Guidelines for Verifying Savings from Commissioning Existing Buildings

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About the California Commissioning Collaborative

The California Commissioning Collaborative is a non-profit corporation with a mission to support and promote the practice of commissioning in California. Its Advisory Council and Board of Directors are made up of utilities, state and federal government, researchers, designers, building owners, and commissioning providers.

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1. Introduction

1.1. Need for Guidelines

This guideline describes methods and procedures to verify energy savings in existing-building commissioning (EBCx) projects. EBCx (also known as retrocommissioning or RCx) is often used to improve energy performance and efficiency in large commercial and industrial facilities. The EBCx process identifies operational strategies to improve the performance of building systems. Recommendations for implementing the strategies account for the related costs and energy-savings benefits. Properly conducted, EBCx verifies that systems operations have improved. However, the EBCx process itself does not describe procedures for quantifying and verifying that a project's energy-savings goals have been met.

EBCx project sponsors and service providers each have motivations for quantifying and verifying the energy savings resulting from an EBCx project. Examples of some motivations include:

- A building owner's requirement to see the actual reduction in energy costs resulting from the investment in commissioning its buildings.
- A program manager's desire to have high confidence in the reported savings attributed to the EBCx program.
- An EBCx service provider's assurance that the project's savings goals have been met.

Significant confusion exists about how energy savings are quantified and verified for energy-conservation measures (ECMs) installed in a building. There is confusion about what distinguishes verifying savings from estimating savings before installing ECMs. Questions include:

- What data must be measured before and after ECMs are installed to verify savings?
- How much data is required?
- Must individual ECM savings be verified, or may they be verified in aggregate?

This confusion is heightened when verifying savings from EBCx improvements. EBCx requires that the correct operation of implemented ECMs be verified, while savings verification requires both operational verification and a quantitative check on the estimated energy savings. The two processes overlap.

The industry-standard reference document for verifying energy savings, ***The International Performance Measurement and Verification Guideline*** (IPMVP),[1] defines measurement-and-verification (M&V) concepts and terminology, and describes four general options that can be applied to projects. It does not describe specific application procedures and methods. It also lacks case studies and examples of M&V applications.

The American Society of Heating, Refrigeration, and Air-conditioning Engineer's (ASHRAE) ***Guideline 14-2002: Measurement of Energy and Demand Savings***[2] provides more descriptive information on the procedures and calculations used for M&V. It provides three options that mirror those found in IPMVP, and a glossary of terms. While much more rigorous in technical

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[1] Available at: www.evo-world.org.

[2] Available at www.ashrae.org.

detail than IPMVP, it also contains few case studies and examples of M&V applications compliant with this standard.

There is a lack of standardized verification methods and procedures specific for EBCx processes. While general procedures are known from IPMVP, and ASHRAE GL-14 provides some technical direction, specific direction is needed for EBCx projects and programs. Standardized methods are needed to eliminate confusion about verification methods and procedures. By eliminating this confusion and working from the same set of methods and procedures, much time may be saved in conducting EBCx projects and in reviewing them on behalf of project sponsors. Documenting these methods and procedures will also help new entrants into the field, as well as commissioning providers who do not normally include savings verification as part of their services.

1.2. Purpose

The purpose of this guideline is to provide standardized methods that may be used within EBCx projects to calculate and verify energy savings. It also provides a framework for EBCx service providers to select a method based on a project's goals, resources, and constraints. This guideline defines the technical requirements and analysis procedures for each method, defines common terminology, identifies useful tools, and provides examples. It addresses common savings risks and describes the methods' relationships to formal M&V protocols.

The verification methods are designed to be integrated with and augment the EBCx process and therefore minimize additional costs. This guideline establishes standardized verification methodologies, terminology, and procedures in order to address project objectives such as:

- Clarify savings-verification concepts and procedures, eliminate confusion concerning verified versus calculated savings.
- Establish common and flexible methodologies appropriate to verify EBCx savings given the project's specific resources and constraints.
- Increase confidence in each EBCx project's reported savings.
- Reduce costs of reviewing EBCx calculations, data, and results, which vary in quality and rigor from project to project, thereby improving the cost effectiveness of both individual projects and energy-efficiency programs.
- Help new entrants into the field of commissioning existing buildings for energy efficiency.
- Provide a means for owners and program managers to verify and quantify the persistence of savings.

1.3. Guideline Organization

This guideline is organized as follows:

2. Integrating the Energy Savings Verification Process describes how to integrate savings verification into EBCx projects and how typical risks that prevent realization of savings are addressed by this enhanced process.

3. Method Selection provides guidance for identifying and assessing important criteria related to a project's goals, resources, and constraints to select a verification method from among those detailed in chapters 4–7.

4. Method 1: Engineering Calculations with Field Verification describes how engineering calculations used to estimate savings prior to implementation are used to verify actual savings. It describes how post-installation measurements used to verify improved operations are used to improve the savings estimates.

5. Method 2: System or Equipment Energy Measurement characterizes the system or equipment energy use by its load and schedule components so that each component is measured separately. The primary impact of the EBCx measures on each component is used to determine post-installation measurements. This verification method may be implemented in adherence with IPMVP's Options A or B.

6. Method 3: Energy Models Using Interval Data describes a verification method in which empirical models of baseline energy use and key independent variables are used to verify savings. It can be used to verify total savings in a whole building or in building subsystems. This verification method may be implemented in adherence with IPMVP Options B or C.

7. Method 4: Calibrated Simulation describes the use of whole-building simulation software to develop and calibrate a building model that correctly reproduces the baseline energy use of a building and its subsystems.This verification method may be implemented in adherence with IPMVP Option D.

In addition, there are several appendices of useful information and supporting material.

2. Integrating the Energy Savings Verification Process

2.1. Basis and Need for Energy Savings Verification

Existing-building commissioning (EBCx) achieves energy savings by improving the operation of building systems. That is, it seeks out and repairs faulty system components, identifies and corrects improperly implemented schedules and controls, or optimizes system operation to minimize energy use while maintaining required building services. Whereas replacing or retrofitting systems with more energy-efficient versions requires complete change out of the inefficient and outdated equipment, EBCx relies mainly on improving operations to save energy without retrofits. There are inherent risks to realizing savings with both retrofits and EBCx projects, and although this guideline's savings verification methods may be applied to retrofits, its primary emphasis is to reduce the risks inherent in EBCx projects. These risks are described in the next section.

This guideline advocates that a savings-verification process be integrated into an EBCx project to address these risks. This chapter identifies appropriate savings-verification pratices and compares savings verification with EBCx processes to show how the guideline's four verification methods may be integrated into the EBCx process. By identifying the activities and data requirements common to the two processes, this guideline helps minimize added project time and cost due to savings verification.

2.2. Common Risks

Calculating and verifying the actual savings in an energy-efficiency project assures that the project is successful and yields the expected energy savings. Though building-system operations are improved by EBCx, there are risks that the energy savings estimated before implementation may not be realized. These risks include:

- **Inaccurate or incomplete engineering assumptions, data, and analysis**

  Engineering estimates of savings vary in quality and thoroughness. Such estimates require assumptions about system and equipment operations and assumptions about key parameters in the calculations. Data on key parameters may be absent, or engineering analysis strategies may be faulty. This may lead to erroneous savings predictions.

- **Inaccurate or incomplete physical understanding of building systems**

  Although the impact on a system may be correctly analyzed, if the ECMs are not installed correctly for any reason, such as incomplete understanding by technicians, incomplete documentation of the ECMs, poor communication of specifications, or other factors, the estimated savings may not result.

- **ECMs are quickly defeated**

  The change in building operation may be too aggressive and cause problems elsewhere in the building, leading to complete removal rather than an adjustment back to less aggressive settings. This risk is common in EBCx projects where many ECMs are implemented through control-system scheduling and programming.

2.3. Common Verification Practices

Without a process to verify energy savings, it is difficult to determine whether the project's expected savings have been realized. Common practices used to verify the actual savings in energy-efficiency projects include:

1. A *sanity check*, such as checking the percentage of savings versus the estimated annual consumption of the building or system, or comparing the results with past projects.
2. *Alternate savings calculations* may be made of the systems and the impact of the ECM, and these results compared with the original calculations. These alternate calculations use different engineering modeling approaches, and often different data, to arrive at a result.
3. *Peer review* of the engineering estimates provides checks that the systems are correctly modeled with proper physical relationships, that the correct data and amount of data have been collected, and that reasonable assumptions have been made.
4. *Correcting engineering savings estimates* based on data collected to verify improved operations. The collected data is used to verify assumptions made about the post-installation energy performance of the equipment or systems. The calculations are corrected if it is found that assumptions were incorrect.
5. *Measurement-and-verification (M&V) methods* using measurements of energy use and operational characteristics before and after ECMs are installed in a building, adjusted to a common set of conditions, to calculate savings.

These practices are listed roughly in increasing order of rigor. The more rigorous practices require more data, more thorough analysis, and additional experts to review calculations and results. The most rigorous practice is based on the industry's M&V standards.

2.4. Measurement and Verification

Energy savings cannot be directly measured. Simple comparisons of energy use before and after an ECM installation are typically insufficient for accurate savings estimations because they do not account for the impacts of routine influencing parameters, such as ambient weather conditions or building occupancy and schedule. However, M&V provides a means to calculate these realized energy savings by making adjustments to account for these influences, thereby comparing the baseline and post-installation energy use under the same conditions. Rigorously applied, M&V methods can provide an estimate of the uncertainty of the resulting savings. This characteristic distinguishes it from the other common practices in that it may provide project sponsors a degree of confidence that the actual savings are within specified limits. However, estimation of the savings uncertainty is not always required by project sponsors.

It is important to note that M&V accounts for energy use by individual energy source. For example, electric savings are verified in a separate M&V process than natural-gas savings. The M&V approach need not be the same for all energy sources in a building. A measurement boundary around systems or equipment may be drawn to verify electric savings, while a boundary around a whole building may be used for natural-gas savings. There are comparatively fewer end uses for natural gas than for electricity in a building which often renders submetering natural gas use unnecessary.

Measurement and Verification is independent of the energy source.

There are two essential components of M&V for any energy-efficiency-improvement project:

- **Operational verification,** which verifies that the ECMs are installed properly and have the potential to generate savings.
- **Savings verification,** which as described above, uses before and after ECM installation energy measurements to calculate and verify that the installed ECMs are generating the expected savings.

While operational verification ensures that the equipment is operating correctly and more efficiently, it also ensures that the savings are due to the installed improvement and not to other changes in the equipment or building. Operational verification directly addresses the second risk identified in the overview—*inaccurate or incomplete physical understanding of building systems*. Savings verification verifies the amount of savings that has been realized. Savings verification directly addresses the first identified risk—*inaccurate or incomplete engineering assumptions, data, and analysis*. Both components address the third risk—*ECMs are quickly defeated*—operations may be periodically checked to see if ECMs are still working, and savings verification may detect the degradation in energy performance as ECMs are removed. For more discussion on tracking a building's energy performance, see the California Commissioning Collaborative's (CCC) ***Building Performance Tracking Handbook***.[3]

As with the common verification practices, operational verification may be applied with more or less rigor. Figure 2-1 shows a spectrum of activities, from least to most rigorous, that may be applied under each M&V component.

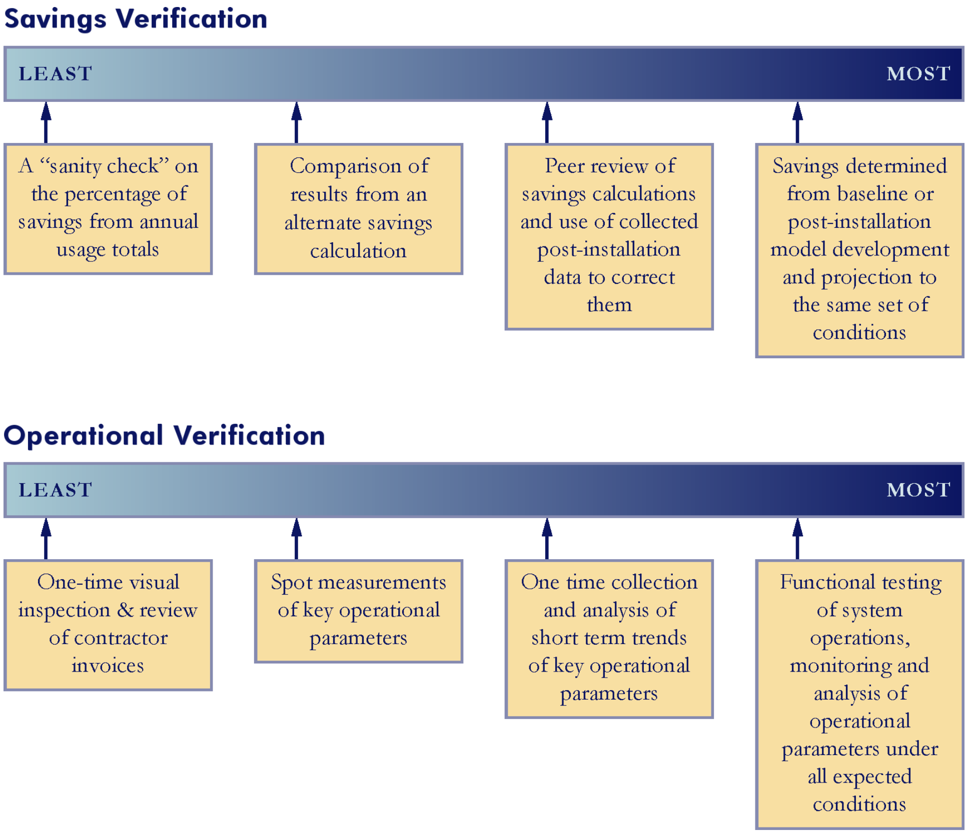

Figure 2-1: Spectrum of Activities to Verify Operational and Energy Savings

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[3] Available at www.caacx.org/PIER/handbook.htm.

The level of rigor applied under each component need not be the same in every project. A more rigorous operational verification method may be used with a less rigorous savings verification method. The level of rigor required is determined by the project's involved parties, after assessing a project's risks. More discussion is provided in ***3. Method Selection***.

2.5. Comparison of EBCx and M&V Processes

Figure 2-2 illustrates a general EBCx process, as outlined in the CCC's ***Existing Building Commissioning Guideline***[4] and the Building Commissioning Association's (BCA) ***Best Practices in Commissioning Existing Buildings***[5]. EBCx is a quality assurance process to make sure the building's systems and equipment are operating according to its current requirements. These requirements are identified in the planning and investigation phases, and the corrections and improvements to operations are verified in the hand-off phase. When energy savings is a requirement, the ECMs actual savings is also verified. The figure identifies which EBCx phase activities occur in the baseline and post-installation period framework of M&V.

There are several common activities in the EBCx and M&V processes. These include:

- **Engineering savings estimates (Baseline Period)**

  The EBCx process makes use of these estimates to weigh the costs and benefits of potential ECMs. The M&V process uses them to identify the proper verification method, assess risks, and to determine the rigor in which M&V activities should be applied.

- **Operational verification (Post-Installation Period)**

  The EBCx process uses operational verification to verify that EBCx improvements have been implemented properly and that equipment is performing to specifications. The M&V process uses it to verify that the equipment operations have been improved and have the potential to generate savings.

In addition, the data used to verify correct operation is often used in the engineering savings estimates and the savings verification methods. These factors limit additional work required to verify that the EBCx project saved energy.

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[4] Available at www.cacx.org

[5] Available at www.bcxa.org

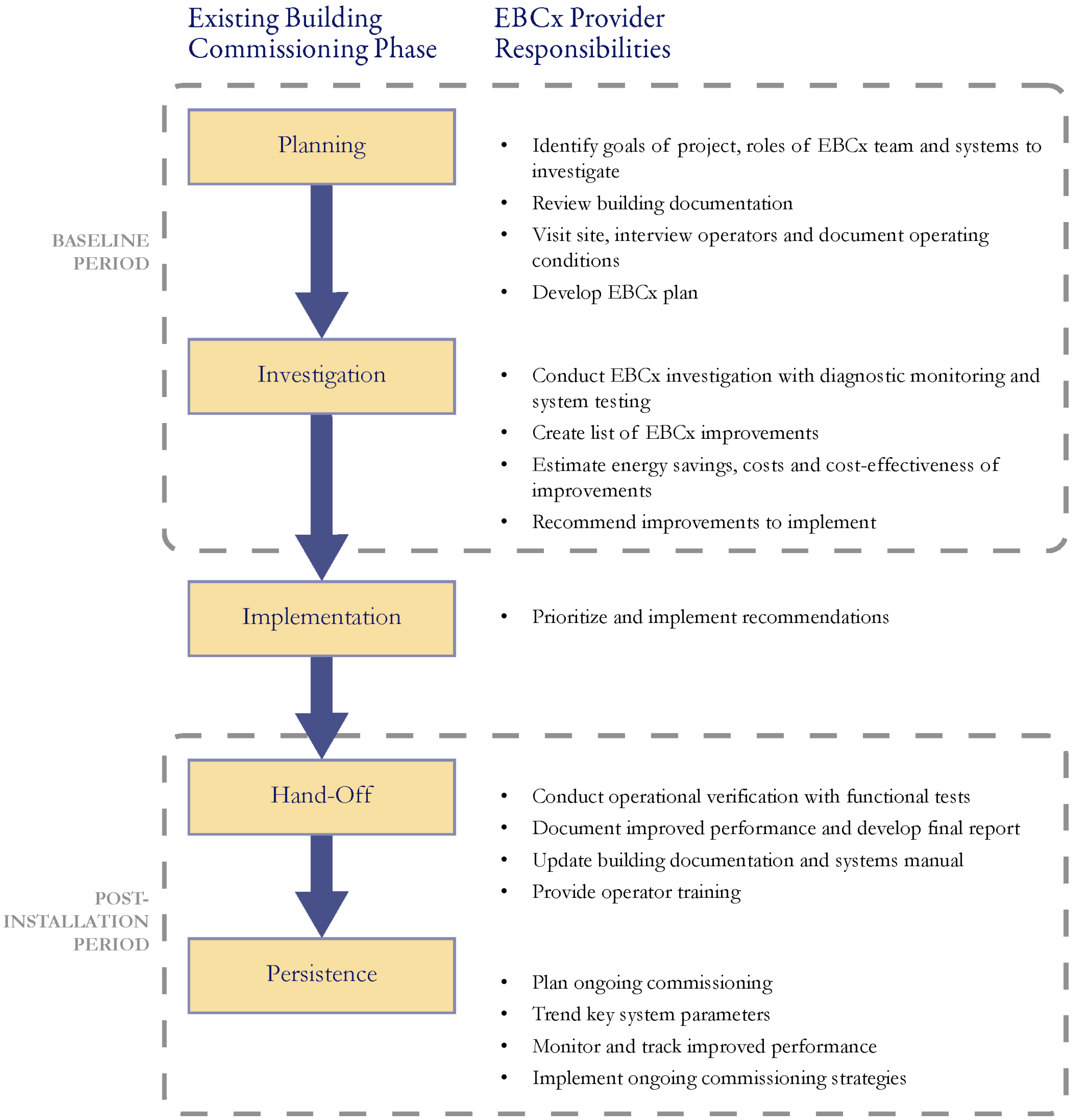

Figure 2-2: EBCx process showing baseline and post-installation periods

2.6. Process Integration

When an EBCx process is used to make building systems more efficient and save energy, it is very similar to other energy efficiency projects that include more capital-intensive retrofits and equipment replacements. Industry standard M&V procedures were established to verify the savings in these often multimillion dollar projects due to the risks of realizing their savings. Similar M&V procedures are applicable in EBCx projects which do not have as large of monetary investments.

As described above, the EBCx process provides one of the essential components of M&V—operational verification—as well as other common activities and data. When one of the EBCx project's requirements is to verify how much of the estimated savings were realized, the more rigorous savings verification methods of the M&V process are essentially added as an additional EBCx process requirement. Adding M&V to an EBCx process should not excessively increase project costs.

This guideline describes four methods of savings verification that are the most rigorous of those presented in Figure 2-1. These methods are titled:

- Method 1: Engineering Calculations with Field Verification
- Method 2: System or Equipment Energy Measurement
- Method 3: Energy Models Using Interval Data
- Method 4: Calibrated Simulation

Method 1 describes how to use the calculations for estimating savings in a verification process. It describes best practices in selecting estimation methods, and correcting them with post-implementation period data. While Method 1 can not be implemented in adherence with the formal M&V guidelines described in ***2.8.1 International Performance Measurement and Verification Protocol (IPMVP)*** (page 11) and ***2.8.2 ASHRAE Guideline 14: Measurement of Energy and Demand Savings*** (page 12), it is generally the lowest-cost approach.

Methods 2, 3, and 4 provide a greater level of saving verification rigor than Method 1 and can be implemented in a manner that satisfies formal M&V procedures. These three methods require measurements of energy use before and after ECMs have been installed. Actual measurements of energy use should increase the accuracy of energy savings estimates.

Figure 2-3 shows how the savings verification activities of the four methods during the baseline and post-installation periods align with the activities of the EBCx process.

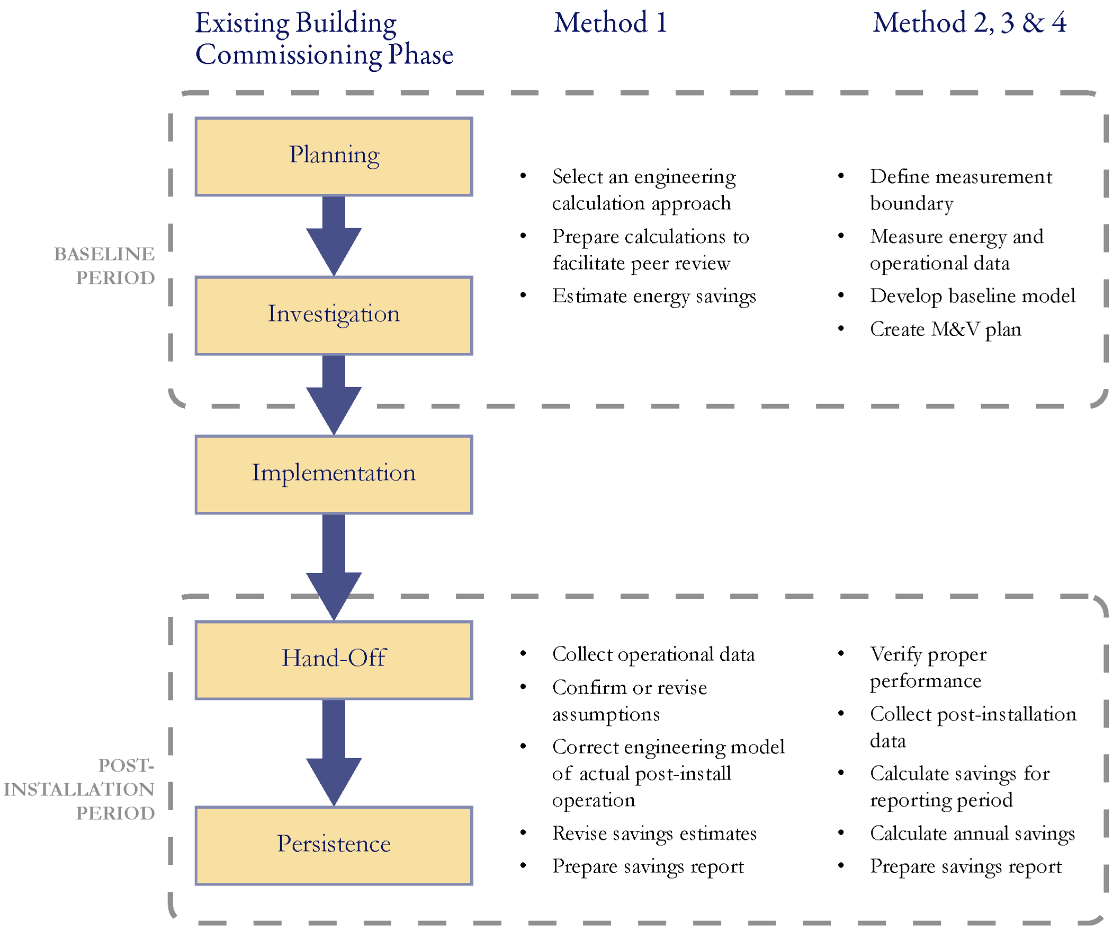

Figure 2-3: Comparison of EBCx process and savings verification methods

The risks that prevent full realization of the estimated energy savings establish the basis and need for practical guidance to verify an EBCx project's savings. Each method presented in this guideline provides specific descriptions of verification activities that must occur during the planning, investigation, hand-off, and persistence phases of an EBCx project. These activities include how to determine the measurement boundary within which savings is determined; how to set up the verification analysis; and determining the type, frequency, and duration of data to collect. Merging these verification activities into the appropriate phases of an EBCx project minimizes additional costs. Further information on selecting a specific method based on the project's goals, resources, and constraints are provided in ***3. Method Selection***.

