • Simultaneous heating and cooling in air stream
AC 21, AC25, AC25, AC51, AC53, AC54, AH1, AH2, AH3	• Economizer repair • Economizer control optimization • Supply air temperature reset with occupancy schedule
Chilled-Water and Hot-Water Pumps	• Chilled water supply temperature set-point reset • Chilled water pump lockout • Reset chilled water EOL pressure set-point

6.1.2. M&V Approach

The library receives electricity through five meters. It receives chilled water from the campus' central plant through two meters. Steam from the central plant is provided through two meters to two heat exchangers, with three loops circulating hot water to heating coils in the zone terminal boxes throughout the building.

M&V Option

An Option C approach will be used for each affected building meter. Affected meters include one electric meter serving the west wing, one chilled water meter, and one steam meter.

Measurement Boundary

The measurement boundary for each affected meter includes all of the energy-using equipment downstream of the meter. The measures generating the electric savings for this project are on the two main west-wing VAV AHU, which are served by the same electric meter. All AHUs investigated throughout the library use chilled water from both meters and hot water from one heat exchanger. The identified measures (e.g., economizer operation and control system resets) save chilled and hot water energy from the corresponding energy meters.

Baseline Period

The EBCx meters were implemented at different times of the year in 2007. Energy meters were installed in 2006 and trending of the energy use in 15-minute intervals was begun. Baseline period data was collected to develop the baseline energy models. The baseline periods for each meter, their analysis time interval, and number of points are shown in Table 6-2.

Table 6-2: Baseline Period

Meter	Start Date	End Date	Interval	Points	Unit
Electric Meter MSHN	Nov 29, 2006	Feb 25, 2007	Days	70	kWh
Chilled Water Meter B	Jul 18, 2007	Sep 9, 2007	Hours	1,152	Tons
Hot Water Meter A	Aug 10, 2007	Sep 9, 2007	Hours	600	MBtu

Post-Installation Modeling Period

After the EBCx measures were installed, there was a very short monitoring time available for the chilled and hot water meters. Table 6-3 summarizes the post-installation monitoring period.

Table 6-3: Post-Installation Monitoring Period

Meter	Start Date	End Date	Interval	Points	Unit
Electric Meter MSHN	Apr 1, 2007	Jun 1, 2007	Days	70	kWh
Chilled Water Meter B	Oct 24, 2007	Nov 6, 2007	Hours	311	Tons
Hot Water Meter A	Oct 24, 2007	Nov 6, 2007	Hours	311	MBtu

6.1.3. Energy Modeling

Baseline Modeling

The library had different operating hours during the week than during the weekend. Both weekend days operation hours were the same. A *workday* categorical variable was used to group weekday and weekend/holiday operations separately. No reliable monthly data were available. A daily analysis time interval was found to work well and met the sufficiency requirement.

For chilled water meter B, an hourly analysis time interval was selected. Daily analysis time intervals did not provide enough data points that showed enough variation over the entire temperature range. In addition, the baseline period was mainly in the warmer months. An hourly analysis time interval was selected in order to obtain data in the cooler nighttime periods, thereby increasing the range of variation in the regressor variables. A categorical variable identifying weekdays from weekends and holidays was not necessary.

Similarly, the hot-water meter baseline monitoring period was short, so that an hourly analysis time interval was selected.

Post-Installation Modeling

The same analysis time interval used for the electric, chilled-water, and hot-water meters, respectively, was used for the post-installation models. Figure 6-1, Figure 6-2, and Figure 6-3 show the scatter plots and resulting regression models developed from the data for the electric, chilled water, and hot water energy use, respectively.