2.7. Documenting Savings-Verification Requirements in EBCx Project Plans

Proper savings verification requires planning and preparation. This guideline will describe several methods that may be used to validate the savings achieved in an EBCx project.

Each of these methods requires activities in the baseline and post-installation periods. Documenting these activities is important so that others who become involved in the project later can fully understand the project's history. As described earlier, each verification method has synergies and overlap with the EBCx process, specifically with data collection and post-implementation operational verification. There is enough overlap that this guideline recommends documenting savings-verification plans as part of any EBCx plan.

The following are the additional essential items of documentation in a savings verification plan not already included in typical EBCx plans, but which can be easily integrated:

- **Scope of the EBCx effort**

  Describe how many systems or pieces of equipment will be affected.

- **Responsible Party**

  Identify the parties involved and their roles in verifying savings. For example, the EBCx agent may be responsible for verifying improved operations in a system, and an analyst may be responsible for verifying the savings.

- **Measurement Boundary**

  Define the boundary within which the savings will be verified. This can be the entire building, one or more building subsystems, or specific pieces of equipment. The chapters on each of the four methods describe how to define measurement boundaries.

- **Baseline Equipment, Conditions, and Energy Data**

  Document the facility's baseline systems, equipment configurations, and operational characteristics. This includes equipment inventories, sizes, types, and condition. Describe their operating characteristics or practices, including operation schedule, set points, and actual temperatures and pressures. Describe any significant problems with operating equipment. Include all energy data from spot measurements and short- or long-term monitoring, from each source. Define the baseline period and include all utility data for the facility. Describe any independent variable parameters used and their sources. Much of this information is usually documented as part of the EBCx plan, so only the specific items that are relevant to M&V should be added.

- **Reporting Period**

  Describe the length of the reporting period and the activities that will be conducted during that period.

- **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. Describe how savings uncertainty will be estimated (if required). For mathematical models, describe the range of independent variables for which it is valid. Describe any extrapolations outside this range of data. Describe any extrapolations of energy use or savings beyond the reporting period. Document all assumptions.

- **Savings Reports**

  Describe what results will be included in the savings reports. Describe when savings will be reported for the project. Indicate the reporting format to be used. Describe what data and calculations will be provided.

2.8. Relationship to Formal Guidelines

There are two primary industry standards for M&V in North America: the International Performance Measurement and Verification Protocol (IPMVP), and the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) Guideline 14-2002: Measurement of Energy and Demand Savings. These two standards are described in the following sections. The descriptions emphasize the requirements for adherence (for IPMVP) and compliance (for ASHRAE) with the standard. Following these descriptions, the relationship of the verification methods provided in this guideline to the industry standards is described.

2.8.1. International Performance Measurement and Verification Protocol (IPMVP)

The IPMVP provides guidance on the best practices in quantifying and reporting savings based on energy measurements and analysis. It presents four options that allow much flexibility in applying the fundamental M&V concepts to calculate and report a project's savings. It defines common terminology, describes project approaches and requirements, and identifies required documentation, reporting periods, and participants. These M&V options are:

- Option A: Retrofit Isolation: Key Parameter Measurement
- Option B: Retrofit Isolation: All Parameter Measurement
- Option C: Whole Facility
- Option D: Calibrated Simulation

While Options A and B draw measurement boundaries around individual systems or equipment, Option C draws it around the whole building or facility. The use of energy-use simulations in Option D is typically applied at the whole-building level, but may be used at the equipment or system level. While IPMVP options require measured energy data, Option A allows certain non-key parameters to be estimated based on well-documented sources, however it requires that the key parameters be measured.

As described earlier, IPMVP's fundamental concept is that savings cannot be directly measured. IPMVP-adherent M&V provides a means to adjust baseline and post-ECM installation energy use to the same set of conditions in order to calculate savings. Energy use must be measured, and cannot be built-up from engineering calculations of systems and equipment that relies on non-energy data and engineering assumptions of system interactions.

Using IPMVP increases transparency and the reliability of the reported savings. IPMVP provides guidance for users to develop M&V Plans that address each project's unique characteristics. IPMVP is not a standard, and therefore has no means of compliance. However, it lists requirements for adherence.[6] Among the adherence requirements are:

1. A complete M&V Plan is developed that:
    a. Uses terminology consistent with the definitions in the IPMVP,
    b. Includes all required information in the M&V Plan,[7]
    c. Is approved by all involved parties, and
    d. Is consistent with IPMVP's principles.[8]
2. The approved M&V Plan is followed.
3. M&V Reports are prepared according to IPMVP requirements.[9]

In addition, important technical requirements for adherence with IPMVP include:

1. Baseline energy measurements should be made over all operating modes of the building or systems; generally this is one cycle of operation.
2. Savings are reported only during the reporting (post-installation) period. They are not IPMVP-adherent if extrapolated beyond this period.
3. Energy use must be compared under the same set of conditions before calculating savings. When the conditions are the reporting (post-installation) period, savings are called "avoided energy use." When they are another set of conditions, the savings are called "normalized savings."
4. Establish the acceptable savings accuracy during the M&V planning process. Sources of error (measurement, data capture, analysis, etc.) should be identified and uncertainty analysis performed in order to manage it to develop reliable savings results.

Compared to engineering calculations performed before implementation, IPMVP-adherent M&V savings are determined and reported after the project has been installed. They also provide the means to determine the project's savings uncertainty.

2.8.2. ASHRAE Guideline 14: Measurement of Energy and Demand Savings

ASHRAE Guideline 14 is an M&V guideline that is a technical application of IPMVP's principles. It provides numerous equations, mathematical and statistical definitions, and examples. Its annexes provide informative discussions on measurement instruments, their accuracy, savings uncertainty analysis, regression techniques, and additional retrofit isolation techniques.

As in IPMVP, ASHRAE Guideline 14 requires that baseline and post-installation energy-use measurements be compared under the same set of conditions to estimate the savings. It provides detailed guidance on measurements, analysis, and quantification of energy and demand savings, including estimates of the resulting savings uncertainties. It has four compliance paths—one prescriptive path and three custom paths that are similar to IPMVP's Options B, C, and D. For

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[6] Chapter 7, IPMVP Volume I, EVO 10000 – 1:2007, available at: www.evo-world.org.

[7] ibid, Chapter 5.

[8] ibid, Chapter 3.

[9] ibid, Chapter 6.

the custom paths, compliance is achieved when savings can be determined with uncertainty less than or equal to 50% at the 68% confidence level. These paths are:

1. Whole-building metering
2. Retrofit isolation metering
3. Whole-building calibrated simulation

Compliance with ASHRAE Guideline 14 provides confidence to participants that energy savings are sound.

2.8.3. EBCx Methods and Formal Guidelines

This section describes the relationship of the four methods described in this guideline to IPMVP and ASHRAE. While each method may be used to verify savings, only the latter three may be implemented in a manner that fully adhers to IPMVP or complies with ASHRAE. The relationship of each method to the formal guidelines is discussed.

Method 1: Engineering Calculations with Field Verification is not described by the formal guidelines, and cannot be implemented in adherence with them. The engineering calculations described in Method 1 are used to estimate savings potential for each ECM. Method 1 desribes best practices in setting up and documenting the calculations, so that they may be reviewed by other experts to determine if their results are reasonable. It also describes best practices in setting up calculations so that their assumptions about post-installation operations may readily be checked and corrected with the data collected for operational verification purposes. Method 1 is commonly used in utility programs as it can identify individual ECM savings.

Method 2: System or Equipment Energy Measurement isolates building systems or equipment, identifies their load and schedule characteristics, and measures their energy and schedule parameters in the baseline and post-installation periods. It is a method that may be implemented in adherence (with IPMVP) and compliance (with ASHRAE) retrofit isolation options. Method 2 allows estimation of non-critical key parameters, an Option A approach, or all parameters may be measured in an Option B approach. Reporting periods are often short, less than one year, using Method 2, so that repetition of measurements and analysis may be required for full adherence. Method 2 also provides a framework for estimating the savings uncertainty, so that its results may be shown to be in compliance with the ASHRAE guideline.

Method 3: Energy Models Using Interval Data uses short time interval data of energy use and independent variables such as ambient temperature in the baseline and post-installation periods to develop regression-based energy models. These models are used to determine what baseline energy use would have been under post-installation or other conditions so that a fair determination of savings may be made. Depending on whether the measurement boundary is drawn around a building's subsystems or the entire building itself, this method may be implemented in adherence with IPMVP's Option B Retrofit Isolation and Option C Whole Building methods. It may also be implemented in compliance with ASHRAE Guideline 14-2002's retrofit isolation and whole building performance pathways.

Method 4: Calibrated Simulation describes how to set up and calibrate whole-building energy simulations to both estimate energy savings from proposed EBCx measures, and to verify the resulting savings. It may be implemented in adherence to IPMVP's Option D or to ASHRAE's Calibrated Simulation compliance pathway.

3. Method Selection

Selecting the optimal strategy to validate energy savings can be challenging as projects seldom have all the required resources readily available for a particular savings-verification approach. Deliberate planning at the onset of a project is necessary to ensure the desired savings-validation method can meet the desired project objectives.

This chapter provides an overview of each of the four verification methods. It also presents an evaluation framework that ranks several key defining criteria across all methods. The framework results should help the stakeholder quickly balance the strengths and weaknesses of each particular verification method for a given situation. The information presented in this chapter is not comprehensive, but is intended to provide the reader with initial direction to identify the verification method most likely to satisfy the project requirements. The specific verification methods are discussed in more detail in subsequent chapters.

3.1. Method Selection Process

This section describes the steps for selecting the appropriate method. Steps 1 and 2 may be completed without any prior knowledge of the verification approaches. Steps 3 and beyond will require some knowledge of the verification methods and their capabilities. General descriptions of each method are provided in ***3.2 Overview of Methods*** and ***3.3 Evaluation Framework***.

Step 1: Define the project objectives.

Create a list of desired goals of the project, including mitigating risks associated with the energy-savings claims. Understanding the desired outcome of the project is critical in selecting the best method.

Typical objectives might include:

- Ensure equipment operation has improved
- Validate and obtain a rough estimate of energy savings
- Validate and obtain a precise estimate of energy savings
- Report savings for each ECM
- Report savings for the entire project

Step 2: Identify potential constraints.

While a given verification approach may satisfy all the identified objectives, the approach may require resources that are not available to the project. Identifying any known constraints at the outset, and comparing those with the key criteria of each method should help focus attention on the most applicable options.

Common constraints might include:

- Time available for verification
- Budget
- Available data sources
- Available tools
- Available skills

Step 3: Select initial verification method.

After completing Steps 1 and 2, review the overview of the four verification approaches described in ***3.2 Overview of Methods***. With the objectives and constraints in mind for a specific project, read though ***3.3 Evaluation Framework*** (Table 3-2 and Table 3-3) which assesses the key objectives and constraints as they apply to each verification method. The framework also includes the primary metrics that influence project risk and cost. Identify an initial verification option that strikes the best balance between the objectives and constraints.

Step 4: Evaluate the detailed capabilities of the selected verification method.

Refer to the appropriate in-depth chapter related to the initial verification approach (Method 1, 2, 3, or 4) identified in Step 3. At this point, a general idea regarding the type(s) of ECM(s) identified and the resources (budget, labor, time) available to the project are required.

Use the detailed chapters to determine if the verification method meets the goals of the project. If the project objectives can be met by a particular method, determine if any known constraints interfere with the core requirements of the method. Keep in mind that cost is a common constaint that may limit the ability to implement a specific approach.

If the verification method does not appear feasible after a detailed evaluation, revisit Step 3 and select a different verification option, as illustrated in Figure 3-1. Once an approach is deemed acceptable, proceed to Step 5.

Step 5: Develop M&V Plan.

Once the optimal method has been identified, develop and document a plan that clearly describes how to meet the objectives of the savings-verification process. The M&V plan should, at a minimum:

- Document the goals of the project and the intent of individual ECMs
- Identify the verification method that will be applied
- Describe the data requirements for each identified ECM
- Assign a responsible party for the data collection and verification activities
- Establish the amount of data required
- Explain how the monitored data will be applied to the savings calculations
- Plan for required adjustments to the baseline
- Describe how results will be reported

For more information on possible components of an M&V plan, refer to ***IPMVP Concepts and Options for Determining Energy and Water Savings, Volume I***.

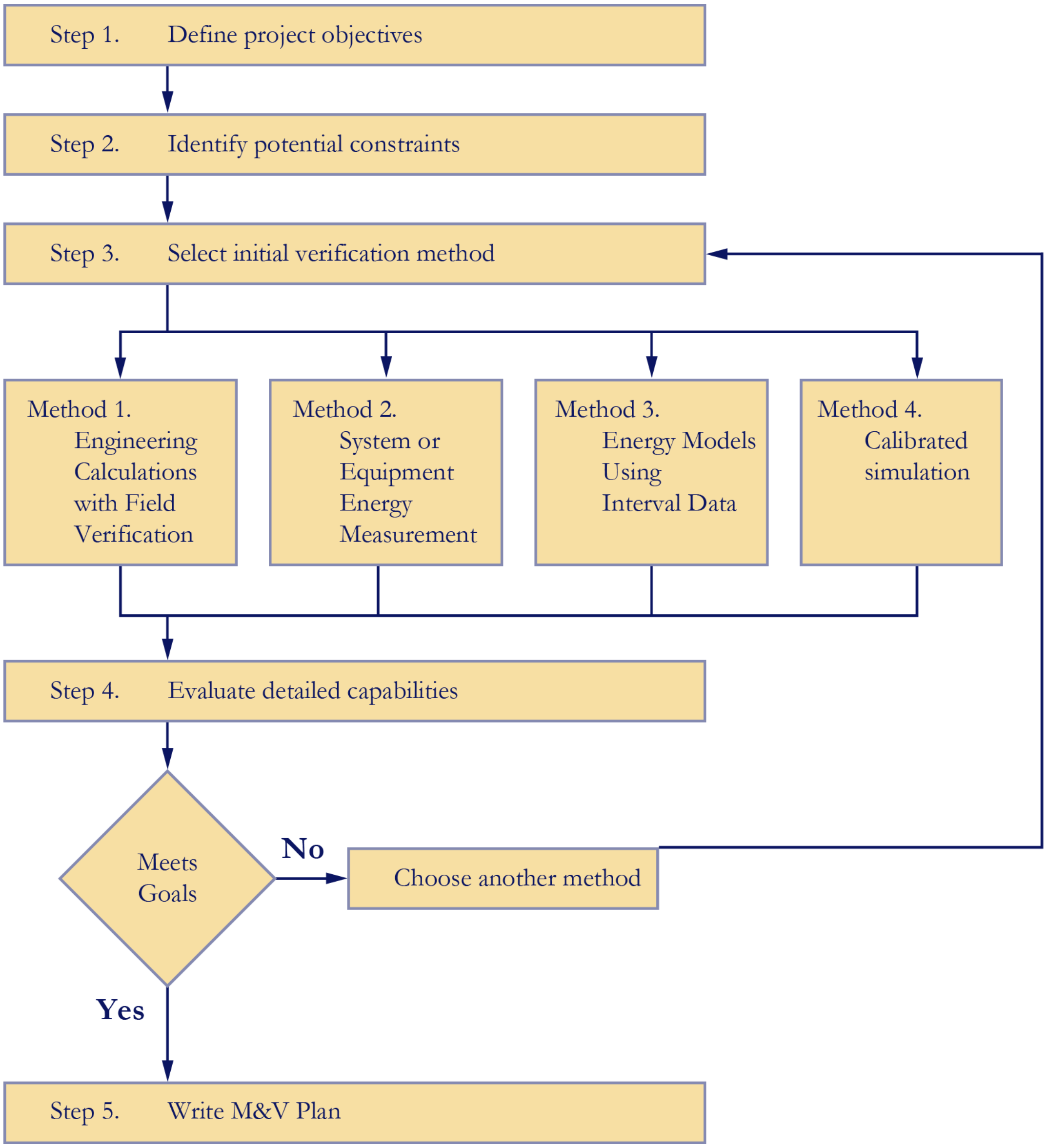


Figure 3-1: Method-selection process

3.2. Overview of Methods

This section describes the basic procedures and key criteria for each of the verification methods. This information should be used to inform the initial selection process, and should help narrow the verification options to those most applicable to the needs of a particular project. Once the initial method is selected, refer to the in-depth discussions of each method presented in subsequent chapters.

Four distinct methods for validating energy savings are:

- Method 1: Engineering Calculations with Field Verification
- Method 2: System or Equipment Energy Measurement
- Method 3: Energy Models Using Interval Data

- Method 4: Calibrated Simulation

3.2.1. Method 1: Engineering Calculations with Field Verification

Engineering calculations use fundamental equations and operational data to estimate energy use of systems (chilled water, air distribution, etc) and equipment (pumps, fans, etc). The calculations are used to estimate baseline and post-installation energy use, using information from design documents, equipment nameplates, and data from spot measurements and trend data. Assumptions and fundamental relationships are used to translate the operational data to estimations of actual energy use. Engineering calculations may be simple load and hours-of-use calculations, or use temperature bin methods when parameters are variable. These calculations are typically documented in a spreadsheet. Uncalibrated computer simulations of building systems and equipment may also be used.

Energy savings are calculated before any implementation occurs. The collected data is used to calculate baseline energy use. The expected impact of the EBCx ECM on the systems and equipment is used in predicting the post-installation energy use. The difference between the baseline and estimated post-installation energy use provides the initial energy savings estimate. Since the energy savings depend on the quality and level of details in the calculation, a third-party review of the calculation approach is required.

Field verification is used after the ECM is installed to confirm that the original calculations adequately predicted the ECM's post-installation energy use. Although verification is required in the EBCx process, Method 1 requires a high-rigor approach where actual operational data is collected in order to prove the ECM functions as expected.

Post-implementation operational data is used to update the savings estimates when actual post-installation performance differs from the performance modeled in the calculations.

This is the most common approach used in utility-sponsored EBCx energy-efficiency programs. Method 1 includes best practices in collecting data, calculating baseline and post-installation energy use, preparing the data and calculations for peer review, as well as performance verification approaches for various types of ECMs.

Best to use when:

- Specific quantification of energy savings is not as important as demonstrating improved operation.
- Measure-level savings can be determined with fundamental equations, and major interactions between multiple measures can be represented.

Core data required:

- Physical data gathered through brief walkthroughs, onsite documents, or short-term monitored data may be sufficient to model energy use.
- The calculation's accuracy should improve as more measured operational data is used to create the representations of equipment performance and energy use.

Core labor required:

- Engineering labor is required to collect and analyze the operational data. Additional efforts are required to follow best practices in calculations by clearly presenting the calculation process, documenting all assumptions and equations used, and developing calculations in a manner that allows for simple corrections when post-installation monitored data is available.
- Since energy savings depend on the accuracy and completeness of the calculations and assumptions, a third-party review is required.
- Additional labor is required to conduct field verification activities in which data is collected and analyzed to prove the ECM operates as predicted by the original engineering calculations. Time should be allocated to update the energy calculations when the field verification data does not align with the performance modeled in the original calculations.

Don't use when:

- High certainty of accurate savings is required.
- Measures cannot be adequately represented by any common calculation techniques.

▶ Detailed description in ***4. Method 1: Engineering Calculations with Field Verification***, page 27.

3.2.2. Method 2: System or Equipment Energy Measurement

Method 2 uses similar spreadsheet calculation techniques as Method 1 to estimate energy savings for equipment or end uses. A system's or equipment's energy use is characterized into its load and hours-of-use parameters, and these parameters are quantified using more rigorous measurements. Engineering assumptions are not sufficient to quantify energy use from operational data when using Method 2. If energy use is not measured directly, operational data may be used to verify savings only after appropriate measurements are taken to verify the relationship with the energy parameters.

Because Method 2 requires measurements for baseline and post-installation periods, energy savings are not quantified until after post-installation data collection is complete. Energy savings estimated before the post-installation data collection does not fulfill the requirement of this approach.

This method may be implemented in adherence to IPMVP Retrofit Isolation Options A or B, or in compliance with ASHRAE Guideline 14 retrofit isolation path.

Best to use when:

- Stakeholders require a high level of certainty regarding quantification of energy savings.
- Energy use of systems or equipment affected by the measures may be isolated and measured.

Core data required:

- Energy measurements in the form of spot measurements or monitored data that characterize both load and hours of use of specific piece of equipment or end use

Core labor required:

- Basic engineering labor is required to collect and use the appropriate energy data or develop verified proxies.
- The requirements for direct energy measurements may increase the labor time required over Method 1

Do not use when:

- Savings result from multiple complicated measures, spanning multiple systems
- Measure level savings are needed and multiple measures impact the same equipment or end use (this approach cannot isolate measure level savings within the same measurement boundary)

▶ Detailed description in ***5. Method 2: System or Equipment Energy Measurement***, page 43.

3.2.3. Method 3: Energy Models Using Interval Data

Method 3 relies on measurements of energy, and their driving variables, in both the baseline and post-installation periods. Regression-based energy models are developed for energy use using monitored short-time interval energy and independent variable(s), often ambient temperature data. Using the model with actual post-installation conditions, savings are determined from the difference between the adjusted baseline and measured post-installation energy use. Interval data regression modeling may be applied at the whole building level or at a building subsystem when submetered data is available.

Guidance is provided to identify building subsystems, appropriate modeling equation forms, length of monitoring period, data preparation requirements, and useful tools.

This method may be applied in adherence with IPMVP Retrofit Isolation Option B, or Whole-Building Option C.

Best to use when:

- Energy use follows predictable patterns that can be represented by an energy regression to a level of accuracy and precision that satisfies the project stakeholders.
- Total savings from multiple measures are detectable at either the whole building or building subsystem level. For example, the total savings should be larger than the variation, or noise, of the energy regression.
- Energy meters and submeters already exist for the desired measurement boundary (whole-building or building subsystem)

Core data required:

- Whole building or subsystem energy data in intervals no greater than 15 minutes over the project timeline
- Independent variables that drive energy use over the same period as the energy data (e.g., ambient temperature, building schedules, and occupied periods)

Core labor required:

- Engineering labor is required to develop adequate energy regressions from monitored data in the baseline and post-install periods. Specialized skill with regression analysis is required to develop representative energy models.

Do not use when:

- Energy savings for each ECM is required
- Regressions of energy use with driving variables are not sufficiently certain to predict savings

▶ Detailed description in ***6. Method 3: Energy Models Using Interval Data***, page 57.

3.2.4. Method 4: Calibrated Simulation

Method 4 describes the use of calibrated computer simulations to model energy flows in a building or subsystem. Calibration is a process that assures the simulation output matches actual measured data from the whole building, or system level, energy use within a predefined limit. Once the simulation is calibrated, the model is used to predict both the baseline energy use and ECM impact.

This method may be implemented in adherence with IPMVP Option D: Calibrated Simulation.

Best to use when:

- The data required for the other verification methods is not available and cannot be obtained
- The building has numerous ECMs that are highly interactive or when the building design is integrated and holistic, rendering isolation and M&V of individual ECMs impractical or inappropriate
- Energy simulations were previously created or are required for another purpose
- Savings from each individual ECM need to be quantified for a project with multiple ECMs
- The budget for M&V is large enough to accommodate the hours required to carry out this procedure

Core data required:

- Applicable when building details are known. Access to record documents such as: construction drawings, specifications, TAB reports, mechanical equipment schedule, submittals, architectural floors plans, architectural elevation drawings, envelope characteristics such as R and U values is required to limit the number of assumptions made in the model
- Historical utility data and actual weather data should be available for at least one whole year in monthly format. Hourly or 15-minute interval data will increase accuracy if used
- Historical subsystem data should be used when available. The additional end-use breakdown is beneficial for calibration purposes and helps to increase accuracy.

Core labor required:

- The qualifications and experience of the simulator is a key factor so Method 4 is intended for only the most qualified practitioners

Do not use when:

- Savings can be verified using any other method
- The software cannot accurately model both the baseline and the ECM conditions, often true when equipment is "broken" or operation is "less than optimal"

▶ Detailed description in ***7. Method 4: Calibrated Simulation.***, page 77.

3.3. Evaluation Framework

The selection of a verification method most suitable to a particular project generally depends on two main considerations—risk and cost. Unfortunately, they are driven by numerous interrelated and interactive factors that vary greatly from project to project. The key metrics that influence both risk and cost are summarized in Table 3-1.

This framework was established to analyze these key metrics in the context of each verification method discussed in this guide. The framework is presented as a matrix in Table 3-2 and Table 3-3. These tables provide a general but holistic view of the capabilities and requirements of each verification method. They are intended to assist stakeholders to quickly interpret the potential benefits and limitations of each verification approach. A detailed discussion of each metric included in the framework is discussed later in this chapter.

Table 3-1: Key Metrics for Evaluating Methods

Main Category	Key Metrics
Stakeholder Objectives	Relative accuracy
	Quantification of uncertainty
	Granularity of savings
	Savings interactions captured
	Persistence
	Formal method
Constraints	Required baseline data (type)
	Required baseline data (quantity)
	Required post-ECM data (type)
	Required post-ECM data (quantity)
	Tools required
	Labor (expertise)
	Labor (level of effort)
	Requires consistent building operation?
	Requires high level of savings (> 5–10% of whole building)

Table 3-2: Evaluation Framework – Objectives

Method	Submethod	Key Metrics				
		Accuracy (1–5)	Quantified Uncertainty	Granularity of Savings	Savings Interactions Captured	Formally Accepted Method
Method 1: Engineering Calculations with Field Verification	Engineering Calcs & Visual Verification	1–2	No	System Measure	No	No
	Engineering Calcs & Performance Verification	2–4	No	System Measure	No	No
Method 2: System or Equipment Energy Measurement	Key Parameter Measurement	2–4	No	System Measure	No	IPMVP - Option A
	All Parameter Measurement	4	Yes	System Measure	No	IPMVP - Option B ASHRAE GL-14

Method	Submethod	Key Metrics				
		Accuracy (1–5)	Quantified Uncertainty	Granularity of Savings	Savings Interactions Captured	Formally Accepted Method
Method 3: Energy Models Using Interval Data	System Approach	4–5	Yes	System	No	IPMVP - Option B ASHRAE GL-14
	Whole Building Approach	4–5	Yes	Whole building	Yes	IPMVP - Option C ASHRAE GL-14
Method 4: Calibrated Simulation	System Approach	4	Yes	System Measure	No	IPMVP - Option D ASHRAE GL-14
	Whole Building Approach	4–5	Yes	Whole building Measure	Yes	IPMVP - Option D ASHRAE GL-14

Table 3-3: Evaluation Framework – Constraints

Method	Submethod	Key Metrics							
		Required Baseline Data (Type)	Required Baseline Monitoring Time (Quantity)	Required Post-ECM Data (Type)	Required Post-ECM Monitoring Time (Quantity)	Basic tools required (Type)	Labor: Expertise required (Type)	Labor: Level of effort (1-5)	Consistent building operation required (Yes/No)
Method 1: Engineering Calcs with Field Verification	Engineering Calcs & Visual Verification	Nameplate, Physical inputs and/or Performance data	spot measurement or up to 1-4 weeks	Snapshots	spot measurement	Logging tools Spreadsheet or Simulation software	Engineer	2-3	No
	Engineering Calcs & Performance Verification	Nameplate, Physical inputs and/or Performance data	spot measurement or up to 1-4 weeks	Performance data	spot measurement or up to 1-4 weeks	Logging tools Spreadsheet or Simulation software	Engineer	3	No
Method 2: System or Equipment Energy Measurement	Key Parameter Measurement	Measured physical inputs and Energy performance data	spot measurement or up to 1-4 weeks	Energy performance data	spot measurement or up to 1-4 weeks	Equipment performance curves Spreadsheet	Engineer	3	No
	All Parameter Measurement	Measured physical inputs and Energy performance data	1-4 weeks	Energy performance data	1-4 weeks	Logging tools Spreadsheet or Simulation software	Engineer	4	No
Method 3: Energy Models Using Interval Data	System Approach	Sub-metered or logged consumption data, energy driving variable	characterize cycle of operation: 1-6 months	Sub-metered or logged consumption data, energy driving variable	characterize cycle of operation: 1-6 months	Spreadsheet or Regression analysis tool	Engineer	4-5	No
	Whole Building Approach	Main meter interval data Energy driving variable	6-12 months	Main meter interval data Energy driving variable	6-12 months	Spreadsheet or Regression analysis tool	Engineer	3-4	Yes
Method 4: Calibrated Simulation	System Approach	Sub-meter consumption data Physical inputs (1 data set only: baseline or post)	characterize cycle of operation: 1 week - 1 month	Sub-meter consumption data Physical inputs (1 data set only: baseline or post)	characterize cycle of operation: 1 week - 1 month	Logging tools Simulation software	Energy simulation expert	5	No
	Whole Building Approach	Physical inputs Monthly data: (1 data set only: baseline or post)	12-18 months (if calibrating to baseline data)	Physical inputs Monthly data: (1 data set only: baseline or post)	12-18 months (if calibrating to post-ECM data)	Simulation software	Energy simulation expert	5	Yes

3.4. Overview of Objectives and Constraints

A determination of risks at the start of a project is pivotal and the impact of potential risk should be considered in the evaluation of each metric in this framework. The following sections describe the objectives, constraints and scoring criteria presented in Table 3-2 and Table 3-3.

3.4.1. Stakeholder Objectives

Before the start of the project, stakeholders should understand how the quantification of savings affects them and if they are at risk of any penalties for either inaccurate savings estimations or for lack of savings persistence. Depending on objectives, some stakeholders might desire a verification approach to demonstrate improvements in system operation only, while others might require significant efforts to quantify actual energy savings as precisely as possible.

The following is a list of key metrics that stakeholders should evaluate as part of the program or project. These metrics (bold text) are rated for each approach so that stakeholders can easily make a comparison between their desired needs and the ability of verification approaches to meet those needs.

Relative Accuracy

Quantifying energy savings has always been a challenge due to the nature of measuring energy that has not actually been consumed. Savings estimation approaches typically require some assumptions and extrapolation which inherently introduces an unknown amount of uncertainty into the final savings value.

Some verification approaches produce very general evidence that savings, or lack thereof, exist. An example is the “deemed” savings approach, which relies on operational verification strategies to make sure the measures installed are operating correctly, while their energy savings numbers are based on averages of similar measures in other buildings or are calculated from generic building simulations. There is no way to verify the actual savings that have been achieved; only that operations are improved.

Other approaches incorporate more rigorous before-and-after comparisons of energy use measurements, factor in the impact of conditions that change between baseline and post-installation periods, and produce an energy savings estimate which may include an estimate of its uncertainty.

The rating of accuracy in the Evaluation Framework is based on a relative 1–5 scale with 1 being the least accurate and 5 being the most accurate. The general assumption used to assign a rating is that accuracy improves with an increasing level of rigor in data collection, analysis thoroughness, peer review, and details required to determine the energy savings estimate.

Quantification of Savings Uncertainty

As part of risk management, some stakeholders might desire a quantifiable evaluation of the savings uncertainty. Only some of the listed verification approaches are able to provide an estimate of the savings uncertainty. This metric is rated as a simple yes/no.

Granularity of Savings

Savings can be reported from a whole building level down to individual measures. A whole-building approach will capture the impact of all implemented measures, including any interactive effects. As such, the effects of individual ECMs cannot be independently quantified. A system approach will capture the impact of all measures implemented within that system only. When multiple ECMs are implemented withing the system, individual impacts cannot be resolved. Some verification methodologies can verify savings of each individual measure. The desired granularity of savings verification should be established at the start of the project. Once the desired granularity is known, the stakeholder can focus on specific verification approaches that match. This metric is rated with three options, whole building, system, or measure level capability.

Savings Interactions Captured

Energy-conservation measures might have interactions across multiple systems where a modification to one system or component impacts the consumption in another. Some stakeholder objectives might require all possible impacts, beneficial or not, be measured and reported. To this end, the verification of savings approaches can differ in the scope and range of measurement. Some approaches can isolate only a single system or piece of equipment and would not capture impacts from other affected systems. Other approaches focus on impacts at the main meter level and inherently capture all associated savings interactions. Savings evaluated at main meters cannot quantify system or measure level impacts accurately.

If the stakeholder goals include capturing all possible savings interactions, then the verification approach must be applicable to all affected systems. Some of the verification approaches described in this guide could capture interactive savings with an additional level of effort.

Persistence of Benefits

A stakeholder's needs may require a system or procedure to promote persistence of EBCx benefits. Some verification approaches are more readily adaptable to establish continuous feedback on energy performance while others require repetition of the entire verification process. This metric is rated as a "repeat" or "continuous." It is important to note that repeating efforts or continuous reporting can have a significant impact on costs and budgets.

Formal Method

Some stakeholders may require a savings verification approach that is described in published industry standards or guidelines. The approaches evaluated in this project range from informal methods that are commonly used to those described in the International Performance Measurement and Verification Protocol (IPMVP) or ASHRAE Guideline 14. Each approach is rated with informal, IPMVP, and ASHRAE GL-14.

3.4.2. Resource Constraints

Cost is a constraint that impacts all phases of a project and often limits the ability to apply specific verification approaches. Costs are affected by multiple interactive factors including, but not limited to:

- The ability to obtain data required for verification
- The complexity of the equipment or measure
- The availability of time savings tools
- The level of rigor required by the specific verification method

Due to the inherent variability of verification costs, it is not realistic to assign a general range. Rather, cost should be considered by the stakeholder on a project-by-project basis while evaluating each constraint. The following is a list of key constraints that stakeholders should evaluate as part of the program or project.

Required Baseline and Post-ECM Data Type

The type of data required, both baseline and post-implementation, can vary substantially among and within verification approaches. Typical data types range from energy consumption derived from monthly utility bills, 15-minute interval electric consumption data, system-level monitored energy use, monitored data from key operating parameters trended over time (e.g., temperatures, flow rates, status, etc.). Equipment performance curves may also be required to link performance data with energy use.

Monthly consumption data and main meter interval data are typically provided by the utility. Submetered interval data might also come from the utility; however, previously installed utility submetering at the desired system level is less common. Submetered interval data often requires the installation of dedicated meters at the start of the project. Performance data (e.g., set points and schedules, airflows, nameplate info.) is typically collected through BAS trends or portable data loggers. The performance data is used by engineering calculations and simulations software to model the building, system, or equipment energy use.

The stakeholder should evaluate the type and availability of data at the project site. If the ability to collect required data is not currently in place, additional capabilities can be incorporated. These additions typically add time and cost to the project. This metric is rated using the options: monthly data, main meter interval data, submetered interval data, performance data, physical inputs, or snapshots.

Required Baseline and Post-ECM Data Quantity

The quantity of data required for each approach also varies significantly. Where possible, data should be collected over an entire range of operation of the equipment of system being analyzed. Constant applications may only require a simple spot measurement to characterize a complete cycle, while variable applications may take days, weeks, or even longer for a valid characterization.

The availability of historical records, such as previous utility billing data or archived trends, might reduce the time and costs related to baseline data collection. If historical data is not available, data collection must start with the project kickoff and the entire baseline monitoring period will be included in the project timeframe. This metric is rated with the generally accepted time required for each approach (e.g., weeks, month and multiple months).

Tools Required

The tools available to a project should be identified and evaluated by the stakeholders. Some verification approaches require readily available tools such as spreadsheets while others require detailed simulation software or analytic tools to create regressions from the available data. Data acquisition tools such as the building BAS or portable data loggers are typically required. The control system should also be considered as a tool since trending capability can significantly reduce data collection time and labor requirements. Portable loggers are also a commonly used tool, but these typically require additional efforts to deploy, which may increase both the time and cost requirements of a project.

The specific tools required for use by each approach are listed. The basic options considered in this evaluation are logging tools (including the control system or portable data loggers), basic spreadsheets, regression analysis tool, and simulation software. Some verification approaches might require more than one of these basic tools.

While this category indicates the required tools to implement a given verification process, there are additional tools that might reduce time and labor by streamlining data preparation and analysis. See ***Appendix C*** for more information on available tools.

Labor (Expertise)

Engineering labor is typically required to identify and analyze the relevant data to establish an energy savings estimate. Specialized skills, such as energy simulation, are required for some of the verification methods presented in this guideline. The type of expertise required by each approach is listed as engineer, or energy simulation expert.

Labor (Level of Effort)

The level of effort is a primary factor that drives project costs. Some verification approaches are relatively passive and require only idle efforts while data collection is under way. Other approaches are extremely active and require substantial data analysis including statistical modeling or calibrating simulations. The labor capacity and budget available to a project should be evaluated. The level of effort component of each approach is rated using a scale from 1–5 with 1 being the least labor intensive and 5 being the most labor intensive.

Consistent Building Operation

Changes to building systems or operation occurring during the monitoring period can affect the ability of some verification approaches to measure savings from a project. It is important to identify the possibility of any major changes to the building that have occurred or are planned to occur during the monitoring period when analyzing the potential approaches. The changes can be as simple as a major tenant moving in or out or as extreme as a system retrofit or major renovation. At times, non-routine adjustments can be made to compensate for thesechanges to the building operation. If significant changes are expected during the monitoring period, it is generally easier to plan ahead and establish procedures for the non-routine adjustments before the project begins. This metric is rated as a simple yes/no to indicate whether the method requires a consistent building operation throughout the monitoring period.

4. Method 1: Engineering Calculations with Field Verification

4.1. Description of Method

This method describes best practices that may be used to estimate energy savings for EBCx projects and outlines procedures to true-up the savings estimates based on operational data collected in the post-implementation period.

Engineering estimates of energy savings are a normal part of the EBCx process and are developed prior to implementation of EBCx improvements. Similarly, in formal EBCx projects, operation data is used to verify that the installed improvements operate as desired. This verification method describes how to enhance these two EBCx activities to better assure the project yields its expected savings. Key enhancements include:

- Improved transparency in the energy calculations due to detailed documentation of main assumptions and data used.
- A third-party review to ensure the recommended ECMs, calculation approaches and savings claims are reasonable for the situation at the specific project.
- Enhanced assurance that final savings estimates are accurate by incorporating post-installation data to confirm assumptions.
- Updated calculations, if necessary, based on the post-installation data to reflect actual post operational conditions.

EBCx service providers use many different calculation approaches to estimate savings that are conducive to savings validation using Method 1. These common approaches include:

1. Simple calculations
2. Spreadsheet-based methods
3. Uncalibrated computer simulations

Data used in these three main calculation approaches spans a wide range and may include weather data, system design information, manufacturer specifications, and operational data from on-site monitoring. The type and quality of these calculations, as well as the availability of building data, vary from project to project. This inherent variation is the primary motivator to include a third-party review to improve consistency and “reasonableness” of the engineering calculations.

Energy savings are estimated before any improvements to the building are installed. As such, the EBCx provider must predict the ECM impact on the system or equipment performance to develop a post installation energy use estimate. The initial savings estimates, along with expected costs, help owners choose the most cost-effective ECMs for installation. Final savings are not approved until the ECM is validated with post-installation performance verification.

4.1.1. Key Criteria

- Method 1 describes an operational verification process that is used to validate energy savings estimates by applying best practices in calculations, incorporating peer review and updating calculations based on post-implementation performance data.
- Energy use is calculated or confirmed indirectly from operational data. As such, the method only proves the capacity to save exists. Energy savings are not validated directly.
- Savings estimates apply to individual ECMs at the equipment or simple system level.
- Engineering calculations are often custom developed by the project engineer. Standardized calculations are not yet widely available in the industry, but as they are developed and adopted, consistency between projects may improve. Interactions between ECMs must be addressed intentionally in the calculation process to avoid double counting of savings where possible.
- The flexible nature of this method provides a relatively low cost approach to estimate measure-level savings, but at a cost of some assurance of savings accuracy
- Method 1 can be utilized when rigorous validation of savings estimates is not required or when the precise quantification of savings is not a priority of the project.

4.1.2. Procedure

Figure 4-1 provides a general overview of the Engineering Calculations with Field Verification process. A more detailed explanation of each step is provided in the next section.

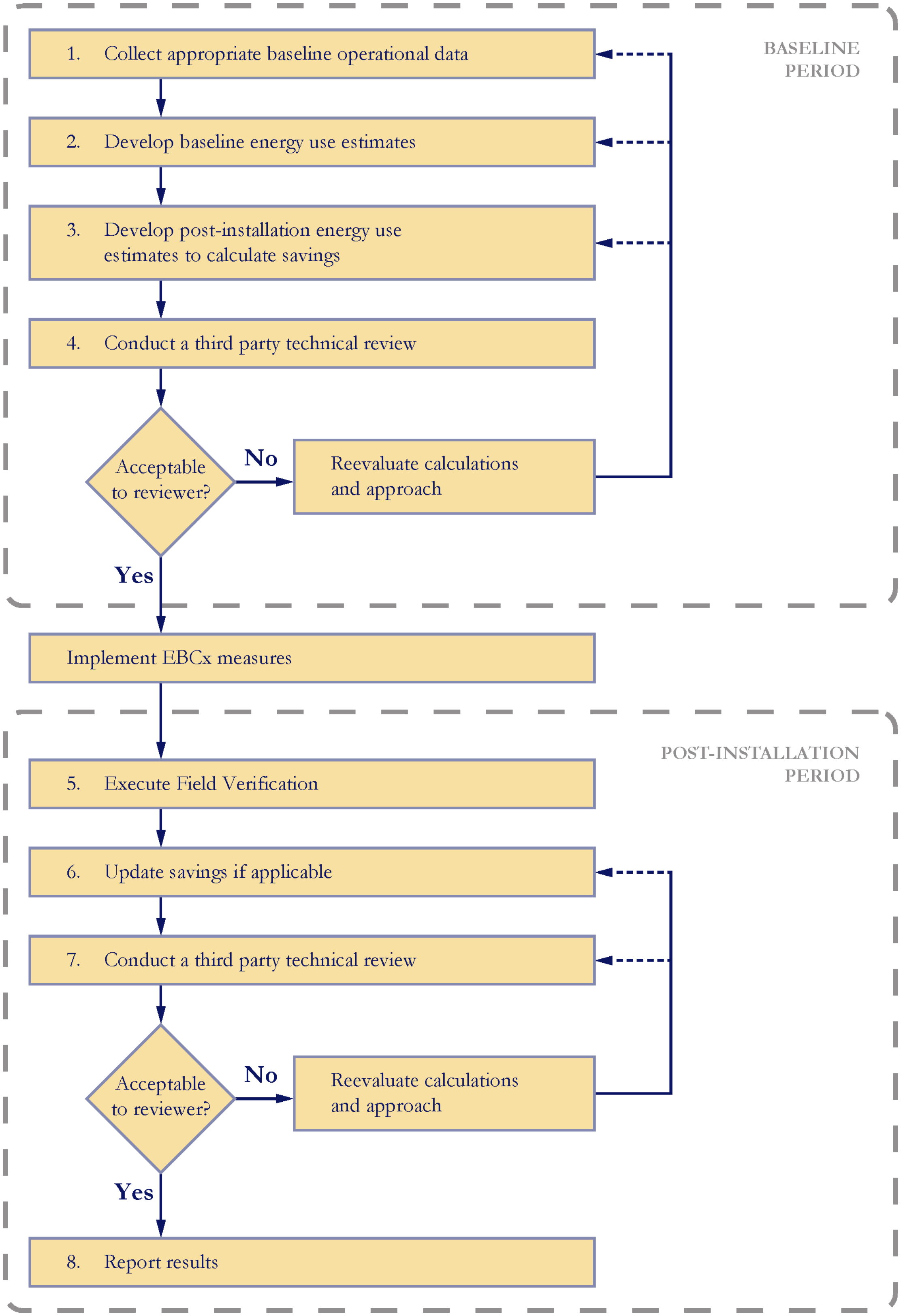


Figure 4-1: Method 1 process flow chart

This section highlights areas the main steps under Method 1 that augments the typical EBCx process.

Step 1: Collect appropriate baseline operational data for identified ECMs.

Baseline data should be sufficient to:

1. Establish a defensible energy use estimate for use in the savings calculations, and
2. Demonstrate the original performance deficiency to validate the ECM recommendation.

Data such as as-built design documents, equipment nameplate information and spot measurements are principal sources used as inputs to engineering algorithms used to develop the energy use estimates. Additional data is often required adequately demonstrate the current performance deficiency. Data from functional performance tests, or extended monitoring of operational performance data (e.g., status, speed, temperature, flow rate, pressure) and driving variables (e.g., outdoor temperatures, occupancy) is usually sufficient to demonstrate the current operation and demonstrate the performance deficiency.

Table 4-2 on page 39 lists the recommended measurements to satisfy the baseline data required to document a variety of common EBCx measure types.

Step 2: Develop baseline energy estimates.

Engineering calculations should be developed in a manner that is clear and easy to follow by a third-party engineer. Baseline data must be presented in a manner that clearly demonstrates the identified deficiency to individuals who have not personally been on the project site. Assume that the reviewer will have no background with this particular project and prepare supporting documentation accordingly. A clear presentation of the data and the calculation process is necessary for an efficient review.

Developing the calculations in a manner that quantifies loads and schedules separately is a best practice approach that greatly reduces efforts in updating the calculations with post-installation performance data. More details regarding calculation techniques are provided in ***4.2.2 Summary of Calculation Approaches***.

All assumptions and inputs must be clearly documented and justified for each equation. Intermediate calculation steps should be shown where possible. If using a spreadsheet analysis, using an additional column to separate the calculation steps improves the review process. Additional supporting documentation should also be included to provide context to the third-party reviewer, preferably within the calculation file. Examples of supporting documentation includes, photos, screenshots, one-line system diagrams and charts showing the development of correlations of independent variables with equipment performance parameters.

Step 3: Develop post-installation energy estimates to calculate savings.

When using Method 1, energy savings are predicted during the baseline period. As such, the project engineer must initially predict the ECM impact on the system or equipment operation and then represent this impact in the calculations. The post-installation energy use estimates are typically established via modifications to the baseline calculations.

The initial post-installation energy use estimate must be developed in a manner that allows for future modifications that true-up the prediction with actual performance data once available. Referencing key assumptions in one place as inputs to the engineering equations allows for ease of updating with actual values, if needed.

Step 4: Conduct a third-party technical review.

The accuracy of energy savings estimates depends completely on the engineering calculation approach, the underlying assumptions and the quality of data used within the calculations. The third-party review provides a fresh set of eyes to ensure the calculation process and underlying data is used to the best extent possible to produce reasonable approximations of energy use and savings. The review should improve confidence that savings estimates are reliable.

Step 4 does require some engineering time and additional effort, but the third-party review is a critical step that elevates the engineering calculation process of a typical EBCx project to a savings validation approach.