Figure 6-1: Whole Building Electric Data and Model

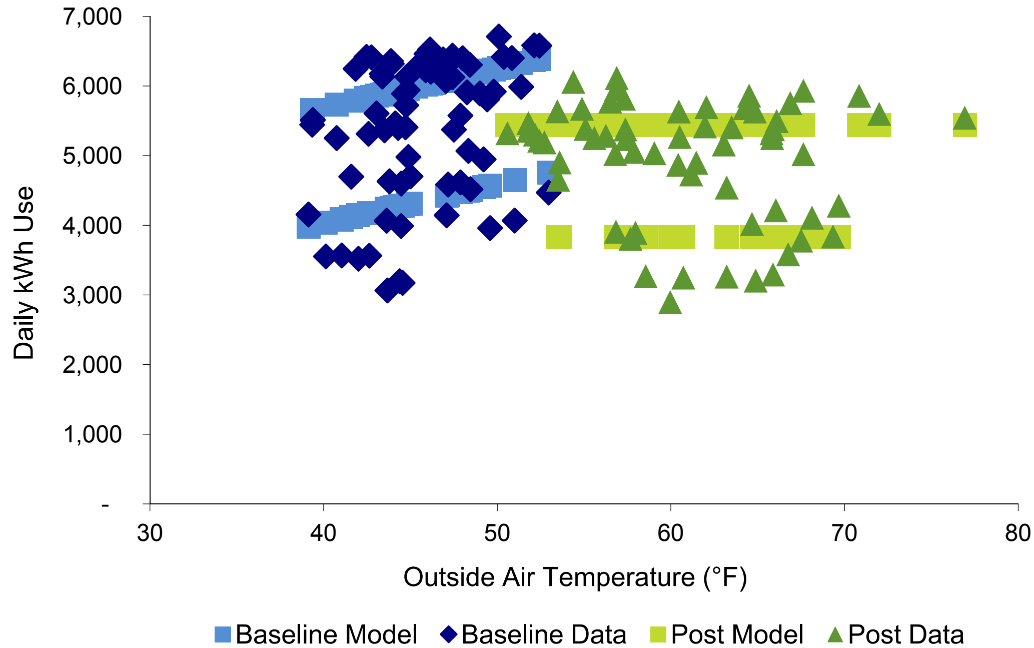


Figure 6-2: Chilled Water B Data and Model

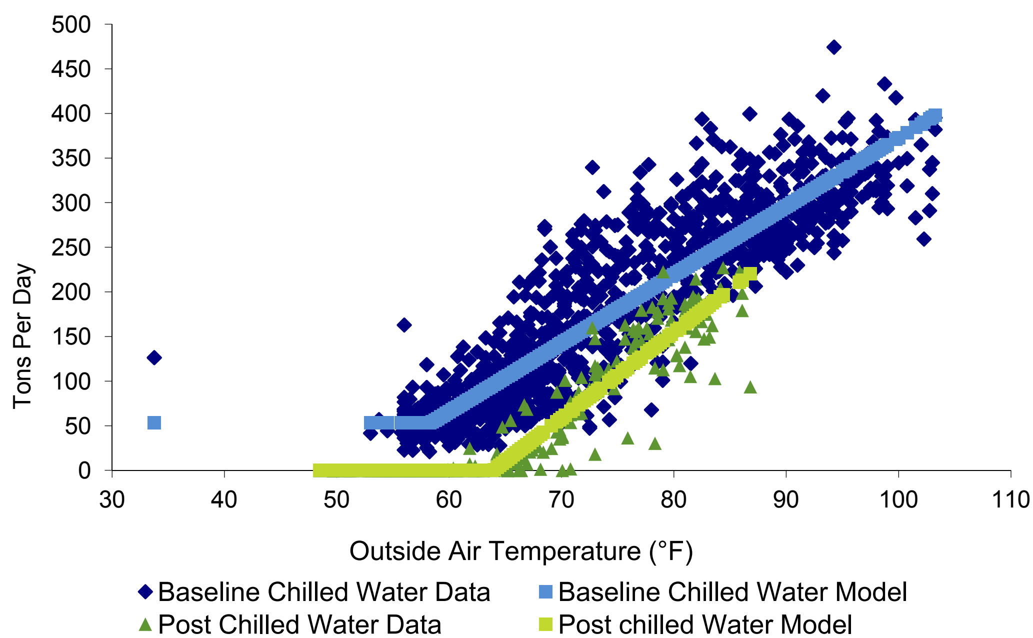
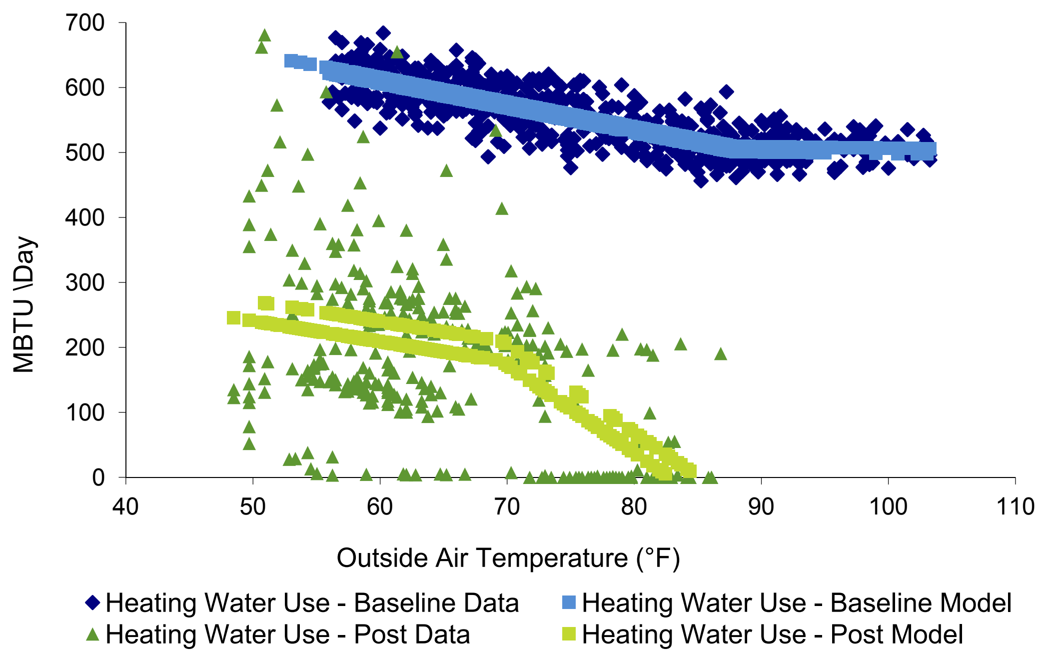