The third-party reviewer should comment on the suitability of the calculation approach, the sufficiency of the baseline data, the appropriateness of the assumptions, and should confirm the correctness of the finding and suggested measure. The comments should be considered and used to enhance the engineering calculations whenever possible.

Step 5: Execute field verification after ECMs are installed.

Verification of the ECM installation is already a component of EBCx, but field verification component of Method 1 requires that the performance of the ECM aligns with the post-implementation calculations.

The data used to prove the successful installation of the ECM should be the same, or at least compatible with the data used to prove the original deficiency. For example, if a functional performance test was used to establish the baseline condition, the same functional test procedure should be used verify the ECM installation.

The performance data should be sufficient to update the savings calculations if any deviations from the original recommendations or assumed ECM operation are observed.

Step 6: Update savings if necessary.

When operational data proves that actual ECM operation deviates from the original expectations, the new data must be used to update the calculations.

Example 1: A simple schedule reduction initially requires an estimate of the reduced equipment operating hours. If performance verification activities prove the actual schedule is different than originally expected, the actual hours would then be used to update the calculations.

Example 2: An ECM that reduces fan speed from a duct static pressure reset requires an initial estimate of the post-installation fan speeds. Field verification data may include trends of post-installation fan speeds that could be developed into an empirical relationship (OAT vs. fan speed regression). These relationships can be used in lieu of the original approximations to update the calculations if the post-installation is different than the original approximation.

Step 7: Conduct final peer review.

The majority of the third-party review efforts focus on the original calculation methodology described in Step 4. However, a brief review of the performance verification data and any subsequent updates to the calculations will increase confidence that the final savings claims are accurate.

Step 8: Report results.

The final step is to document the results in a report fomat required by the project stakeholders. The report should include a description of the individual measures and the associated updated savings. Including visual representations of the the baseline and field verification data can also be useful documentation.

4.1.3. Persistence Phase

Persistence of benefits is not inherently guaranteed when using a field verification approach. This method provides only a snapshot of current operation of the equipment affected by the ECM(s). The performance may change, for the better or worse, before the predicted savings are realized.

If project budgets allow, field verification activities may be conducted periodically to ensure the ECM continues to operate as expected.

4.2. Analysis Methods

As stated in the overview of approach, the quality of these calculations will inherently vary from project to project. Therefore, producing results with consistent quality is an ongoing and challenging task when using engineering calculation approaches. Efforts are currently underway to improve consistency via the development and adoption of standardized calculations for specific measures. Currently, there are two publicly available savings calculation tools—"BOA" and "C-BOA"—which cover most common EBCx measures. Both of these tools are available as a free download from the CCC website. Standardization is expected to streamline the energy savings estimation process, but it is unlikely these future tools will apply to every possible EBCx situation. Until these standardized approaches are available and adopted by the stakeholders of a particular project, or for future EBCx measures that aren't covered by a standardized approach, applying best practices in the calculation development will help establish a level of consistency. Method 1 promotes the use of best practices in energy savings calculations.

4.2.1. Calculation Best Practices

Clearly label all assumptions.

Most engineering calculations require some level of assumptions in order to produce energy use estimates from operational data. For example, a load factor and motor efficiency are often assumed values used to calculate the power of a motor from nameplate data. Often, these assumptions have significant impacts on the final energy use estimate but are not substantiated.

Consider separating the assumed values from the calculation and reference them directly by the engineering equation. Using a designated location for assumptions facilitates a streamlined review.

Quickly test all assumptions.

The overall impact of assumptions can be efficiently tested when assumed parameters are referenced from a global location. Use an appropriate range for the assumed values input several values across this range. Monitor the impact on the final savings estimate with the various assumed values. If the assumed parameter has significant impact on the final results, consider replacing the assumption with a measured parameter.

Include supporting documentation.

Documentation that provides project specific context should be included within the calculation files. Trend data used to develop empirical relationships, functional test results, and simple line diagrams of applicable systems are examples of useful information that assists third-party engineers conduct effective reviews. The documentation should be included within the calculation files whenever possible so all required information is located in a single location.

Use as much measured data as possible.

Engineering calculations should produce more realistic results when driven by measured data instead of unsubstantiated assumptions. Calculations that utilize simple data such as nameplate, design information and assumptions may not achieve the same level of accuracy as calculations that utilize detailed measurements taken over a period of time, especially when the energy use parameters experience a high level of variation.

Account for interactions.

Interactions between ECMs may have significant impacts on the final savings. For example, improving the efficiency of a chiller plant by reducing the condenser water temperature may reduce the savings from another ECM that corrects a failed economizer.

Whenever possible or applicable, use the post-installation case of a likely ECM as the input of another. The following is a recommended order to analyze ECMs.

1. ECMs that reduce operating hours
2. ECMs that impact system loads
3. ECMs that impact central plant performance or efficiency

Develop calculations to allow for easy correction with post-installation performance data.

EBCx typically results in ECM recommendations that impact either load or hours of use. Calculations that break down energy into the load and hours-of-use components are typically the easiest to review and update when post-installation data is available. This breakdown allows each component to be quantified separately, and data collected independently. The common calculation approaches discussed in *4.2.2 Summary of Calculation Approaches* (below) are all capable of simple corrections with post-installation data based on separate load and hours-of-use parameters.

Perform checks on results for reasonableness.

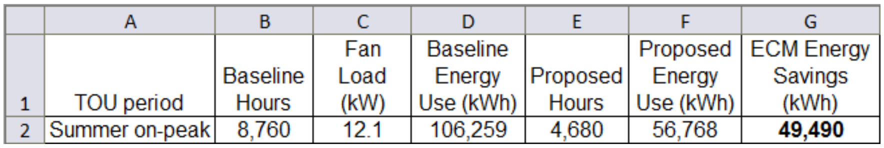
Often, energy savings estimates may be flawed and over- or underestimate savings. The following checks are helpful:

- Perform energy balance on building. Verify equipment loads and operating hours align with the annual energy use of the facility.
- Calculate baseline energy use of the system and compare to whole building data. Ensure the predicted use is reasonable for the facility type.
- Calculate percent energy savings for system and for whole building. Make sure energy savings are reasonable for the recommended measures.

4.2.2. Summary of Calculation Approaches

Energy savings estimation strategies used to calculate EBCx savings include simple calculations, spreadsheet calculations, and computer simulations. Not all of these approaches lend themselves equally to generate accurate savings estimations and care should be taken in selecting an adequate calculation approach suitable for a particular situation. In general, spreadsheet based calculations are the best choice for most EBCx projects. The following is a brief summary of the most common approaches:

- **Simple calculations** are limited in application, generally to systems or equipment that have uncomplicated and consistent operational characteristics. An example is a constant speed exhaust fan with known operation hours. These calculations typically involve a simple multiplication of load and time to establish an annual energy use estimate. Figure 4-2 provides an example of a simple calculation that determines savings from a schedule reduction applied to a constant load.



	A	B	C	D	E	F	G
1	TOU period	Baseline Hours	Fan Load (kW)	Baseline Energy Use (kWh)	Proposed Hours	Proposed Energy Use (kWh)	ECM Energy Savings (kWh)
2	Summer on-peak	8,760	12.1	106,259	4,680	56,768	**49,490**

Figure 4-2: Simple calculation example

- **Spreadsheet calculations** are better suited to address equipment with variable loads and inconsistent schedules. Main applications are operational type improvements that affect schedules and system controls. Spreadsheet calculations may use data ranging from design-based data to extensive monitored performance data. Design data includes equipment specifications from manufacturers, as well as information from mechanical drawings or equipment nameplates. Monitored performance data includes data from BAS trends, portable data loggers and spot measurements. Monitored data is used to develop physical or empirical relationships between operational parameters and their driving variables, especially for heating and cooling loads driven by weather conditions. Spreadsheet calculations include both bin and 8760-hour methods:
  - **Bin methods** are used to separate main driving variables, such as outdoor temperatures or loads, into manageable groups (e.g., 2° F to 5° F intervals for temperature bins). Operating schedules and other parameters will determine the number of hours in each bin (e.g., TMY[10] data). Bins are often made for each utility period so cost savings can be accurately predicted. Physical or empirical relationships are then developed between the binned values and operational parameters that determine load and energy use estimate.

    Some dynamic effects of system operation are not captured due to averaging within bins, but the lost resolution is typically a minor impact on overall savings estimates.
  - **8760-hour methods** also separate load and hours-of-use parameters, but unlike bins, each hour of the year is represented by a separate calculation line. The empirical relationships are typically the same used in bin calculations, but 8760 approaches provide a greater level of resolution. These calculations may require an incremental increase in effort, both to create and to review, when compared to bin methods, but an advantage is an improved resolution. 8760 calculations also have the ability to estimate actual peak load effects for demand reduction.
- **Computer simulations** such as eQuest or Energy Plus utilize programmed algorithms based on fundamental engineering relationships of buildings and their systems. They are dynamic models that calculate energy flows on a regular time interval, usually hourly, based on building features, location, and operational characteristics. Uncalibrated simulations are occasionally used in EBCx projects, but often cannot simulate malfunctioning or non-optimal systems. Non-optimal systems are typically the bulk of identified EBCx measures.

  Simulations should be used with care when following Method 1, as the results may not represent the actual performance of the project site. Additional performance data should be collected to demonstrate the original baseline deficiency.

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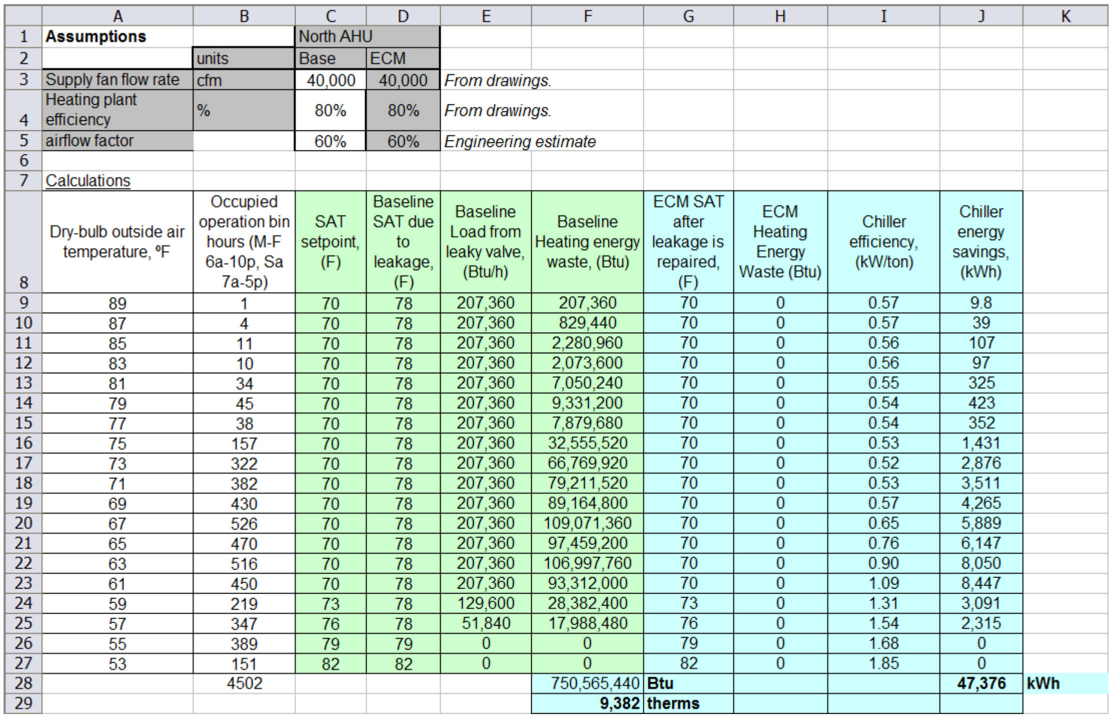
[10] Typical Meteorological Year data is a collection of typical weather data for specific locations throughout the United States.



	A	B	C	D	E	F	G	H	I	J	K
1	**Assumptions**		North AHU								
2		units	Base	ECM							
3	Supply fan flow rate	cfm	40,000	40,000	*From drawings.*						
4	Heating plant efficiency	%	80%	80%	*From drawings.*						
5	airflow factor		60%	60%	*Engineering estimate*						
6											
7	Calculations										
8	Dry-bulb outside air temperature, ºF	Occupied operation bin hours (M-F 6a-10p, Sa 7a-5p)	SAT setpoint, (F)	Baseline SAT due to leakage, (F)	Baseline Load from leaky valve, (Btu/h)	Baseline Heating energy waste, (Btu)	ECM SAT after leakage is repaired, (F)	ECM Heating Energy Waste (Btu)	Chiller efficiency, (kW/ton)	Chiller energy savings, (kWh)	
9	89	1	70	78	207,360	207,360	70	0	0.57	9.8	
10	87	4	70	78	207,360	829,440	70	0	0.57	39	
11	85	11	70	78	207,360	2,280,960	70	0	0.56	107	
12	83	10	70	78	207,360	2,073,600	70	0	0.56	97	
13	81	34	70	78	207,360	7,050,240	70	0	0.55	325	
14	79	45	70	78	207,360	9,331,200	70	0	0.54	423	
15	77	38	70	78	207,360	7,879,680	70	0	0.54	352	
16	75	157	70	78	207,360	32,555,520	70	0	0.53	1,431	
17	73	322	70	78	207,360	66,769,920	70	0	0.52	2,876	
18	71	382	70	78	207,360	79,211,520	70	0	0.53	3,511	
19	69	430	70	78	207,360	89,164,800	70	0	0.57	4,265	
20	67	526	70	78	207,360	109,071,360	70	0	0.65	5,889	
21	65	470	70	78	207,360	97,459,200	70	0	0.76	6,147	
22	63	516	70	78	207,360	106,997,760	70	0	0.90	8,050	
23	61	450	70	78	207,360	93,312,000	70	0	1.09	8,447	
24	59	219	73	78	129,600	28,382,400	73	0	1.31	3,091	
25	57	347	76	78	51,840	17,988,480	76	0	1.54	2,315	
26	55	389	79	79	0	0	79	0	1.68	0	
27	53	151	82	82	0	0	82	0	1.85	0	
28		4502				750,565,440	**Btu**			**47,376**	**kWh**
29						**9,382**	**therms**				

Figure 4-3: Bin-based calculation example

4.2.3. Quantifying Equipment Loads and Hours using Operational Data

Engineering calculations use measurements of operational parameters along with engineering assumptions to calculate loads. Before being translated into direct energy use units of therms or demand, loads may be described in terms of tons of cooling, heating rates (BTU/hr), or brake horsepower. Examples of common engineering equations used to calculate load are included in Table 4-1. When loads are defined in these terms, equipment efficiencies are then applied.

Determining what variables will be measured or estimated to determine loads and operating hours is a key step. System and equipment specifications are used along with measured equipment operating parameters (e.g., status, speed, temperature, flow, pressures) and their driving variables (e.g., outdoor temperatures, occupancy). These variables are used as inputs into basic engineering equations to determine the load or load profile, if variable.

Table 4-1: Fundamental Energy Equation Examples[11]

Purpose	Equation
Energy content of air	$Q = 1.08 \times CFM \times \Delta T$
Energy content of water	$Q=500 \times GPM \times \Delta T$
Pump energy use	$BHP = (GPM \times \Delta P_{(psi)})/(1714 \times \eta_{pump})$
Fan energy use	$BHP = (CFM \times \Delta P_{(in\ wg)}/(6356 \times \eta_{fan})$
Fan affinity laws*	$(BHP_2/BHP_1)=(CFM_2/CFM_1)^3$

* An exponent of 3 represents an ideal condition but may not be appropriate for actual conditions.

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[11] Various engineering equations are presented in typical engineering reference books, such as ASHRAE's Fundamentals Handbook or Michael Lindeburg's Mechanical Engineering Reference Manual.

The hours-of-use parameters are typically gathered from monitored data used to measure loads. Measured hours are preferred for Method 1, since using reported schedules can lead to incorrect assumptions. For example, a two-week trend of fan speed would provide scheduling information as well as part of the data required to use the fan affinity law shown in Table 4-1. The load and hours-of-use parameters are then combined using one of the calculation approaches described in ***4.2.2. Summary of Calculation Approaches***.

4.3. Field Verification Approaches

Operational verification is already a component of EBCx, but Method 1 augments the typical process using field verification to validate initial assumptions of post installation energy use, and update the energy calculations if needed. Method 1 requires physical evidence collected from the site to demonstrate agreement of post-implementation conditions with the performance modeled in the savings calculations.

There are two main approaches for field verification that are differentiated by their levels of rigor. The two categories are:

- Visual verification
- Performance verification

Visual verification is not typically rigorous enough to qualify for a Method 1 approach, but is a commonly used in a formal EBCx process, especially for low risk situations such as low savings improvements. A brief description of visual verification is provided below for reference, but a Method 1 approach should adopt a higher level of rigor described by the performance verification process.

4.3.1. Visual Verification

Visual verification is a high-level, low-cost option that provides a snapshot of current equipment operation. Its use in savings verification should be limited to low risk situations such as verifying measures with relatively low savings compared to the entire project savings.

Visual verification can include spot measurements, photos of new equipment, screenshots of setpoints or control logic, test results from installation contractors, TAB reports, etc. The visual evidence should demonstrate that the ECM has been implemented as designed and represented in the engineering calculations. For example, Figure 4-4 shows two photograpghs that prove the original faulty economizer damper actuator was replaced with new actuator as recommended by a particular ECM.

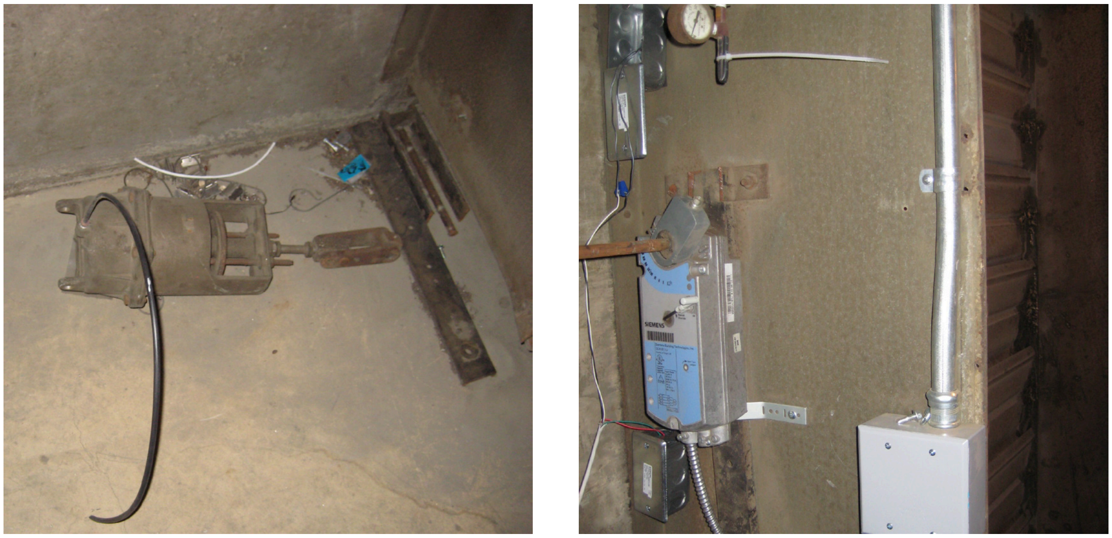

Figure 4-4: Photographic evidence showing replaced economizer damper actuator

Visual verification provides a snapshot to determine whether an ECM was installed as recommended but may not confirm that the actual post implementation performance matches the performance predicted in the calculation. For example, confirming that a pressure setpoint has indeed been lowered does not guarantee the motor speed will reduce to the level shown in the calculation. In addition, a snapshot of current operation may not guarantee the improved operation will continue.

4.3.2. Performance verification

Performance verification represents an increase in rigor over visual verification and is the minimum level of effort recommended as a savings validation approach. The performance verification process utilizes post implementation operational data from sources such as functional tests and monitored from the BAS trends or portable data loggers to confirm the measure operates as intended. The post-implementation data is used to compare the actual and predicted performance as modeled in the calculations. Figure 4-5 and Figure 4-6 are examples of performance verification data for an ECM that repaired a malfunctioning economizer.

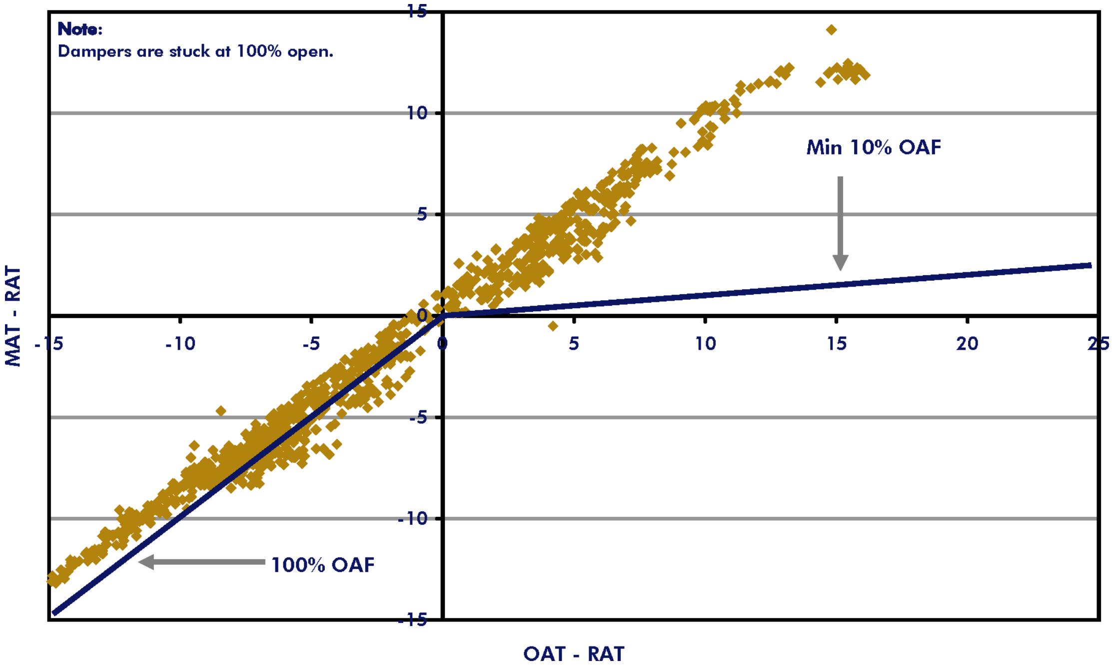

Figure 4-5: Baseline economizer performance

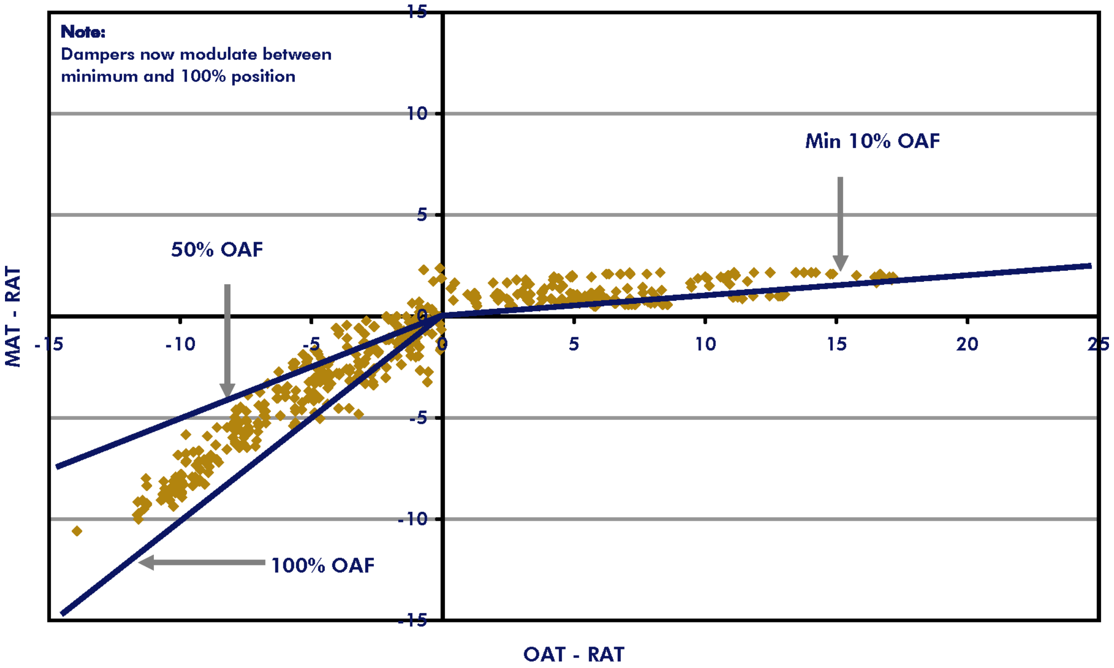

Figure 4-6: Post-installation economizer performance verification

The energy savings predictions are updated with the performance verification data when significant differences from the original calculations are shown to exist. When the calculations are developed with this process in mind, corrections represent only a minor increase in the level of effort. For example, if a baseline operation was dependent on a correlation between outside air temperature and fan speed, this same regression can be developed using post implementation data. The actual post-implementation regression can then replace the original estimated post-implementation fan speed estimation.