Figure 6-3: Hot Water A Data and Model



6.1.4. Annual Savings

Savings were estimated for each energy source by adjusting both baseline and post-installation energy use to TMY conditions. This was done simply by selecting the correct TMY weather file for the library's climate zone for use in the analysis. For electric savings, the hourly kWh data was summed for each day and the hourly TMY temperature was averaged over each day. The weekends and holidays were identified in the TMY dataset and flagged with a *workday* variable.

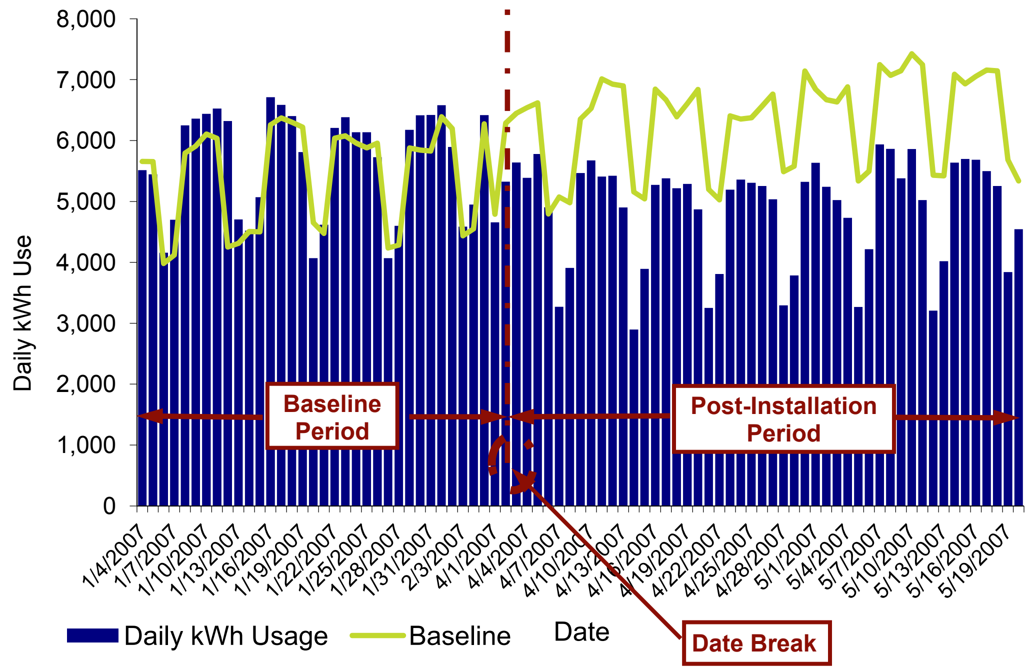
For chilled-water and hot-water energy, the hourly TMY data were used directly in the baseline and post-installation models. For each energy source, the annual baseline energy use and the annual post-installation energy use were calculated. The annual post-installation use was subtracted from the baseline use to determine savings. Results are shown in Table 6-4.

Table 6-4: Library Energy Savings

Meter	Annual Baseline Use	Annual Post-Install Use	Savings	Units
Electric MSHN	2,283,502	1,798,942	484,560	kWh
Chilled Water B	881,082	337,675	543,406	ton-hrs
Hot Water A	5,391,112	1,758,674	3,632,438	MBtu

Plotting the measured data with the baseline model on a chart, as in Figure 6-4, provides conclusive evidence that the implemented EBCx measures are savings energy.

Figure 6-4: Electric Savings Resulting from Retro-Commissioning University Library



6.2. Example 2 System – Level Verification

6.2.1. Overview

An EBCx project was conducted in a five-story 110,000 square foot high-technology building. It has offices and conference rooms located around the building perimeter on each floor, as well as several computer and electronic labs, and small data centers in its interior zones. In the core near the elevator shafts are small data centers, each cooled with water-cooled DX units. There are two 215-ton screw chillers located in the basement. Two dual-speed cooling towers are on the roof. The interior zones, except for the data centers, are served by one large variable air volume air handling unit. This AHU has an economizer, a heating coil, and a cooling coil. It serves VAV terminal boxes throughout the interior zones. These boxes do not have heating coils. Two separate VAV AHUs located in the penthouse serve the east and west perimeter zones. These AHUs are also equipped with economizers, and have cooling coils. Their VAV terminal boxes have reheat coils.

The EBCx process uncovered several areas of inefficiency in the HVAC systems:

- Simultaneous heating and cooling due to unnecessarily large minimum-air-flow damper settings in each of the VAV terminal units
- Inoperable VFDs serving several of the supply and return fans
- Bent and disconnected economizer damper linkages, resulting in poor control over economizer settings
- Absence of a chilled-water-system lockout temperature

Because a full year of monitoring before and after the measures are installed is not possible, both baseline and post-installation models were developed and normalized to a TMY dataset to determine savings.

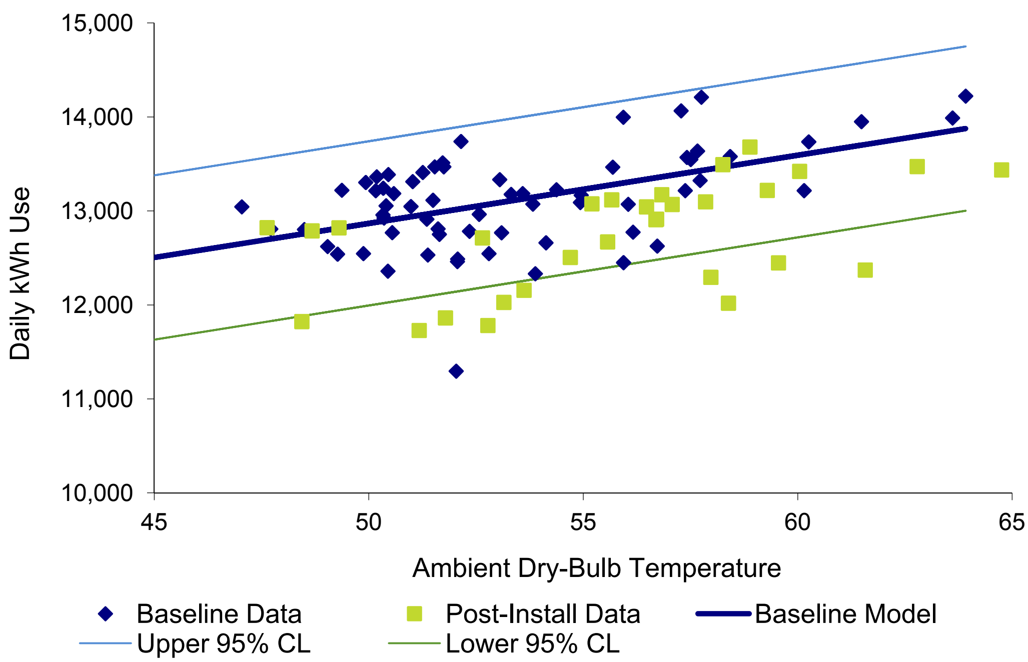
6.2.2. M&V Approach

M&V Option

Overall electric savings from installation of these measures was estimated to be approximately 483,000 kWh. This was approximately 5% of the annual building electricity use. An initial baseline energy-use model was developed, as shown in Figure 6-5. The analysis time interval was daily. Note that the post-installation data points fall within the model's uncertainty limits. This indicates that the model is insufficient for use in quantifying the actual savings.