Truing-up the predicted equipment operations with actual post-implementation performance data should greatly increase the probability of accurate final savings estimates. Since the existing calculations are updated with post implementation performance data rather than completely re-created, the additional labor and time involved should be minimized. Since the post-implementation data collection may be tied with the existing verification of a formal EBCx process, the additional time requirement may be relatively small.

Performance verification is still limited due to a focus on operational verification and not savings verification. Proving the impact of an ECM does not necessarily guarantee its predicted energy savings exist or will last. Further guarantees require additional M&V activities which are described in subsequent Methods.

4.3.3. Field Verification Examples

Determining the data required to establish baseline operating conditions and verify performance is a critical step in implementing Method 1. Table 4-2 includes seven categories that represent many of the commonly identified EBCx measures. For each category, recommended data collection options are provided,

Table 4-2: Examples Measurements for Typical EBCx Measures

Measure Category	Example Finding	Data Collection Options for Calculations and Verification	
		Performance Verification (High rigor – Method 1)	Visual Verification (Low rigor)
Equipment Scheduling and Enabling	■ Equipment is operating more than necessary	■ Trend command signal and status during all operating modes ■ Trend other parameters that provides status information (e.g., fan speeds, duct pressures, etc.)	Screenshots of schedules
Economizer/Outside Air Loads	■ Inadequate use of free cooling ■ Over-ventilation	■ Trend and analyze OAT, MAT, RAT during all operating modes	Provide baseline and post-implementation photos of economizer dampers
Controls Problems	■ Sensor out of calibration ■ Controls need tuning	■ Trend sensor reading and compare with calibrated sensor input ■ Perform spot measurements at several operating conditions	Provide screenshots of verified sensor values
Controls (Setpoint Changes)	■ Duct static pressure is high ■ Zone setpoint/setback is not optimal	■ Trend applicable setpoints and actual points though an operating cycle ■ Spot measure actual points	Screenshots of setpoints
Controls (Reset Schedules)	■ No reset on CWST ■ No reset on HHWST ■ No reset on SAT	■ Trend applicable setpoint and the driving variable(s) during a typical operating cycle ■ Perform and document a functional test	Screenshots of control logic
Equipment Efficiency/Load Reduction	■ Day lighting controls can be optimized ■ Pump discharge is throttled	■ Trend applicable operational points and the driving independent variables. ■ Spot measure conditions at various operating conditions	Provide photos of new equipment and specifications

Measure Category	Example Finding	Data Collection Options for Calculations and Verification	
		Performance Verification (High rigor – Method 1)	**Visual Verification (Low rigor)**
Add/Repair VFD or restore VFD to auto	■ No VFD on variable load pump ■ No VFD on variable load fan ■ VFD in hand	■ Spot measure constant baseline load, trend fan VFD speed for verification along with any independent variables ■ Perform and document a functional test to ensure proper installation	Provide photos and screenshots of VFD installation and operation

4.4. Additional Considerations

4.4.1. Calculation and Verification of Demand Savings

Demand saving opportunities for HVAC measures may be limited with EBCx since the peak demand period for the utility likely occurs during the same period as the peak load on the building, during which time systems operate at their full capacity. While actual coincident demand is typically defined by the highest use during a 15 minute interval, most engineering calculations are able to produce estimates at an hourly resolution. As such, engineering calculations may be used to predict estimates of coincident demand savings. Average hourly demand during a predefined period is generally an accepted approach to estimate peak demand savings. See ***Appendix F: Algorithms for Peak-Period Demand Savings*** for more information regarding peak demand savings.

Additional considerations should be made when claiming demand savings that are estimated with engineering calculations:

- The likelihood of obtaining baseline and verification data during the respective peak demand periods is small and peak reduction may not be directly observed.
- Demand savings at the building level are usually built up from individual measure level demand savings. The final demand savings value from engineering calculations is an estimate only. The calculations might not capture interactions between measures that impact the actual building level demand reduction, or savings from different measures may not occur simultaneously during the peak.
- The definition of demand savings may vary greatly between stakeholders. The various calculation approaches may be able to address the specific definition of demand reduction required by the project. Calculation approaches capable of analyzing time of use savings estimates provide the most flexibility in satisfying various demand reduction definitions.

The following describes demand savings considerations based on the common engineering calculation approaches:

Bin calculations

Exact time of day peaks are lost to averaging during the binning process, thus bin calculations are not typcially the best option to determine demand savings. However, when bins are based on temperature, kW savings from the highest temperature bin (or lowest, depending on season) with weekday opeartional hours are typically used as a reasonable estimate for peak demand savings.

If monthly demand cost savings approximations are desired, bins must be created by individual months in order to capture the highest monthly bin temperature. To facilitate demand calculations, multiple bins may be used to represent the peak and off-peak operational periods.

8760-hour Calculations

Hourly calculations provide a closer approximation of time of day peaks due to less averaging than a bin method. These calculations provide ample flexibility to determine peak demand reduction over a wide range of peak demand definitions, but can typically only capture demand impacts at an hourly resolution.

Building Simulation

If the building simulation software is capable of generating hourly reports, demand savings may be estimated the same way as 8760 calculations. Some simulation packages allow the user to input specific time of use tariffs and can calculate demand savings automatically. Again, an hourly resolution may miss the actual coincident peak demand which typically occurs over a 15-minute period.

4.4.2. Requirements and Costs

The available resources and costs are main constraints that typically drive the success of a project. This section describes how core constraints relate to the deployment of Method 1.

Data Type

The data required to create energy savings calculations are operational parameters that can be used to predict energy use. Typical values that should be collected include:

- Independent variables that drive loads or characterize loads directly for systems such as heating, cooling or lighting (e.g., ambient temperature, flow rates and differential temperatures, etc.)
- System type & equipment capacity (e.g., motor size, tonnage, rated capacities)
- Performance characteristics (e.g., setpoints, VFD speeds, sequences of operation, equipment curves from manufacturer's data or eQuest[12])
- Length of operation (operational schedules)

This data is typically gathered from onsite building documentation, equipment nameplates, spot measurements, BAS trend logs, and portable data loggers.

Data Amount

The amount of data required to create an accurate energy profile using engineering calculations depends on both the system complexity and the amount of variation experienced by the equipment or system. Constant loads, such as lighting, might only require a single spot measurement while highly variable loads such as variable-air-volume fans require long term trends to understand how the systems react under the entire range of operation conditions, and to accurately predict and extrapolate performance.

Labor Requirements

If the development of energy savings calculations and basic operational verification are already a requirement of the EBCx process, then utilizing Method 1 for verification requires only an incremental increase in labor. The majority of additional labor required for the use of Method 1 results from the additional need for adequate planning, collecting additional baseline and post-implementation data, a third-party review of savings calculations for quality assurance and the updating of calculations with post-implementation data if necessary. The use of "Standard Calculations" where available can substantially reduce the labor required for calculations and third-party review (see ***Appendix C: Tools***).

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[12] Default equipment curves can be accessed from eQuest but are not as accurate as manufacturer data.

Costs

The costs above and beyond a typical EBCx process include the labor time to develop rigorous energy calculations (where not required by the EBCx sponsor) , conduct a third-party review, perform adequate field verification and update the final savings calculations. The verification will likely involve at least one post-implementation site visit to collect the required post-implementation data. Performance verification might require an additional visit to retrieve any operational trend data if the trends or loggers are not in place and monitoring ahead of the visit or if the controls are not accessible remotely.

5. Method 2: System or Equipment Energy Measurement

5.1. Description of Method

This method quantifies and validates energy savings pertaining to EBCx improvements in individual pieces of equipment such as fans, pumps, and motors as well as larger systems such as air handlers, chillers, boilers and lighting. This method is based on retrofit isolation approaches defined by IPMVP and ASHRAE Guideline 14-2002.

Energy use of equipment or systems may be characterized into load and hours-of-use components, and EBCx ECMs may affect one or both components. Method 2 focuses on the impact of the EBCx process on these components and includes a strong emphasis on measurement. The separation of energy use into its primary parameters facilitates a direct analysis of the component(s) most affected by the ECM. Energy savings are calculated after adjusting the baseline and post-installation energy use to the same conditions for comparison.

Method 2 requires isolating the equipment or system affected, identifying energy into the system, and using measurements to quantify the energy parameters. Non-energy variables, such as fan speed or equipment status, may be used as proxies for load or hours-of-use when the variable is confirmed through measurements to represent the energy parameters. Estimations may also be used for some energy parameters when based upon reliable sources such as previous measurements that are not affected by the ECM. Measurements are always required for the parameters that are impacted by the ECM.

The level of measurement required to quantify each energy parameter depends on whether the parameter is classified as constant or variable, and also on how the ECM installation impacts these characteristics. Constant parameters may only require a simple spot measurement while variable parameters typically require substantially more data. When the energy parameter characteristics of load and hours are understood for the baseline and post-installation periods, measurement and analysis activities can be planned and implemented efficiently.

As the title of this method suggests, the load parameter must be measured at least once. For example, if an ECM affects hours of use, but not load, the operating hours should be measured in both baseline and post-implementation period, but the load need only be measured in one period.

After the load and hours-of-use parameters are quantified, they are combined into the predicted energy use for baseline and post periods using common engineering calculation approaches such as:

- Simple calculations (for constant load, constant schedule applications)
- Spreadsheet calculations (for variable applications)

As a part of the calculations, the baseline and post-implementation energy use estimates are brought to the same set of conditions for comparison. The comparison can be normalized[13] which involves driving both baseline and post-implementation regressions with a common dataset (often outside air temperature from TMY data). The comparison can also follow an avoided energy use process which involves an adjustment to the baseline regressions using the

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[13] See IPMVP Section 4.6.2

driving variables from the post-implementatation period. The actual measured post-implementaiton energy use is then compared with the adjusted baseline to determine the energy savings.

Since measurements are required to establish energy use estimates in both baseline and post-installation periods, validated savings are not available until well after the ECM is installed.

5.1.1. Key Criteria

- Method 2 is a savings verification process where energy savings are established using before and after measurements that are adjusted to the same set of conditions. This process fits the standard industry definition of M&V.
- This method applies to equipment systems with loads that can be isolated and measured, or correlated to other measured parameters through confirmed engineering or statistical relationships.
- Energy use and resulting energy savings are determined using measurements of load and hours in lieu of engineering estimations.
- If multiple ECMs affect the same equipment, only the cumulative energy effect can be verified. Savings from multiple individual ECMs cannot be resolved.
- This method will not account for the potential interactive effects between ECMs installed across multiple systems. EBCx measures that affect multiple pieces of equipment that are not part of a single system are not ideal applications for this method.
- Utilizing this method may result in slightly incremental efforts over a traditional EBCx project due to the costs of energy measurements. The additional efforts should be weighed with the increased potential for accuracy in the reported savings.
- This approach is applicable when the expected energy savings are too small to detect at a whole building level and when the stakeholders require more certainty of accurate savings than engineering calculations can provide.

5.1.2. Procedure

Figure 5-1 provides a general overview of the System or Equipment Energy Measurement Method. A more detailed explanation of each step is provided in the next section.

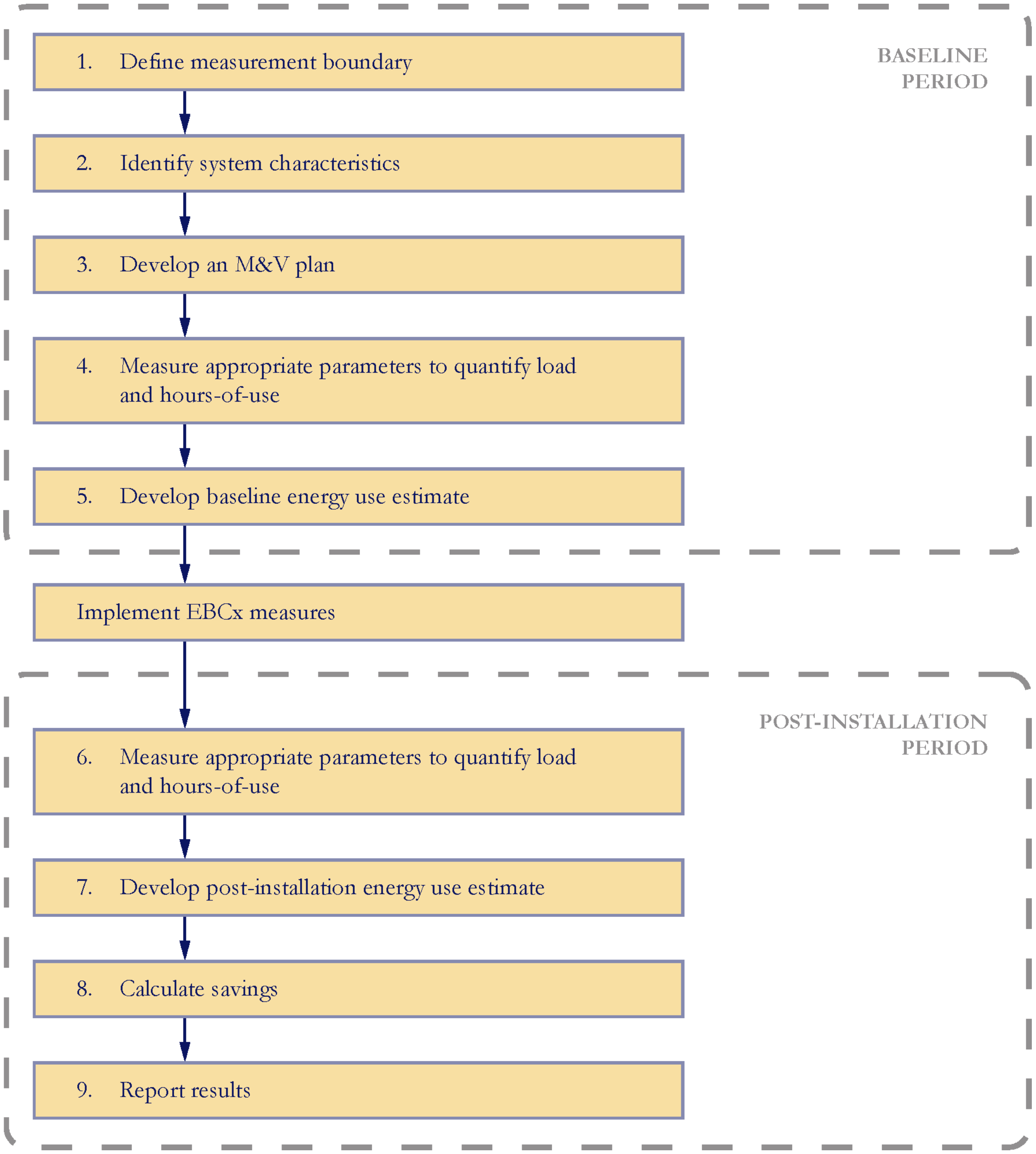

Figure 5-1: Method 2 process flow chart

Step 1: Define the measurement boundary.

A critical step in the use of Method 2 is the establishment of an appropriate measurement boundary around a piece of equipment or system affected by a recommended ECM. Energy flows from all energy sources across that boundary are measured. This step begins after ECMs are identified by the investigation phase of a typical EBCx process.

The measurement boundary should be chosen so that energy flows across the boundary are clearly defined and measureable. For example, when an ECM recommends the installation of a VFD on either a fan or pump motor, a measurement boundary capturing only the power input to the motor should be sufficient since only the motor is affected. Conversely, when an ECM repairs a malfunctioning economizer, the impact will encompass more than a single component (i.e., cooling load and fan speed) and a system level boundary is required. Figure 5-2 shows examples of possible measurement boundaries related to an air handler.

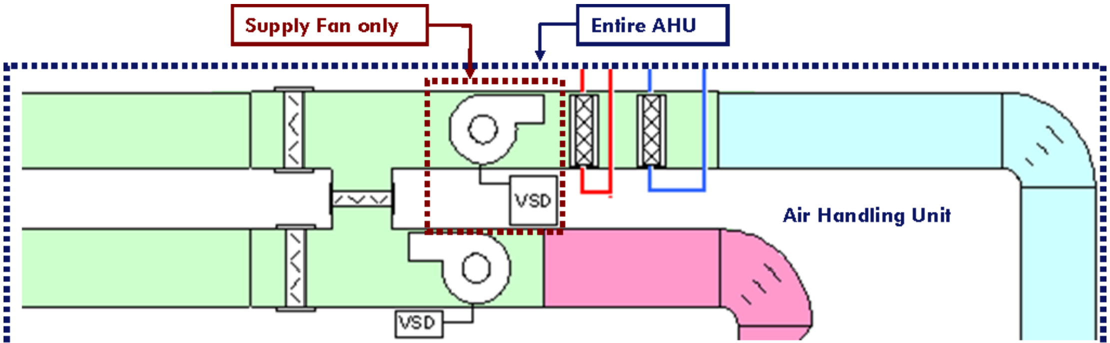

Figure 5-2: Potential measurement boundaries (AHU)

The primary effects of the individual ECM should occur within the defined measurement boundary. Effects that occur outside the boundary are not verified using this method. These external effects are known as interactions and should be considered whenever possible as they might have a significant impact on the actual savings realized. The interactive effect may be positive or negative.

Step 2: Identify system characteristics.

EBCx improvements may impact a system's load, hours of use, or sometimes both. Focusing on these individual energy parameters provides a direct means of comparison of energy use before and after ECM installation. This direct comparison is a defining component of standard M&V activities.

Before attempting to quantify each parameter, the baseline and post-ECM operational characteristics of each should be evaluated and classified as variable or constant. This exercise will identify how much data and effort is required to quantify each parameter, as there are differing strategies required based on the classification.

The installation of an ECM may change the post-installation load or hours-of-use parameter classifications from the baseline classification. The expected impact of the ECM recommendation should be considered and the post-implementation classification understood during this step. Understanding both the baseline and post-implementation operational classifications helps in the selection of a sufficient measurement strategy and will also help determine an appropriate energy savings calculation technique.

Step 3: Develop M&V plan.

Once the level of variation of each energy parameter is known for both the baseline and post-installation periods, the development of a comprehensive M&V plan[14] should be straight forward. Time spent developing an M&V plan now should streamline the remainder of the savings validation process. The plan, at a minimum, should:

1. Determine the appropriate and required measurements to quantify load and hours-of-use equipment affected by the measures identified during EBCx
2. Detail how the data will be collected (measured directly, measured by proxy or estimated)
3. Specify how much data is required to quantify each parameter in both the baseline and post-implementation periods

If possible, the M&V plan should recommend the data and collection method used in the post-implementation period mirrors the approach used to collect the baseline data. Using different

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[14] Refer to EVO: IPMVP Volume 1 for comprehensive recommendations for M&V plan content

data types and sources to quantify baseline and post-implementation operation may not provide a reliable comparison.

Step 4: Measure appropriate parameters to quantify baseline load and hours of use.

Measurements of the energy parameters, or their proxies, and other required non-energy parameters including driving variables such as outdoor air temperature and occupancy are collected for the monitoring duration defined in the M&V plan. Proxies, if applicable, are confirmed as appropriate representations of energy use.

Step 5: Develop baseline energy use estimate.

An appropriate calculation technique is selected and applied to combine load and hours-of-use parameters into an estimated baseline energy use estimate. The techniques applicable to a Method 2 approach are typically:

- Simple calculations
- Spreadsheet calculations

Simple calculations are generally limited to equipment with constant loads and schedules that are quantified with simple spot measurements. Spreadsheet calculations are capable of representing more complicated systems and are used to model variable operating parameters with engineering relationships or observed data.

Step 6: Measure appropriate parameters to quantify post-installation load and hours of use.

As part of the EBCx process, the operation of the ECM should be field verified using performance verification strategies to ensure the measure was installed correctly and functions properly. This verification should be completed prior to initiating the post-installation measurements required by the M&V plan.

Once the ECM operation is verified, the measurements specified in the M&V plan are taken to quantify the required parameters.

Step 7: Develop post-installation energy use estimate.

Utilizing the baseline energy calculations strategy conducted in Step 5, an appropriate calculation technique is used to combine the post-installation energy parameters into an estimated energy use. This estimation will represent the reduced energy use resulting from the ECM installation.

Step 8: Calculate savings.

The baseline and post-implementation energy use estimates are normalized[15] by adjusting the baseline and post-install equations to the same set of conditions (often outside air temperature from TMY data). The difference between baseline and post-implementation energy use estimates is the verified energy savings.

Step 9: Report results.

The M&V Plan specifies requirements for the savings report, which the owner and program manager have agreed upon. The report should include details regarding any measurement boundaries and clearly identify whether the load and hours-of-use parameters for each affected system were measured or estimated. The use of any proxies should also be presented in the final report.

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[15] See IMPVP Section 4.6.2.

5.1.3. Persistence Phase

As with Field Verification described in Method 1, the short term field measurements used for verification of savings in a Method 2 will not inherently guarantee the energy savings will last. This method provides only a snapshot of energy performance during the monitoring period. The performance may change, for the better or worse, before the predicted savings are realized.

If project budgets allow, energy measurements may be conducted periodically to ensure the ECM continues to operate as expected.

5.2. Analysis Methods

5.2.1. Characterizing Load and Hours of Use

This section describes the characterization of load and hours of use of the equipment or system introduced in Step 2 above. Before trying to quantify each parameter, the baseline and post-ECM operational characteristics of each should be evaluated and classified as variable or constant. Understanding the operational characteristics provides a basis to select measurements that adequately quantify the energy parameters and create the plan for measurement and monitoring described in Step 3.

There are four categories of equipment load and hours-of-use parameter characteristics:[16]

- Constant Load, Constant Hours of use
- Variable Load, Constant Hours of use
- Constant Load, Variable Hours of use
- Variable Load, Variable Hours of use

Constant Load, Constant Hours of Use

The load and hours of use both remain the same in this category, as shown in Figure 5-3.

ASHRAE's Guideline 14-2002[17] indicates a 5% limit in the variance over time of load or hours of use to be considered constant. The measured load (e.g., kW, Btu/hr) is often used directly in calculations, after verifying that the load is constant.

Hours of use are typically measured for a representative operating period, but may be estimated if known with certainty. Simple calculations are generally used to calculate baseline and post-installation energy use for equipment in this category.

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[16] See ASHRAE Guideline 14-2002 Section 6.2.2

[17] Defined in ASHRAE Guideline 14-2002 Section 6.2.3

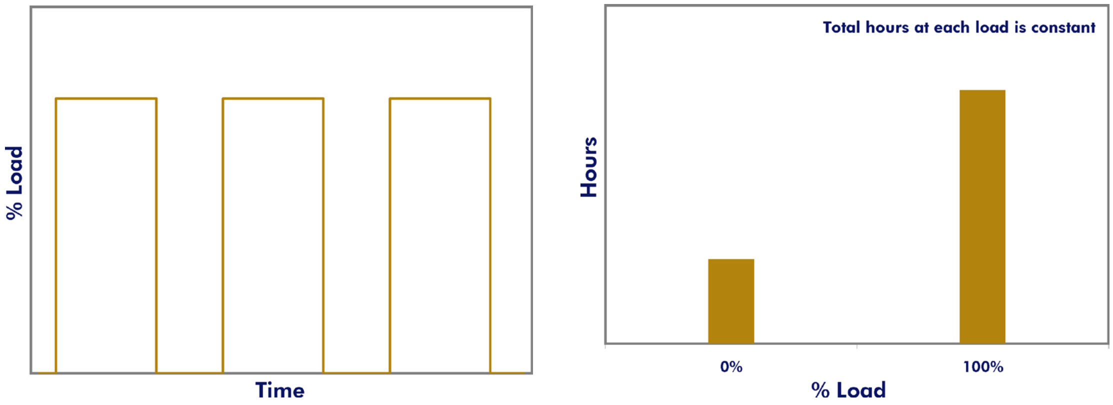

Figure 5-3: Constant load (left), Constant hours of use (right)

Examples of equipment with constant load, constant hours of use operating characteristics include:

- Lighting under time clock control
- Constant volume air handling units under time clock control
- Water fountain pumps

Variable Load, Constant Hours of Use

The load changes over time, while the hours of use at different loads remains the same for equipment in this category, as shown in Figure 5-4.

The loads (Figure 5-4, left) are typically determined from monitored data or proxies confirmed with manufacturer's performance data. In this category, the loads depend on some driving variable (e.g., flow, temperatures, or ambient conditions). Hours of use are typically extracted from the monitored data and may depend on other variables (e.g., time clock settings or predictable processes). Hours of use may be estimated if known with certainty.

Simple calculations of load and hours of use at each load, or bin methods may be used to calculate baseline or post-installation annual energy use for equipment in this category. Bin methods may be preferred when ambient temperature is a driver of load.

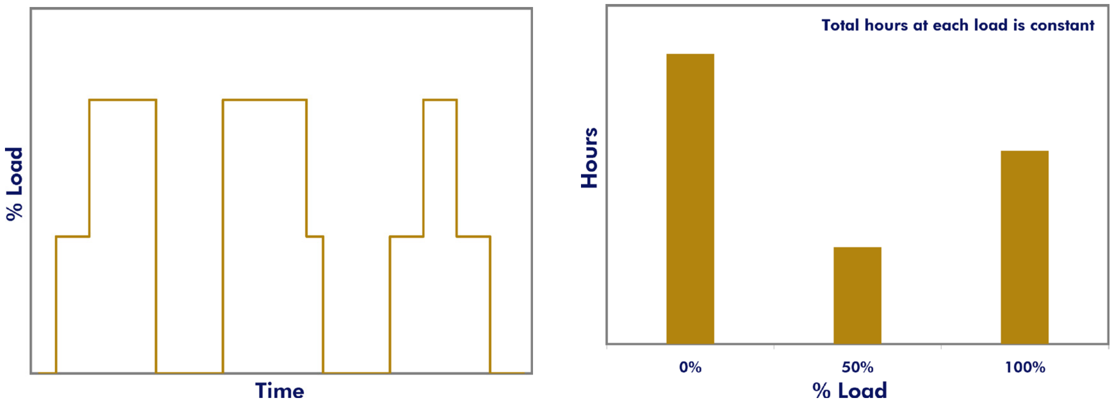

Figure 5-4: Variable load (left), Constant hours of use (right)

Examples of equipment with variable load, variable hours of use operating characteristics include:

- Bi-level lighting under time-clock control at each level
- Two speed exhaust fan under time-clock control.
- Industrial 2-speed cooling tower fan operation with speeds controlled by process schedules

Constant Load, Variable Hours of Use

The load remains the same, while the hours of use changes, as shown in Figure 5-5. The number of operating hours at each load condition is unknown and the total number of hours may or may not be known.

The load can be quantified using spot measurements, but monitoring over a range of normal operating conditions will be required to determine operating hours. In this category, the number of hours of use depends on some driving variable (e.g., number of daylight hours, ambient temperature, or load).

Simple calculations may be used once the hours of use have been determined. Alternatively, bin methods or 8760 hour calculations[18] may be used once the relationship of hours of use with the driving parameter(s) is known.

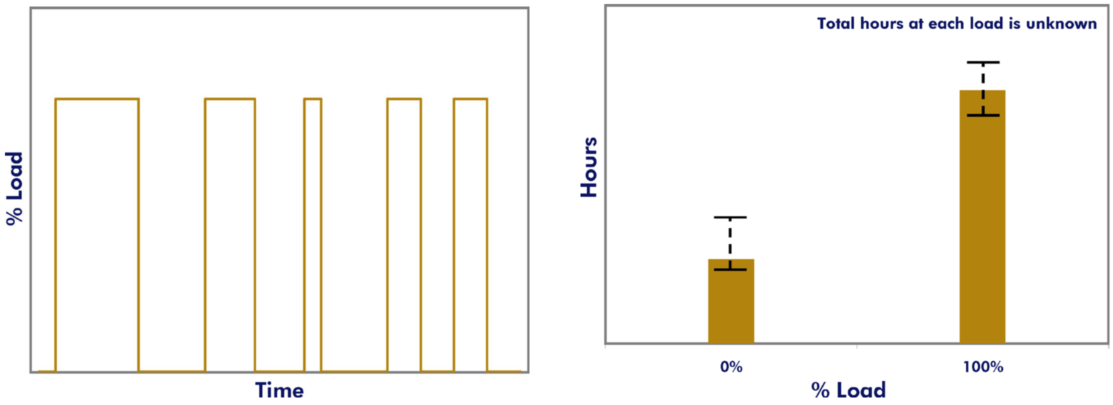

Figure 5-5: Constant load (left), Variable hours of use (right)

Examples of equipment with constant load, variable hours of use operating characteristics include:

- Lighting under occupancy sensor control
- Constant speed cooling tower fan operation (schedule varies with outdoor air conditions)
- Hot water or chilled water constant volume pumping (schedule varies with boiler/chiller operation)

Variable Load, Variable Hours of Use

In this category, both the load and the hours of use change as shown in Figure 5-6. The number of operating hours at each load condition is unknown and the total number of hours may or may not be known.

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[18] 8760 calculations were described in Method 1.

The loads (Figure 5-6, left) are typically determined from monitored data or proxies confirmed with manufacturer's performance data. The loads may be a function of one or more driving variables (e.g., flow, temperatures, or ambient conditions) which must be established.

The hours of use are typically determined from the monitored load data. The hours of use may be functions of other parameters (e.g., flow, temperatures, or ambient conditions).

Bin methods or 8760 hour calculations are generally used to determine annual energy use of the baseline or post-installation equipment. This requires that the relationships between load and its driving variable(s), and hours of use its driving variable(s) are known or can be developed.

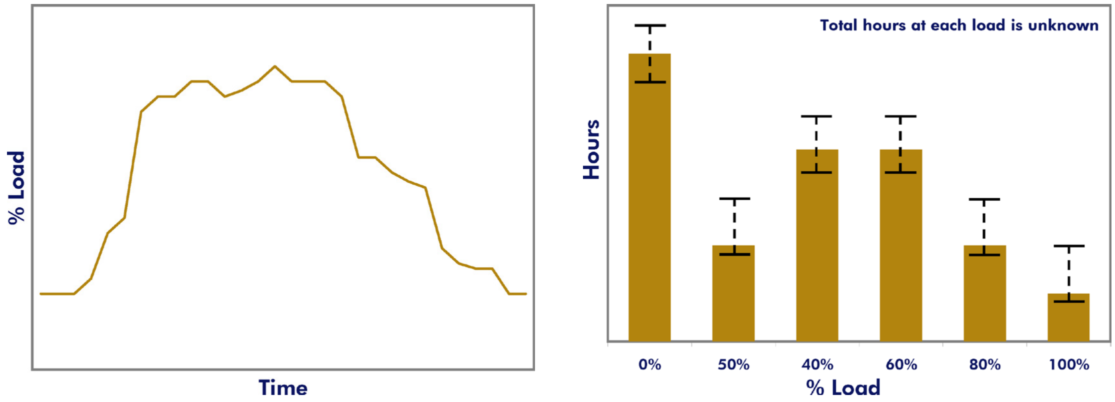

Figure 5-6: Variable load (left), Variable hours of use (right)

Examples of equipment with variable load, variable hours of use operating characteristics include:

- Variable air volume AHU under thermostat control
- Hot water boiler serving reheat coils in zones
- Chilled water system maintaining a chilled water supply set point reset schedule

5.2.2. Quantifying Energy Parameters

Load and hours of use are quantified in Method 2 using direct measurements or confirmed proxies, or in some cases, estimation. This section elaborates on the use of proxies and estimations that may be included in the data collection strategy detailed in the M&V plan (Step 3, above).

Confirmed Proxies

Confirmed proxies are non-energy parameters that are proven with measured data as adequate representations of load, hours of use or both. The relationship of the proxy with the energy parameter may be developed from single spot measurements for constant load systems. Multiple spot measurements or continuous monitoring over a period of time covering a full range of operating conditions may be required to prove the energy use relationship with variable parameters.

Once validated, the proxy can be used to develop the load profile from the monitored driving variable(s). The driving variables for the proxy must be measured. If the driving variables are estimated, the verification approach does not meet the requirements of Method 2 and should be considered an engineering calculation as described in Method 1.

Proxies come in many forms, but several are commonly used in EBCx projects. The following are a few examples that cover a range of potential applications:

- **Status signals (on/off)** may be used as a proxy for load when the load of the equipment is constant (e.g., lighting circuits or electric reheat). With constant loads, a single spot measurement is sufficient to characterize the load parameter for all conditions. After spot measuring the load while the equipment is running, the "on" status will act as a verified proxy. Continually monitoring the status will also simultaneously quantify the hours-of-use parameter.
- **Multiple spot measurements or continuous monitoring of load** (e.g., power) may be recorded along with the proxy variable, such as a pump or fan VFD speed, to develop an empirical relationship. Once the relationship is established, the proxy variable (fan speed in this case) is a verified substitute for kW and can be used to develop load as shown in Figure 5-7.
- **Manufacturer's performance curves** should be validated with multiple measurements taken at different loads. At a minimum, a single spot measurement should be used to confirm the equipment is operating as expected.

Once a load proxy is verified, it may be used in the same manner as energy measurements to establish estimates of annual energy use. Confirmed proxies should be considered as reliable as measuring the energy parameter directly.

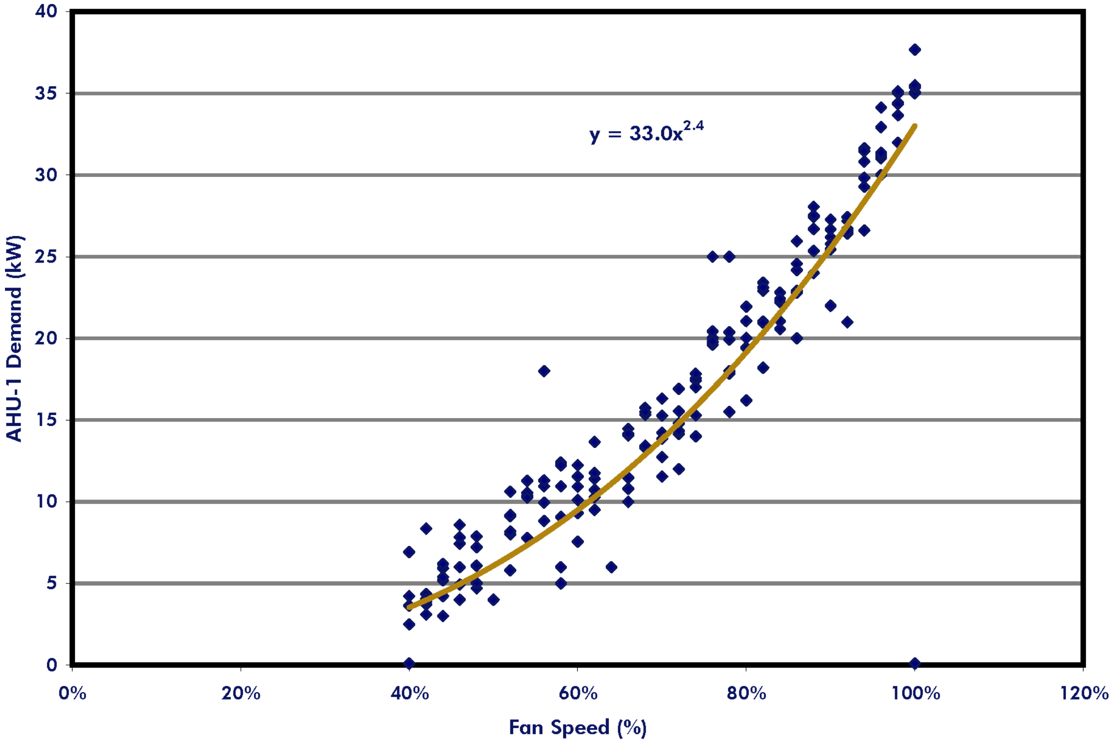

Figure 5-7: Example of a verified proxy (load vs. fan speed)*

*Due to the potential for large error propogation, extreme caution should be used whenever exponential or polynomial relationships are used to extrapolate preditions beyond the measurement range.

Estimates of Energy Use Parameters

Estimating energy parameters can reduce time and costs in a project, however, estimation can negatively impact the accuracy of the energy savings. Estimation should only be used for parameters that are known with relative certainty or for parameters measured in one period (either baseline or post-implementation) and used in the other. Extrapolation from one measurement period to the other should only be used when the energy parameter is not expected to change as a result of the ECM. If the parameter is not known with enough certainty to satisfy all project stakeholders, then the parameter should be measured.

Since **energy measurement** is a key requirement of Method 2, the load component should be measured in at least one period (baseline or post-implementation) if it remains unchanged by the ECM. Load must be measured in both periods when affected by the ECM. Conducting measurements in the baseline period, however, provides information to adequately predict savings prior to implementation. When load is estimated in both periods, the approach is considered an engineering calculation defined by Method 1.

The following describes common uses for estimation based on the specific operational classification:

- **Constant Load:** Load should be measured in either the baseline or post-implementation period. The measured load can be used in the other period when the ECM affects operating schedules only.
- **Variable Load:** Relationships with driving variables should be developed for variable loads using multiple or continuous measurements taken over a typical cycle of operation. When the ECM affects the operating schedules only, the load relationship can be used in the other measurement period.
- **Constant Hours of Use:** Constant schedules may be quantified using continuous measurements over a representative operational period. For variable load applications the representative period should include a full range of operating conditions. If hours of use is not affected by the ECM, then the hours of use in one period can be used in the other.
- **Variable Hours of Use:** Estimated variable schedules are not recommended, and continuous monitoring over a typical cycle of operation is recommended. Again, if the ECM does not impact the operating schedule, the hours-of-use quantification from one measurement period may be used in the other.
- **Special Considerations:** If load and hours of use are variable in both baseline and post-implementation periods, the development of an empirical relationship or regression between the parameters and a driving variable is typically required. Empirical relationships are discussed further in ***6. Method 3: Energy Models Using Interval Data***.

5.2.3. Calculation Techniques

As described in Step 2, the impact of the ECM on the load or hours-of-use parameters must be understood so that analysis procedures can be planned and implemented. This will reduce requirements and save time for data collection in both baseline and post-installation periods. Equation 5-1 is the fundamental equation used for Method 2 electric savings calculations. For other forms of energy savings, substitute the load variable (e.g., Btu/hr) for kW.

Equation 5-1: Fundamental Energy Savings Equation

$$kWh_{saved} = \sum\left(kW_{base} * Hours_{base}\right) - \sum\left(kW_{post} * Hours_{post}\right)$$

where:

kW = electric power demand
kWh = electric energy use
$Hours$ = hours of operation
$base$ indicates parameter measured (or estimated) in baseline period
$post$ indicates parameter measured (or estimated) in post-installation
$saved$ indicates quantity saved

Table 5-1 through Table 5-4 show energy savings equations that may be used for each combination of load and hours-of-use parameter. Within each table, the impact of the EBCx improvements on the load, schedule, or both, determines the form of the savings equation that should be used. These equations show which energy parameters to measure in the baseline and post-installation periods, and are generally arranged from the most simple to the most complex. All of these equations are based on the fundamental energy savings equation shown in Equation 5-1, which have been reduced to show synergies in using measured data from the baseline period in the post installation period wherever possible.

Table 5-1: Equations for Constant Load, Constant Hours of Use Baseline Conditions

ECM Impact	Electrical Energy Savings
Changes load only	$kWh_{saved} = \left(kW_{base} - kW_{post}\right) * Hours_{base\_or\_post}$
Changes hours-of-use only	$kWh_{saved} = kW_{base} * \left(Hours_{pre} - Hours_{post}\right)$
Changes load and hours-of-use*	$kWh_{saved} = \left(kW_{base} * Hours_{base}\right) - \left(kW_{post} * Hours_{post}\right)$
Changes load from constant to variable*	$kWh_{saved} = \left(kW_{base} * Hours_{base}\right) - \sum\left(kW_{post} * Hours_{post}\right)$
Changes hours of use from constant to variable*	$kWh_{saved} = \left(kW_{base} * Hours_{base}\right) - \left(kW_{base} * \sum\left(Hours_{post}\right)\right)$
Changes both load and hours of use from constant to variable*	$kWh_{saved} = \left(kW_{base} * Hours_{base}\right) - \sum\left(kW_{post} * Hours_{post}\right)$

Table 5-2: Equations for Variable Load, Constant Hours of Use Baseline Conditions

ECM Impact	Electrical Energy Savings
Changes load only	$kWh_{saved} = \left(kW_{base} - kW_{post}\right) * Hours_{base\_or\_post}$
Changes hours of use only	$kWh_{saved} = \sum\left[kW_{base} * \left(Hours_{base} - Hours_{post}\right)\right]$
Changes load and hours of use*	$kWh_{saved} = \sum\left(kW_{base} * Hours_{base} - kW_{post} * Hours_{post}\right)$
Changes hours of use from constant to variable	$kWh_{saved} = \sum\left[kW_{base} * \left(Hours_{base} - Hours_{post}\right)\right]$

Table 5-3: Equations for Constant Load, Variable Hours of Use Baseline Conditions

ECM Impact	Electrical Energy Savings
Changes load only	$kWh_{saved} = \sum\left(kW_{base} * Hours_{base} - kW_{post} * Hours_{post}\right)$
Changes hours of use only	$kWh_{saved} = kW_{base} * \left(Hours_{base} - Hours_{post}\right)$

ECM Impact	Electrical Energy Savings
Changes load and hours of use	$kWh_{saved} = (kW_{base} * Hours_{base}) - (kW_{post} * Hours_{post})$
Changes hours of use from constant to variable*	$kWh_{saved} = (kW_{base} * Hours_{base}) - \sum (kW_{post} * Hours_{post})$

Table 5-4: Equations for Variable Load, Variable Hours of Use Baseline Conditions

ECM Impact	Electrical Energy Savings
Changes load only	$kWh_{saved} = \sum [(kW_{base} - kW_{post}) * Hours_{post}]$
Changes hours of use only	$kWh_{saved} = \sum kW_{base} * (Hours_{base} - Hours_{post})$
Changes load and hours of use*	$kWh_{saved} = \sum (kW_{base} * Hours_{base}) - \sum (kW_{post} * Hours_{post})$

* This is the general equation (Equation 5-1) that will capture the impact of a particular EEM that causes a change in operating conditions, such as a constant load shifting to a variable load, As an example, a constant load, constant hours-of-use equipment where the EBCx improvement reduces load, such as opening a balance valve and rebalancing a constant speed pump, energy savings are calculated as:

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

In this case, the hours of operation will not change, only the load seen by the pump will change. A measurement plan would include a spot measurement of the baseline demand of the pump, and measurement of demand and hours of use in the baseline period. Conversely, the hours of use may be measured in the post-installation period.

5.3. Additional Considerations

5.3.1. Calculating and Verifying Demand Savings

Method 2 typically provides an approximation of average demand savings only, unless continuous monitoring is conducted for the duration of the peak period in both the baseline and post-install periods. In summary:

- Monitoring may not occur during actual peak demand periods in both baseline and post-implementation phases, so demand reduction will not be directly observed and must be inferred.
- Interactive effects or diversity in equipment operations may prevent the sum of equipment level demand savings amounting to the level actually observed at the main meter.
- Averaging due to bin methods or hourly calculations dilute the actual time of use peaks which typically occur in 15 minute intervals.
- The use of normalized driving variables such as TMY temperature data will not likely represent conditions at the actual peak period of the building.

The stakeholder must determine if the approximation of demand savings meets the requirements of the project. See ***Appendix F: Algorithms for Peak-Period Demand Savings*** more information regarding peak demand savings.

5.3.2. Requirements and Costs

The required resources and associated costs depend on the objectives, including level of rigor, selected by the stakeholders (See ***3. Method Selection***)

Data Sources

Preferably, a BAS capable of collecting and storing points related to energy use or driving variables is already present and can be used to gather the required data. Often times, the points required to characterize energy parameters are not available in the BAS and are added. If the desired data is not already available and cannot be added to the BAS, new meters or portable loggers can be installed for an additional cost.

Data Amount

The amount of data required to develop the energy profiles depends on the level of expected variation of each component. Constant parameters can be established using simple spot measurements while highly variable parameters require multiple spot measurements or extended monitoring of energy and driving variables.

Labor Requirements

Engineering expertise is required to establish the initial M&V plan and develop the baseline and post-implementation energy use estimates that are used to determine the final savings. Additional labor is typically required to gather the appropriate data in the baseline and post-installation period. Labor is increased if portable data loggers are used to collect both baseline and post-installation energy data.

Costs

Costs will vary greatly between projects, and are based on labor and equipment required. The availability of data, the complexity of baseline or post-implementation operation and the applicability of estimation will all impact costs.

Simple spot measurements will generally cost less than the requirement of dedicated loggers that remain in place for the duration of the monitoring period. Labor costs increase when portable data loggers are used to collect both baseline and post-installation energy data.

6. Method 3: Energy Models Using Interval Data

6.1. Description of Method

This method employs energy models for the baseline and post-installation periods and uses them to quantify and verify savings for EBCx projects. The energy-use models are empirical; they are developed using statistical regression techniques between the dependent energy (or demand) variable and one or more independent variables, such as ambient temperature, building schedule, or occupancy. The data is measured in short time intervals (e.g., less than one hour, such as 15-minute interval electric data) and built up into analysis time intervals of one hour or one day. Such short intervals allow data to be collected over a broad range in a limited amount of time. Regression models built from the broadest range of data introduce the least bias error in their use.

This chapter describes how to collect and prepare the required data and apply these regression techniques to verify savings from EBCx projects. It describes how to apply the techniques to energy data from whole-building meters, as well as from the building's subsystems. This methodology quantifies the cumulative total of each individual EBCx measure's savings within the measurement boundary (i.e., whole building or building subsystem).

Whether the verification approach considers the building as a whole or focuses on its subsystems, the method's model development and analysis procedures are the same. Empirical energy models, such as linear regression models, change-point models,[19] and multivariate models, and so on are employed to capture and define the baseline energy use behavior of the selected building, meter, or subsystem. These models are used to adjust the baseline energy use with the post-installation period conditions to determine baseline use under those conditions. Measured post-installation energy use is subtracted from the adjusted baseline to determine the measurement period's savings. Note that any set of conditions, such as typical mean year (TMY) weather data may be selected as the basis of adjustment for both baseline and post-installation energy use. Annual savings are determined by extrapolation of the measurement period savings, generally by using a full year of weather data.