As 5% is a small amount of savings compared to overall building energy use, and as most of the energy savings measures were performed in the HVAC systems, an Option B energy modeling type approach for the building's HVAC system was employed to verify the EBCx project's savings. For this example, only the electric savings using this approach are demonstrated.

Figure 6-5: High Tech Building Whole Building Baseline Model



Measurement Boundary

The building's HVAC system consists of multiple pieces of equipment, as follows:

- **Chilled water system**: two screw chillers, two 10-hp constant-speed primary pumps, two 20-hp variable-speed secondary pumps, two 2-speed cooling towers, and two 15-hp constant speed pumps

➡ **Air handling system**

- *AHU1, interior zone*: 75-hp variable-speed fan motor, two 20-hp variable-speed return fans and motors
- *AHU2, west perimeter zone*: 40-hp variable-speed fan motor, 20-hp variable-speed return fan motor
- *AHU3, east perimeter zone*: 40-hp variable speed fan motor, 20-hp variable-speed return fan motor

The measurement boundary does not include the hot water pumps, or the pumps providing condenser water to the data centers, as no EBCx improvements are planned in these systems. No significant interactive savings from the planned EBCx improvement in other systems were anticipated.

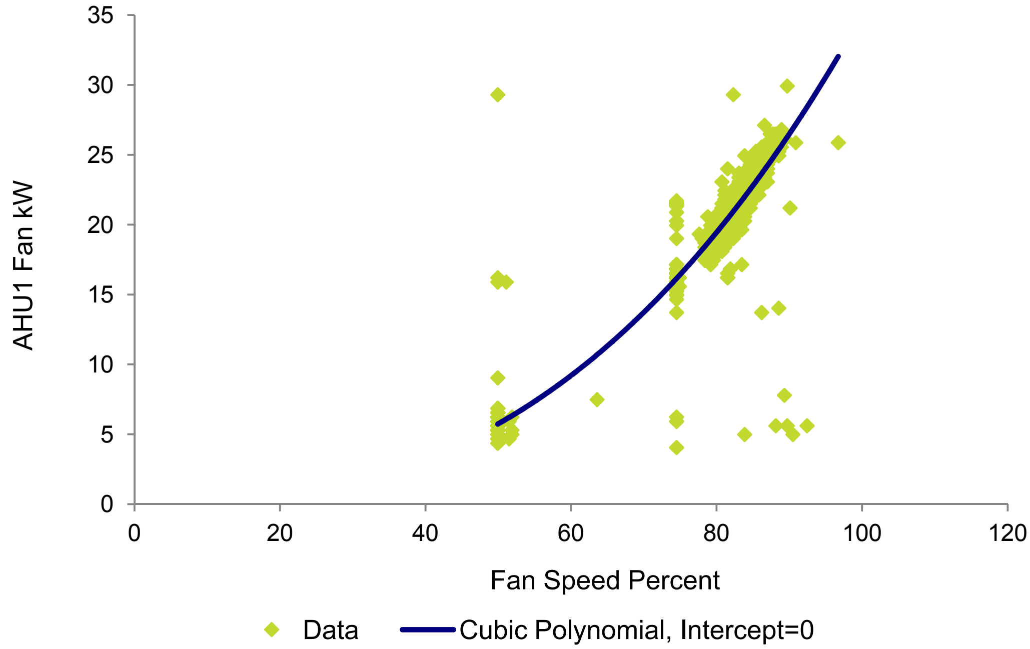
In order to develop energy models for the systems within the measurement boundary, energy use for each energy-consuming piece of equipment as identified above had to be measured. Fortunately, most of the points were available on the energy-management system as either actual kW measurements or as feedback status signals. Table 6-5 describes the available data for each piece of equipment, and additional measurements required.