This M&V methodology may be applied in adherence with IPMVP's Option C Whole Building, or Option B Retrofit Isolation approaches. IPMVP has several requirements for adherence; these requirements were presented in ***2. Integrating the Energy Savings Verification Process***.

The whole-building analysis procedure described in this chapter may be applied in compliance with ASHRAE Guideline 14-2002 Whole Building performance path. This guideline's performances paths and compliance criteria were described in ***2. Integrating the Energy Savings Verification Process***.

6.1.1. Key Criteria

The following is a list of key criteria required to successfully implement this method. More detailed information on data types, amount, and sources may be found in ***6.3 Requirements and Costs***.

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[19] "Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models," Kissock, J.K., J. Haberl, and D. Claridge, ASHRAE Research Project 1050, available at www.ashrae.org.

Data requirements

All data should be measured in short time intervals (an hour or less) and should span a minimum of three months, but six months or one year of data is preferable. Short duration data sets should include the broadest range of data possible.

- Whole building or meter level energy data.
  - Electric energy use or demand
  - Natural gas consumption
  - Chilled or hot water energy use
  - Steam consumption
- System energy use. Any source that provides continuous short-term interval energy data for subsystems within a building that are affected by the EBCx project. Metering should be in place and recording data, otherwise data recording should be initiated as quickly as possible. There are no standard data sources, however the following sources often exist:
  - Chiller electric energy
  - Submetered major electrical equipment or systems
  - Motors equipped with variable frequency drives with output power monitored by the building-automation system (BAS).
  - Feedback status signals for equipment controlled by the building's BAS may be developed into proxy energy variables.
  - Independently installed data loggers.
- Independent variables
  - Ambient temperature (include relative humidity in humid climates)
  - Building operation schedule
  - Other measureable parameters that influence or drive energy use

Labor required includes:

- On site tasks may include identifying data sources, installing monitoring points, establishing connections for remote access, and collecting the data from onsite monitoring systems
- Analysis tasks include preparing the data, sorting the data, developing regression models, and assessing their uncertainty
- Reporting tasks include writing M&V Plans and Savings Reports

Tools required include:

- At a minimum, spreadsheet programs with regression functions are required.
- Statistical analysis software capable of working with large datasets are useful
- Energy modeling software designed specifically for developing these empirical energy models are available (see ***Appendix C: Tools***).

Applications include:

- Savings are determined for all EBCx improvements inside the measurement boundary
- Energy models developed for baseline and post-installation periods will be used for other purposes, such as tracking on going building performance
- Savings are required to be stated with an estimate of its uncertainty

6.1.2. Definition of Measurement Boundary

Improvements made as a result of EBCx are corrections to systems operations, and can affect one or multiple systems within a building. The amount of savings generated by an EBCx project varies widely, with most projects reporting savings between 5 and 15% of the building's annual energy use.[20] Energy use in buildings or systems can vary greatly over the year, and have a degree of randomness that is unexplained by any measurable factors. In order to obtain sufficient resolution, the savings must be significantly greater than this randomness, or uncertainty, in the data. This is accomplished by defining appropriately sized measurement boundaries.

The measurement boundary can be drawn around a single piece of equipment, a system of equipment, multiple systems within a building, systems downstream of an energy meter, or around the whole building. In this guideline, the whole building approach draws the measurement boundary around the entire building and uses data from the main energy meters. The systems approach draws it around affected equipment or systems, and uses data from available sources, such as the building-automation system (BAS), submeters within the building, or data loggers installed for the duration of the project. These approaches are illustrated in Figure 6-1.

The **whole building approach** is straightforward to define for a building with one meter per energy source. For a building with multiple energy meters on the same energy source, data from each meter may be combined before proceeding with analysis. It may also be applied to one of multiple energy meters when the EBCx measures affect systems downstream of only one building meter, however, the affected systems on the meter must be assessed to be sure they do not affect energy use in equipment connected to other meters. If they do, data from both meters must be included in the analysis.

The **systems approach** requires a boundary around specific equipment or systems, and all energy flows of the same energy source across that boundary measured. Most building subsystems are electricity users, so that the systems approach is usually applied to electric systems. The measurement boundary should be drawn so that measurements and modeling are as simplified as possible. Because EBCx projects often focus on HVAC and their control systems, it is convenient to define the building's systems in HVAC and non-HVAC categories.

Energy use in HVAC systems is strongly influenced by ambient conditions. Thus similar energy modeling techniques as in the whole building approach may be used for HVAC systems. Energy modeling is described in ***6.2.1 Modeling Techniques*** on page 68.

In HVAC systems, the primary independent parameter is ambient air temperature, and the time-of-day parameter tends to be secondary. For non-HVAC systems, the reverse tends to be true: the building schedule is the key parameter and weather is secondary to inconsequential. Define the building systems after consideration of the parameters that influence energy use, as they can facilitate model development and reduce analysis time.

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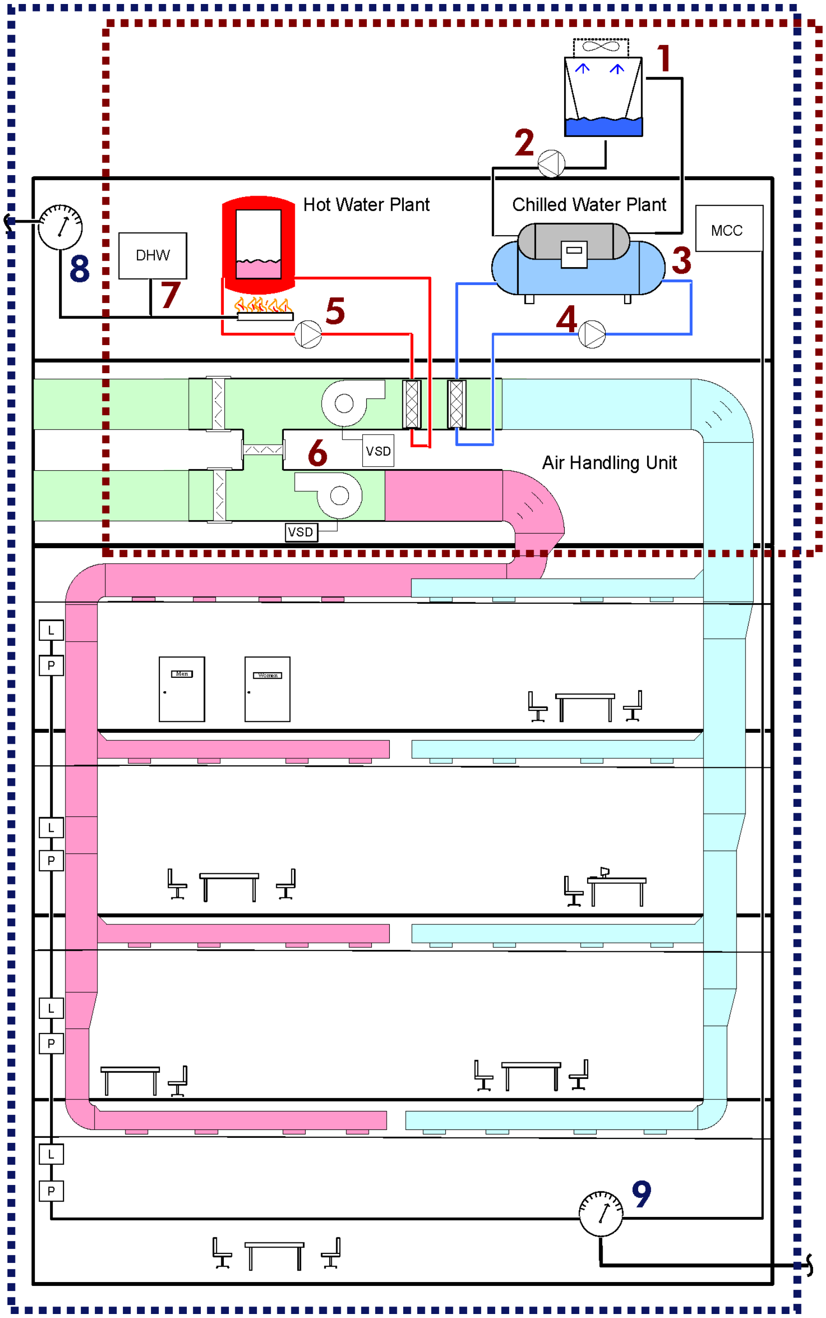
[20] Mills, E., *et.al.*, "The Cost-Effectiveness of Commercial-Buildings Commissioning," available at: http://eetd.lbl.gov/Emills/PUBS/Cx-Costs-Benefits.html.



HVAC SYSTEM - ELEC

1 Cooling tower fan kW

2 Condenser water pump kW

3 Chiller kW

4 Chilled water pump kW

5 How water pump kW

6 Air handler supply and return fan kW

HVAC SYSTEM - GAS

7 HVAC gas meter

WHOLE BUILDING

8 Natural gas meter therms/hr

9 Electric meter kW

Figure 6-1: Measurement boundaries and energy points

A measurement boundary may be drawn around the HVAC system as a whole, as shown in Figure 6-2 (red boundary), or it may be drawn to define more discrete systems, such as chilled water, condenser water, hot water, or air distribution systems. Figure 6-2 shows the measurement boundaries for a chilled water system and for an air handling system.

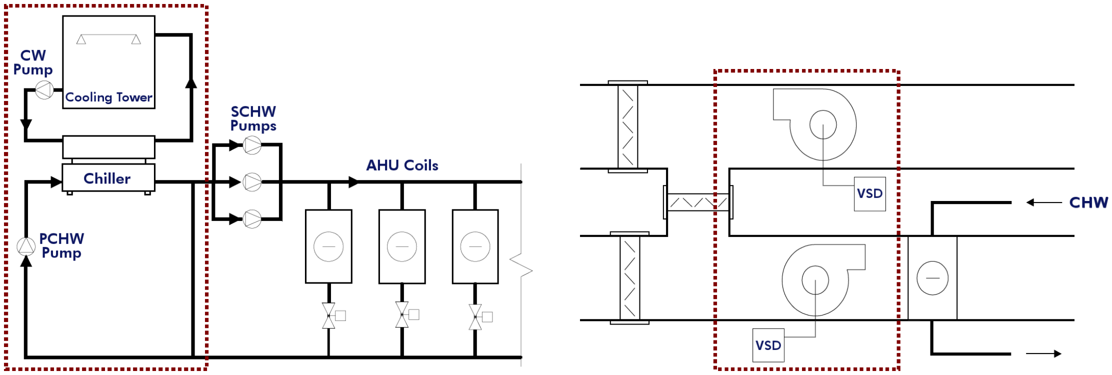


Figure 6-2: Measurement boundaries. Chilled-water system (left) and fan system – electric energy only (right)

Defining systems by the service they provide is advantageous when the EBCx improvements are localized within these systems. In EBCx projects, there tend to be multiple recommendations within a system that affect the system energy use but have a high degree of interaction. For example, a chilled water system's energy use may be improved with the implementation of a supply water temperature set point reset control sequence, while simultaneously an inoperable coil valve is replaced, and flow in the chilled water bypass is reduced. Correcting each of these measures will result in reduced chilled water production, more efficient chiller operation, and reduced pumping energy, each of which reduces the entire chilled water system's energy use. This method verifies the cumulative savings of each individual measure implemented in the chilled water system.

Often, measures implemented within one system affect another system. For example, the measures described above may also affect the air distribution system. These impacts will be accounted for if the air distribution system is included in the M&V Plan. Either the measurement boundary must be drawn around all the affected systems, or all affected systems must be included in the M&V Plan.

6.1.3. Procedure

Figure 6-3 shows how Method 3's verification process is integrated with an EBCx project. In the baseline period, as the EBCx process conducts testing and identifies system improvements, several steps are taken to set up the the verification strategy and prepare the M&V plan. In this period, data is collected and analyzed, and several decisions are made regarding measurement boundary, analysis time interval, and measurement period in order to develop the baseline energy model. The procedure for verifying the savings is then described in the M&V Plan. This section describes the step-by-step procedures to determine the verification strategy, develop the baseline model, and document the M&V Plan.

In the post-installation period, after the operational performance of the systems improved by the implemented EBCx measures has been verified, the required data is monitored and collected, and the savings analysis is carried out according to the M&V Plan. The results are compared to the original engineering savings estimates, and results are reported. These post-implementation verification activities may be repeated to verify savings are persisting.

This section describes the steps in planning and implementing the interval data method within an EBCx project. The steps are closely aligned with the EBCx process as shown in Figure 2-2 (page 8). The numbered steps of this process correspond with the flowchart in Figure 6-3 below.

This method applies to both whole building or system measurement boundaries. The selection of one boundary over another depends in part on the project objectives and in part on the sufficiency of the whole building or system baseline model. Model sufficiency is addressed in the following process description.

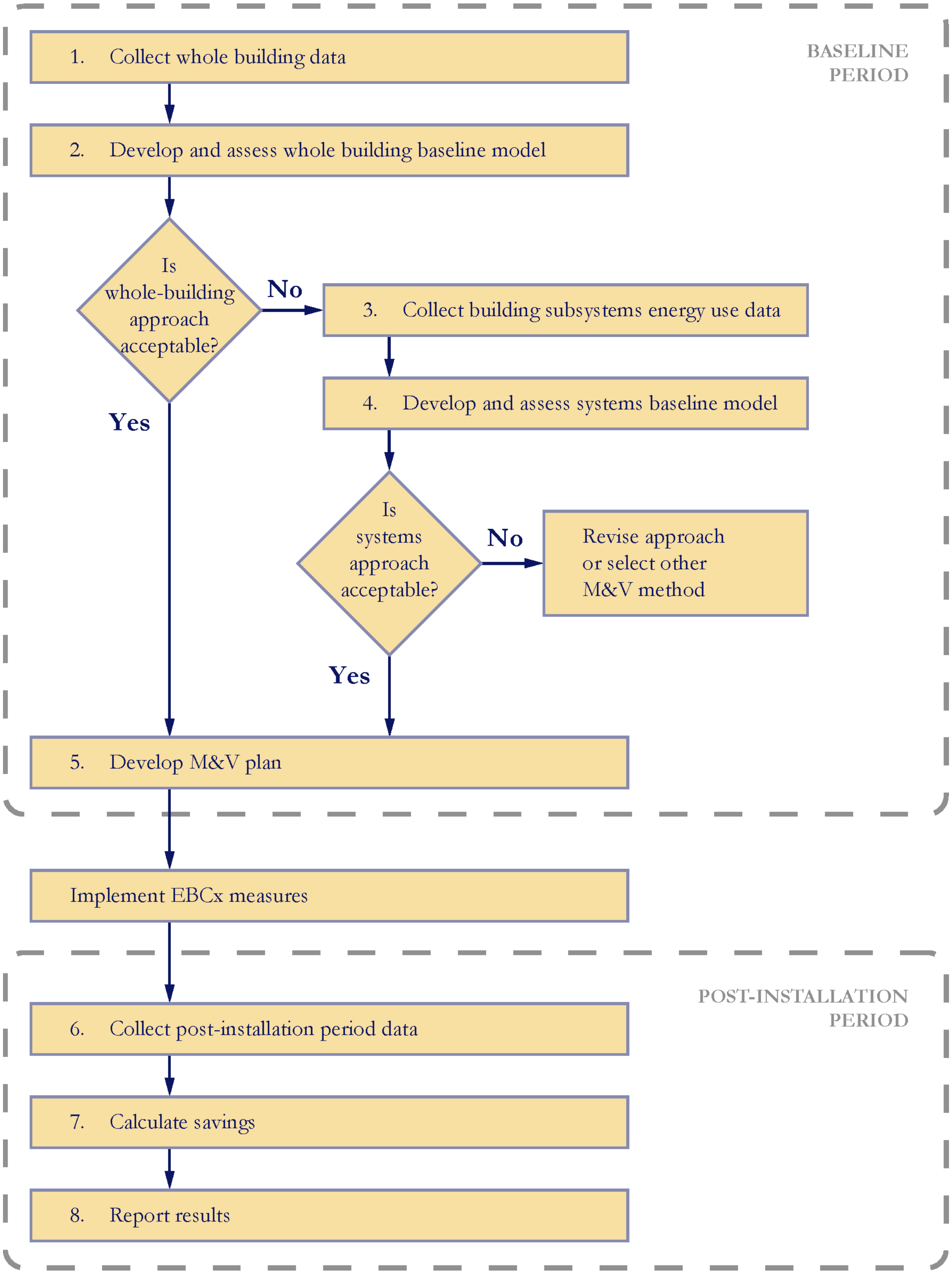


Figure 6-3: Method 3 process flow chart

Step 1: Collect whole building data.

At the outset of any EBCx project in a building, available monthly and short time interval energy data should be collected, as should data from a local weather station. A whole building energy baseline model may be quickly developed and assessed as to whether it is sufficient to verify the expected amount of savings from the EBCx project. If it is insufficient, a decision to pursue a systems approach or a different M&V method may be made. Should another approach prove necessary, there will still be time to develop data collection plans and other necessary steps concurrently with the EBCx investigation.

If only monthly billing data is available, it should be used to develop a model and assess whether the model is sufficient for verifying the expected amount of savings. ***Appendix C*** describes some useful software tools that streamline development of baseline models from monthly data.

The primary factors influencing whole building energy use that are straightforward to monitor and analyze using this method are ambient temperature, building schedule, and occupied periods. This data must be collected for the same time period as the energy data.

Identify any time periods when the building experienced unusual loads—for example a building tenant moved in or out of the building, or there were major equipment failures, and so on. These effects are called non-routine adjustments, and must be accounted for before developing baseline energy models. Before the baseline model is developed, these effects may be measured and factored out of the data, or the affected time period when they occurred may be removed from the data set entirely.

To develop rigorous whole-building baseline energy models, the collected interval data must span the range of operating conditions of the building. This is normally assumed to be one year for buildings, but often 3 to 6 months of data from the heating to the cooling season is sufficient.[21] Section ***6.2.3. Amount of Data to Collect*** (page 69) provides more insight on the amount of data required to develop baseline energy models.

Once the data is collected, it must be inspected to assure it is free of large gaps, erroneous values, and other data quality problems. ***Appendix C*** describes useful tools that streamline the data inspection process. All energy and independent variable data must then be combined and normalized to a common analysis time interval.[22] This guideline recommends an analysis time interval of one hour or one day for use in model development. Determine the total energy use during the interval, and the average ambient temperature.[23] Develop the model with a daily analysis time interval first. If the model is insufficient according to the criteria outlined below, develop the model using an hourly time interval.

Step 2: Develop and assess whole building baseline model.

Develop appropriate regression energy models. These models may be simple linear regressions, change-point models, polynomial models, or multivariate models. Change-point models are described in detail in ***6.2.1 Modeling Techniques*** (page 68) and ***Appendix D: Data-Driven Regression*** Models. Tools for developing linear simple and multivariate change-point models are described in ***Appendix C: Tools***. ***Example of Model Development and Assessment Procedure*** (page 72) provides a detailed procedure to develop and assess a change-point baseline energy model with ambient temperature and occupancy schedules.

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[21] The question of how much data is enough is the subject of ASHRAE Research Project 1404, not yet completed at this time.

[22] The California Commissioning Collaborative provides a useful spreadsheet tool: Energy Charting and Metrics (ECAM) tool, that develops occupancy and operation schedule data. It is available at: www.cacx.org and described in Appendix C.

[23] Note that other representations of ambient temperature may be used, including the minimum temperature for the time interval, or the maximum. When the interval is daily, a heating or cooling degree-day or degree-hour variable may be used.

If the model does not meet the model sufficiency criteria as described in ***Model Sufficiency Criteria*** on page 71, a systems approach may be developed as described in Step 3 below.

If peak period demand reduction must be verified, determine the governing demand reduction algorithm. Refer to the peak period definition provided by the local utility or by the energy efficiency program. Examples are shown in ***Appendix F: Algorithms for Peak-Period Demand Savings***. If the algorithm is average peak demand reduction, a baseline model must be created for the peak period energy use, and must be based on hourly time intervals. The model is developed following the same procedure as described above, except only the peak period hours are included in the development.

If the algorithm is coincident peak period demand reduction, a baseline model of electric power must be developed. It may be based on hourly or 15-minute time intervals. The model is developed with the same procedure as described above, except that power is used as the dependent variable in place of energy, and only the peak period hours are included in its development. Refer to ***Appendix F*** for descriptions of both average and coincident peak period demand algorithms.

Step 3: Collect building subsystems energy use data.

Determine the measurement boundary for the systems approach. As described in ***6.1.2 Definition of Measurement Boundary*** (page 59), the measurement boundary may include all HVAC systems in the building, or may include air handling and chilled water systems separately. This decision relies on what systems the anticipated EBCx measures affect, and on the difficulty in monitoring and collecting the required data.

Begin by identifying what equipment is included within the defined system boundary. For each component of the system, identify whether its energy use is being monitored and the data is available. If no such data is available, identify whether the equipment's status is being monitored. Equipment status signals may be binary (i.e., 1 or 0) for constantly loaded equipment, or analog (i.e., from 0 to 100) for variably loaded equipment, and are usually found in the building's BAS. Status signals may be converted to proxies for energy use as described in ***6.3.1 Required Energy Metering*** (page 73).

Unless the energy or status points have been monitored and stored prior to the start of the EBCx project, monitoring of these points must begin immediately. The objective is to capture as much of the range of system operation as possible. Some systems modulate through their range of operation in a short time, such as within 2 weeks. Others take up to six months or longer. Review the system's operation characteristics to determine the required monitoring period and be sure data is collected through the highest and lowest points in their range. Identify the independent parameters, usually ambient temperature and equipment operation schedule, and monitor them for the same time period. Monitor all the data in short time intervals, such as 5, 10, or 15 minutes.

Periodically check the monitored data to insure good values are being collected. After the prescribed amount of monitored data has been collected, prepare the data for analysis. ***Appendix B: Data Sources and Management*** describes data quality checks and preparation techniques.

Step 4: Develop and assess systems baseline model.

Normalize the data to the same time interval, either daily or hourly. Combine the energy use data of each component within the system so that there is one system energy use data point for each time interval. As in the whole-building analysis, use a daily time interval first, then an hourly time interval if necessary. Follow the same procedure to develop and assess a baseline energy model as was followed with the whole building baseline model development.

Peak demand savings may also be determined for building subsystems. However only the average peak demand reduction algorithm described in ***Appendix F: Algorithms for Peak-Period Demand Savings*** applies. As described above for the whole building, a baseline energy model is developed using hourly data from only the peak period hours.

Step 5: Document savings verification requirements in the EBCx plan.

As described in ***2. Integrating the Energy Savings Verification Process***, it is very important that baseline data collection includes documenting the inventory of systems and equipment, their condition, and operating parameters. Collecting this information is a central task of any EBCx process, so this should not be considered additional work for M&V purposes. However, once the EBCx recommendations have been implemented, there will be no way to recapture the as-found baseline conditions. Without a well-documented baseline, the EBCx provider's and program manager's ability to demonstrate the overall benefits of commissioning will be compromised, and add unnecessary risk to the project.

With the required baseline information collected and the baseline model developed, the EBCx provider must document the baseline equipment and conditions, M&V approach, the selected baseline model, and the model sufficiency criteria. The baseline model documentation should include all the parameters used to develop it, including a description of the accounting for non-routine events. It should also include all the data, identify the analysis time interval, and describe the derived statistical coefficients (CV, R^2, confidence interval, etc.). If required by stakeholders, it should also include the estimated fractional savings uncertainty.

The post-installation activities can then be anticipated and documented. These activities include:

- identifying the data to be collected in the reporting period, the sources of data, and any required independent data logging activities,
- developing the algorithms to determine the savings,
- deciding how to account for non-routine adjustments, and
- establishing the length of the reporting period (that is, the amount of time after the measures are installed that the data will be collected and savings reported).