Table 6-5: Available Monitoring Points

System	Equipment	EMS Point Type	Unit	Issue	Measurement Type
Chilled Water	Chillers (2)	Demand	kW	None	—
	Primary Pump (2)	Status	1 or 0	None	Spot kW
	Secondary Pump (2)	Speed	Percent	None	Logged kW
	Cooling Tower (2)	Speed	Off, Low, or High	None	Spot kW
	CW Pumps (2)	Status	1 or 0	None	Spot kW
AHU1	Supply Fan	Speed	Percent	None	Logged kW
	Return Fan (2)	Speed	Percent	VFD inoperable, running 100%	Spot kW
AHU2	Supply Fan	Speed	Percent	None	Logged kW
	Return Fan	Speed	Percent	VFD inoperable, running 100%	Spot kW
AHU3	Supply Fan	Speed	Percent	None	Logged kW
	Return Fan	Speed	Percent	VFD inoperable, running 100%	Spot kW

The additional measurements were required to create *proxy energy* variables from the constant or variable feedback status signals that are trended on the energy management system (EMS). For constant speed equipment, a one-time *spot* measurement of the equipment power is made. For variable speed equipment, data loggers were installed to record power as the equipment ranges through its speeds; while simultaneously, the speed data was trended on the EMS. These data were then used to develop an empirical power-speed relationship, as shown in Figure 6-6. Similar proxy variables were developed for each point listed in Table 6-5.

Figure 6-6: Proxy Energy Variable for AHU1 Supply Fan Speed



Baseline Period

Once the approach was determined, trends were set up in the EMS to record the status and chiller demand data at 5-minute intervals. Simultaneously, data loggers were set up to record power on the variable speed equipment. Spot measurements were taken on the constant load equipment. The baseline monitoring period is shown in Table 6-6.

Table 6-6: Baseline Period

Meter	Start Date	End Date	Interval	Points	Unit
Chilled Water System	Jan 1, 2006	Mar 9, 2006	Days	68	kWh
AHU1, AHU2, AHU3	Jan 1, 2006	Mar 9, 2006	Days	68	kWh

Post-Installation Modeling Period

After the EBCx measures were installed, there was a short monitoring time available. Table 6-7 summarizes the post-installation monitoring period. The points are the same as in the baseline monitoring period for which a trend line was generated by the EMS.

Table 6-7: Post-Installation Monitoring Period

Meter	Start Date	End Date	Interval	Points	Unit
Chilled Water System	Oct 31, 2006	Nov 29, 2006	Days	29	kWh
AHU1, AHU2, AHU3	Oct 31, 2006	Nov 29, 2006	Days	29	kWh

6.2.3. Energy Modeling

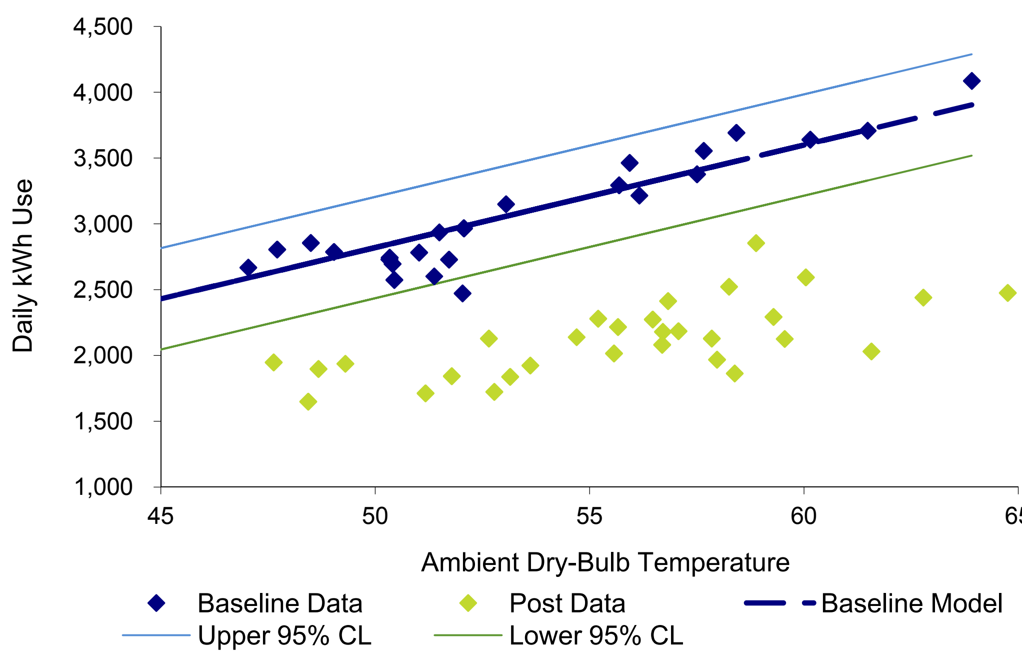
The HVAC system in this building was designed with excessive cooling capacity in anticipation of heavy occupant loads and anticipated computer and server equipment to be installed. These loads never materialized. As a result, the oversized HVAC system served lightly-loaded zones and was not heavily influenced by occupancy. An energy model based on daily energy use was found to provide sufficient accuracy.

Baseline Energy Modeling

The energy use of each component of the HVAC system was summed to determine its total daily energy use. Ambient temperatures were averaged over the operating hours of the day. These pairs of points were used to develop a baseline energy model for the HVAC system. No weekday or weekend/holiday categorization of the data was necessary.

A scatter plot of the energy use and ambient temperature data was created, and a linear regression (also called a 2P model) was found to provide the best fit to the data. The data and the resulting model are shown in Figure 6-7.

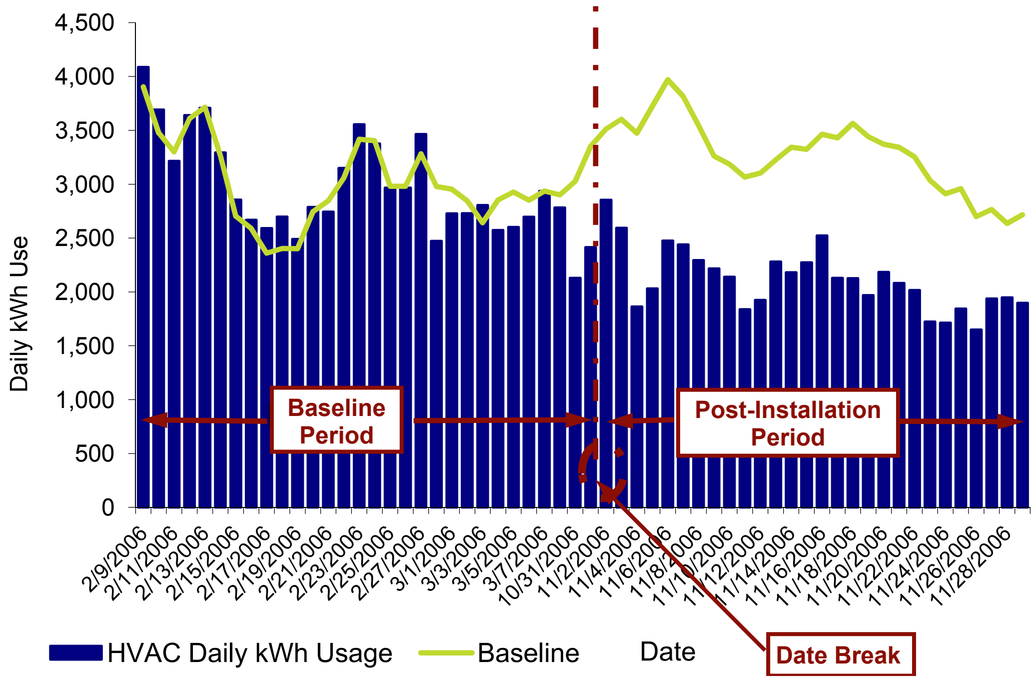
Figure 6-7: High Tech Building HVAC System Baseline Model



Post-Installation Modeling

The energy use of each component was summed to daily values and the ambient temperatures were averaged over the operating hours of the day to create daily data for the HVAC system. These points are also shown in Figure 6-7. A linear regression model was developed from the data. Both baseline and post-installation energy use models are shown in the time-series representation in Figure 6-8.

Figure 6-8: Projecting the Baseline Energy Use Into the Post-Installation Period



6.2.4. Annual Savings

Due to the short duration of the baseline and post-installation periods, annual energy use totals were determined based on the local TMY dataset for the climate zone of the building. The ambient TMY temperatures were averaged over the operating hours, and entered into the baseline and post-installation model equations. These calculations produced annual baseline and annual post-installation estimates of HVAC system use. The resulting *fixed conditions* savings were determined from their difference. Savings are shown in Table 6-8.

Table 6-8: HVAC System Savings

Meter	Annual Baseline Use	Annual Post-Install Use	Savings	Units
HVAC	1,264,299	801,827	462,472	kWh

7. References and Resources

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