The frequency of data collection, analysis, and reporting may be proposed in the EBCx Plan, or prescribed by the building owner or utility program. Clarity on verification activities prior to implementation of the plan will avoid unnecessary conflicts with building owner expectations or EBCx program requirements.

The calculated energy savings benefits at the conclusion of the commissioning process must be reported, and any ongoing and periodic reporting intervals must also be identified. For EBCx projects it is recommended to continuously track energy use, and provide savings reports on a quarterly basis.

The EBCx recommendations are implemented by the owner or facility personnel, and are not a formal part of the verification process. The start and end dates of the implementation process should be noted so that the actual implementation period data is not used in the baseline model development, nor as part of the post-installation dataset that is used to calculate savings.

Step 6: Collect post-installation period data.

After installation of the EBCx recommendations the improved operation of the equipment or system must be verified. This is a normal requirement of EBCx projects. Requirements for verifying improved operation depends on each individual recommendation that was installed, and may include simple visual inspection, trending and analysis of operational data, or functional testing. These activities are described in ***4.3 Field Verification Approaches*** (page 36).

The savings are verified based on the documented approach and data requirements in the M&V Plan. The energy use and independent variable data required to perform the savings analysis is collected. Data should be collected in the season of the year when the savings are expected to accrue. For example, if the operation of the cooling plant has been improved, then data over the warmer months of the year need to be collected. As in the baseline period, the data must be prepared for analysis by examining it for reasonableness, eliminating gaps, and adjusting it to the specified analysis time interval (e.g., hourly or daily).

The data should be periodically inspected at least monthly to understand whether unexpected changes in energy use occur. When this occurs, the building should be inspected to understand the cause of the unusual energy use, and how long it lasts. If possible, this unexpected excess or absence of energy use should be quantified with measurements, so that adjustments can be made to properly account for savings. If the unusual energy use is random, and occurs in a very limited time in the reporting period, this data may be excluded from the analysis. If the unusual energy use is attributed to the EBCx improvement and cannot be corrected, the savings estimate must be recalculated.

Step 7: Calculate savings.

Reporting Period Savings: In some cases, such as for very long reporting periods, only the actual accrued savings in the period must be determined. In these cases, the measured post-installation energy use may be subtracted from the adjusted baseline energy use as determined by the baseline model. This approach is similar to the "avoided energy use" concept in IPMVP.

If savings are to be stated for conditions other than the post-installation period, a post-installation energy model that relates the energy use with independent variables describing those conditions must be developed. Usually the conditions are typical meterological year (TMY) weather conditions. Both baseline and post-installation energy use must then be determined using the TMY data, and savings determined under these conditions. This approach is similar to the "normalized savings" concept in IPMVP.

Annual Savings: Unless the reporting period is a full year or more, the collected data sets will be for a shorter time period. In these cases, to determine the verified savings based on an entire year, the energy use from the measured reporting period must be extrapolated to an entire year. This is done by:

- Creating a post-installation model from the collected data in the same way as the baseline model was created.
- Using the ambient temperature data from a TMY weather file in the baseline and post-installation models to calculate baseline and post-installation annual energy use,
- Subtracting the estimated annual post-installation energy use from the baseline energy use.

Note this is not an IPMVP-adherent procedure, as the savings in this case will not be based on actual measurements in the post-installation period for the entire year.

The EBCx provider and owner or program manager should establish criteria for reporting period duration in which the data is collected so that robust post-installation energy use models may be developed. Examples of such criteria may be:

- Collect enough data to include a "cycle" of operation (IPMVP requires data through one cycle).
  - Constant load equipment: spot measurements may suffice
  - Variable load equipment: through entire range of its operation
  - Chilled water system: entire cooling season from swing to peak season

  - Building – 12 months, or 6 months from coldest to warmest months
- Collect enough data to capture 90% of the expected data range
- Collect the data through the season when the EBCx improvements have the most impact

Step 8: Report results.

Savings report requirements are specified in the M&V Plan, and agreed upon by the owner or program manager. If any non-routine adjustments must be made, the data and algorithms used to determine the adjustments must be fully documented in the savings reports.

Depending on the owner's or program managers objectives, the owner's facility operations personnel or the commissioning provider may be engaged over a multiyear term to make sure energy savings last for their expected lifetimes. This essentially adds a persistence phase to the verification process. If this activity is required, this phase generally includes the same tasks as in the post-installation phase. Tasks in the persistence phase include verification of continued operational performance, tracking energy performance over time, and periodic savings reporting. Specific to the Interval Data Method, two additional steps may be added to the process for the persistence phase. These steps are not shown on the flowchart in Figure 6-3.

Step 9: Verify equipment continued performance.

Once the EBCx project is complete, the operational verification steps taken in the post-installation phase should be repeated in regular, predefined intervals such as quarterly to insure continued performance. Requirements for verifying improved operation depends on each individual recommendation that was installed, and may include simple visual inspection, trending and analysis of operational data, or functional testing. These activities are described in ***4.3 Field Verification Approaches*** (page 36). Meters and sensors should also be periodically inspected and calibrated to ensure accurate data is collected.

The Building Performance Tracking Project, sponsored by the California Energy Commission[24] provides good descriptions of useful tools for ongoing performance maintenance and a good framework to help owners and program managers understand the tools, methodologies, and required data resources to implement them.

Step 10: Verify continued energy savings.

The baseline energy model may be used to account for savings over time. This requires the energy and independent variable data to be continuously monitored and used in the savings calculations. Savings calculations are performed in the same way as described in Step 7. Savings should be reported at least on an annual basis.

6.2. Analysis Methods

This guideline emphasizes empirical models, which are models developed using statistical techniques from the measured data. These models describe relationships between dependent and independent variables that have some physical significance between the parameters. These techniques identify how a dependent variable, such as energy use or electric demand, is influenced by independent variables, such as ambient temperature, building schedule, or occupancy. Sometimes called "inverse energy models" or "data driven" models, empirical models can be developed from any building or system where there is a dependence of energy use or demand on identifiable and quantifiable independent variables.

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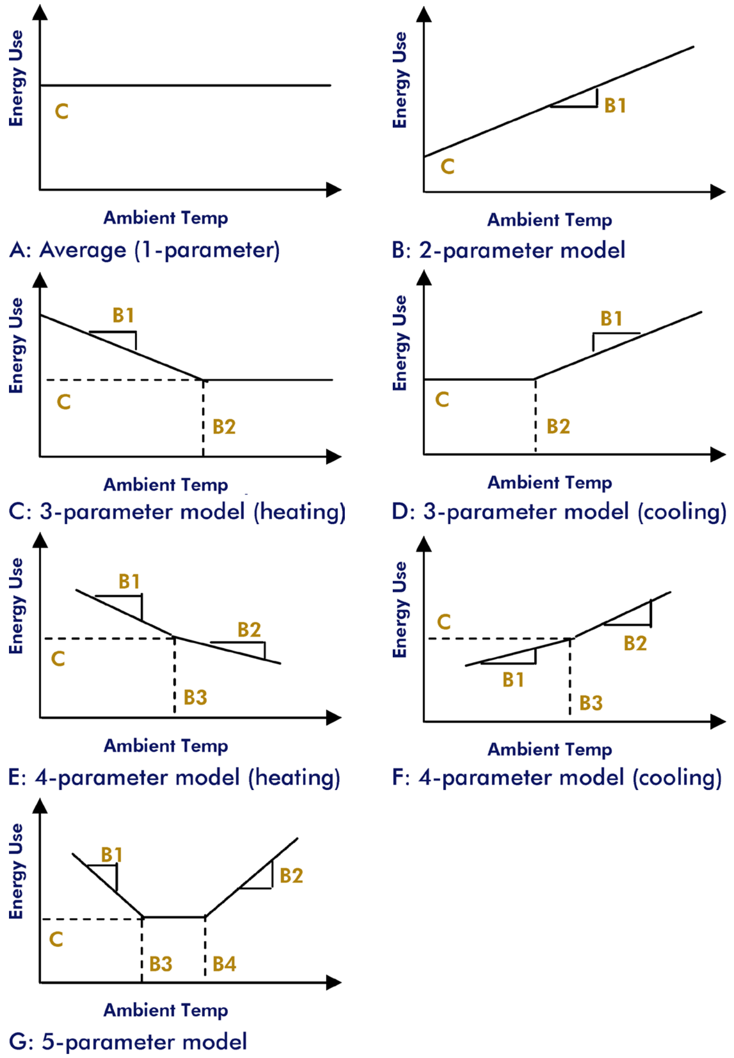
[24] Available at www.cacx.org/PIER/handbook.html.

Empirical modeling methods can be applied to whole buildings using one or multiple energy meters in the building. Empirical models can also be applied under a systems isolation approach using energy data from defined building subsystems. The modeling techniques are discussed in ***6.2.1 Modeling Techniques*** (below), and procedures for developing the models are in ***6.2.4 Developing, Assessing, and Selecting the Appropriate Model*** (page 70).

6.2.1. Modeling Techniques

The statistical modeling techniques recommended for use in this method include simple averages, linear regressions, multiparameter change point models, and multivariate models. Other model types may also be used when it is shown that they best represent the data. These model types include second-, third-, and higher-order polynomials, and asymptotic models. Polynomial models must be used with extreme caution, as they can quickly overestimate energy use when extrapolating beyond the data range upon which the model was developed.

The basic steps in using the linear, multiparameter change-point, and multivariate modeling techniques are described in this method and are based on the results of ASHRAE Research Project 1050.[25] Other model types (polynomial, asymptotic, etc.) may be developed according to the same procedures.



A: Average (1-parameter)

B: 2-parameter model

C: 3-parameter model (heating)

D: 3-parameter model (cooling)

E: 4-parameter model (heating)

F: 4-parameter model (cooling)

G: 5-parameter model

Figure 6-4: Linear regression models

The simple linear models (A–G) are shown in Figure 6-4[26] These models are used to find the best fit of the energy use and independent variable data that would normally be plotted in a scatter plot. Model B for example may be used to show the linear relationship between the daily energy use and average daily ambient temperatures for an HVAC system. Model B is a linear 2-parameter model. In Figure 6-4 only the model types are shown. Models C–G are the change-point model types. The change points are the points at which the model's slope changes. Change-points are additional parameters in the model. ***Appendix D: Data-Driven Regression*** Models contains descriptions and equations for each of the models depicted in Figure 6-4.

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[25] ASHRAE Research Project 1050, available at www.ashrae.org.

[26] Figure 6–4 is adapted from Figure 5.1 on p. 28 of ASHRAE Research Project 1050.

Modeling the data with regression techniques produces statistical indexes that are used to help select the model that best represents the data, and provides a means to estimate the uncertainty in the resulting savings. These issues are further discussed in ***Appendix D: Data-Driven Regression*** Models and ***Appendix E: Uncertainty Analysis***.

Haberl and Culp[27] report that linear change-point models are advantageous over other models in that they are simple and have been validated with a large dataset of buildings. They cite several sources that indicate the coefficients of the linear change-point models have physical significance in buildings. The disadvantages include poor modeling of dynamic effects and solar loads, and buildings that have unusual operating characteristics that result in multiple change-points. Most of the following discussion on energy use models is based on information presented in Haberl and Culp, ASHRAE Research Project 1050, and ASHRAE Guideline 14-2002.

6.2.2. Selecting a Time Interval for Data Analysis

The energy use and independent variable data must be conditioned to the same time interval and time stamp before developing and testing the models. This guideline recommends that an analysis time interval of an *hour* or a *day* be selected. If an hour is the analysis time interval, then for the same monitoring period, much more data will be collected than if a day was selected. More data is always advantageous when developing the models and reducing uncertainty, but is not always required. If the energy use depends strongly on the day of the week as opposed to hour of the day, this supports selecting a day as the analysis time interval. If the energy use is strongly dependent on the occupied period or daily operation schedule, then selecting an hour as the analysis time interval is justified. Other choices that make sense are to use only the occupied hours of the day, or only the daily peak period hours, which can be from noon to 6 P.M. on non-holiday workdays depending on the working definition from the local utility (see ***Appendix F: Algorithms for Peak-Period Demand Savings*** for more discussion on determining electric demand savings).

If an hourly analysis time interval is selected, then the energy use of the shorter time intervals must be summed to one hour increments. Similarly, the energy use for the shorter time intervals must be summed to daily values if days are the analysis time interval. If the interval data is in units of demand, not energy, an average demand over the selected analysis time interval must be determined, and then multiplied by the unit of time, to determine energy use for that period.

Ambient temperatures can be averaged over the analysis time interval, however if days are the analysis time interval, averaging the ambient temperature over each day will lose some meaningful information in regard to its influence on energy use. For example, the same average temperature may result from two entirely different days, one being a relatively mild day, and another that is very cool in the morning hours, and very warm in afternoon hours. For the daily analysis time interval, it may be better to determine the heating and cooling degree hours for each day for use in the models. Other choices may include using only the occupied hours of the day to average the ambient temperature, or using the day's peak temperature.

6.2.3. Amount of Data to Collect

At the time of the publication of ASHRAE Guideline 14-2002, there was much unsettled debate on the amount of data required to establish a baseline. Until this issue is resolved, ASHRAE Guideline 14-2002 requires one year or more of data prior to the installation of energy improvements. Method 3 is less restrictive, recommending that data over most of the operating range of the building or equipment be collected. For example, for improvements to cooling

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[27] Haberl, J.S., and C.H. Culp, "Review of Methods for Measuring and Verifying Savings from Energy Conservation Retrofits to Existing Buildings," Energy Systems Laboratory, Texas A&M University System, report no. ESL TR-03-09-01, 2003.

system operations, data characterizing the baseline should be collected in warm spring, summer and fall months.

The amount of data collected is proportional to the available time. These methods require that baseline energy use and independent variable data be collected to cover most of the range of variation in each parameter. Extrapolation of the models outside the data range in which the energy use models have been developed is discouraged; however it is often unavoidable due to project time constraints. Several issues must be considered in order to collect enough data to properly characterize baseline energy use.

- Are the energy impacts to be verified on cooling or heating systems, or base loads in the building? The highest cooling and heating energy uses in a building are generally six months apart. If there is insufficient time in the baseline period to span six months of data collection, three months in the spring or fall seasons may be used. This may be acceptable in milder California climates near the coast, but not in California's more extreme climate conditions in its inland valleys, or other parts of the nation.
- If average peak period demand reduction must be verified, then the baseline monitoring period must capture the peak demand period energy use. If peak demand coincident with the electric system distribution peak or the building's actual billing period peak demand is to be verified, then the peak demand, time, and ambient temperature during the distribution system peak, or billing period peak, must be collected. See ***Appendix F: Algorithms for Peak-Period Demand Savings***.
- Changes in building energy use may cause delays in collecting data for baseline modeling. Tenants moving in or out, or major renovations in a significant portion of the building may delay start of baseline data collection. Alternatively, the impact of these non-routine events may be quantified and used to correct the baseline energy use.
- If the analysis time interval is daily, and very few weeks of data are available in the baseline period, consider switching to an hourly basis for modeling, as more data, and a wider range of values can be collected as the energy use and independent variables vary. However, there will generally be more scatter in the model, which can result in higher model uncertainty.

6.2.4. Developing, Assessing, and Selecting the Appropriate Model

Model Development

After the analysis time interval has been selected, and all data prepared, plot the energy use and ambient temperature data in a scatter plot. Identify an appropriate regression model that best represents the scatter pattern, and fit the model to the data, determining the slopes, intercepts, change points, and so on. ***Appendix C: Tools*** lists tools that assist in this process. The best fitting models are those that minimize both random and bias error from the measured data. The random and bias error are determined by the following statistical indexes:

- Coefficient of determination of the standard deviation, CV(STD)
  (for average, or one-parameter models)
- Coefficient of determination of the root mean squared error, CV(RMSE)
  (for 2- or higher parameter models)
- Net mean bias error, NMBE
- Net determination bias error, NBE

Both the CV(STD) and the CV(RMSE) provide an indication of how much variation there is in the data about the model. These indexes are an indication of the random error in a model's ability to estimate energy use. The NMBE and NBE provide an indication of how much bias error there is in the model's ability to predict the energy use. Formulas for each of these are provided in ***Appendix D: Data-Driven Regression*** Models. A more thorough discussion of model error and uncertainty is provided in ***Appendix E: Uncertainty Analysis***. For each model tested, determine the value of each of these indexes. Select the model with the lowest CV(RMSE), NMBE, and NBE.

In developing 3-parameter or higher change-point models, determining the change point is the most difficult task, because it is found by trial and error. An initial change point is selected and the model is developed by linear regression of the dependent and independent variable data to the right of the change point, and again for the data to the left of the change point. A good initial guess at the change point can be made by viewing the data in a scatter plot. After this first iteration change point model is developed, its variation and bias indexes are calculated. A new change point is selected and the process is repeated. The variation and bias indexes of each model are compared and the model with the higher variation and bias indexes is eliminated. New change points are then tested according to the same procedure. This is a cumbersome process without software automation tools, which are listed in ***Appendix C: Tools***.

If "categorical" independent variables such as day-of-week or hour-of-day have been included in the model, it is best to separate the data sets according to each category, and build independent models from the separate data sets. For example, if the day-of-week variable is used, separate the weekday data from the weekend and holiday data and develop models for each data set. The models do not need to be the same type (i.e., both 2-P models, etc.). Using the categorical variable, combine the two resulting equations into one equation. The categorical variable, which will be either "1" or "0," will insure that the correct model will be used for each day of the week.

Model Sufficiency Criteria

After the best-fitting model has been developed, it must be assedd to determine whether it is adequate, or sufficient, to verify the expected savings. Model sufficiency criteria should be determined by the stakeholders at the outset of the project. There are many ways to specify this criteria, this method describes only two of them.

A rule-of-thumb method may be used to specify the model sufficiency criteria. The stakeholders specify the minimum fraction of annual savings to annual energy use (within the measurement boundary) allowable. When this fraction is lower than the specified minimum, the model is insufficient to verify the savings, and a better model must be developed.

A more formal way to specify the model sufficiency criteria is to estimate the maximum amount of uncertainty acceptable to the stakeholders. There are various methods to estimate the resulting savings uncertainty. The most straightforward method is to estimate the fractional savings uncertainty. ASHRAE Guideline 14-2002's Annex B provides a methodology to quantify and assess the savings uncertainty that would result from use of a particular regression model to verify savings. It is termed fractional savings uncertainty, ***Appendix E: Uncertainty Analysis*** summarizes the procedure. Performing these simple calculations is very useful in selecting the final approach to be used throughout the project, as well as establishing the confidence limits in the final calculated savings.

Steps for model development and model assessment using each of these model sufficiency criteria are described in the following section.

Example of Model Development and Assessment Procedure

Given a set of hourly or daily energy use and corresponding average ambient temperature data, and a categorical variable that describes when the building is occupied, develop individual change-point regression models for each set of occupancy schedule data, using the following general procedure:

Model Development

- Group all of the same occupancy type data into one dataset and plot it (energy vs. ambient temperature).
    - When the analysis time interval is daily, split up the weekday data from the weekend and holiday data (or equivalently, into occupied days vs. unoccupied days, and so on).
    - When the analysis time interval is hourly, split it up into occupied and unoccupied (or equipment on/off) periods.
- Identify any unusual data points or groupings that may be explained by other unconsidered factors—such as poor occupancy or operations schedule definition or non-routine building events, and so on. Correct the schedule or account for non-routine events.
- For each group of data, chart the data and identify which regression model (linear simple regression, change-point, polynomial, etc.) best fits the data.
- For each selected group, determine the regression coefficients and change-points for the selected model.
- Combine the weekday/weekend or on-hours/off-hours energy models in equation form, with ambient temperature and the occupancy schedule as independent variables.

Model Assessment

- Estimate the total savings within the measurement boundary expected from the EBCx project as a fraction of its annual energy use. The baseline model may be used to estimate annual energy use of the systems with the measurement boundary.
- If the fraction of savings is less than 10% or another predefined amount agreed upon by stakeholders, the model is insufficient to verify the savings.
- If the model assessment is based on its ability to resolve the saving above its uncertainty, estimate the fractional savings uncertainty, as described in Equation E-3 in ***Appendix E: Uncertainty Analysis***.
- Compare the fractional savings uncertainty with the estimated energy savings, expressed as a fraction of annual energy use. If the fractional savings uncertainty is 50% or greater, or another predefined amount agreed upon by stakeholders, the model is insufficient to verify the savings.
- Should the model be found insufficient, several steps may be taken to obtain a better model:
    - Extend the baseline or post-installation monitoring period (number of extra hourly or daily data points to collect), determine the new fractional savings uncertainty, and compare again.
    - If the initial attempt to develop a baseline energy model was based on a daily analysis time interval, try again with an hourly time interval.
    - Consider selection of a lower confidence level (e.g., 90% as opposed to 95%).

  - Consider use of other independent variables.
  - If the fractional savings uncertainty cannot be lowered below 50%, consider using the systems approach or another M&V method.
- If the model provides enough resolution to verify the expected savings, proceed to Step 3 to document the verification requirements in the EBCx Plan.

6.3. Requirements and Costs

This section describes the resources required to use this method. These resources include systems for collecting the type and amount of data required, and familiarity with the regression analysis techniques. If these resources are not present, please consult the other verification methodologies included in this Guideline.

6.3.1. Required Energy Metering

Energy and demand data, measured and recorded in short time intervals, are essential to carry out this savings verification analysis. The maximum time interval between data points should be no more than one hour. Short time intervals are necessary to obtain an understanding of how energy use is affected as its influencing parameters change over time. The following sections discuss data types and sources.

Whole Building Energy Use

- **Whole building electric energy or demand.** In California, buildings with loads over 200 kW have real-time electric metering and the data are available through the web sites listed in Table 6-1. These data are typically averages over the time interval, not instantaneous readings. Many buildings have multiple electric meters, in which case the energy use should be collected from each meter.

Table 6-1: Websites with Electric Utility Data in Short Time Intervals

Utility	Web Site
LADWP	http://www.ladwp.com/ladwp/cms/ladwp003154.jsp
PG&E	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/tools/
SCE	http://www.sce.com/business/business.htm
SDGE	http://www.sdge.com/business/
SMUD	https://www.smud.org/en/business

- **Natural gas consumption.** Short time interval data for natural gas consumption is far less common than whole-building electric interval data. However natural gas interval data can be measured using permanently installed calibrated digital flow meters or pulse counters attached to the gas meter faceplate. Their output is usually in volumetric units, such as cubic feet, and can be monitored by the building's energy management and control system (BAS), or an independent monitoring system.[28] While the pulse counters are also relatively inexpensive, they should be installed by the utility or a licensed contractor.
- **Chilled or hot water use.** A building may be connected to a central or district chilled or hot water generation plant. "Btu" meters are commonly used that have flow meters to measure

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[28] Such as an energy information system (EIS). Such systems are discussed in the Building Performance Tracking Handbook, available for free download at www.cacx.org/PIER/handbook.html.

water flow and temperature sensors that measure the temperatures of the entering and leaving water. The Btu meters calculate instantaneous thermal energy use and the result may be recorded by the BAS or an alternate system. Alternatively, the measured water flow and temperatures are recorded independently and energy use is calculated from this data.[29] These points should be periodically checked for proper calibration.

- **Steam use.** A building may also obtain steam from a central plant. At the building, steam is measured using permanently installed steam meters, which measure total pounds of steam entering the building, or steam condensate meters which record the amount of condensed steam returning to the central plant. Condensate meters can be less reliable due to age and corrosion problems, and possible steam system leaks in the building.

PG&E's Tool Lending Library[30] has many different metering technologies that collect electric and non-electric short-term interval energy data, including gas meter faceplate pulse counters and Btu meters for hot and chilled water energy flows.

A well-written primer on metering technologies, communications, and data storage, is available.[31]

System-Level Energy Use

Measurements of energy use in building subsystems and equipment are required for this approach. Energy meters for directly monitoring energy use at the systems level in buildings are limited, but can be found on a case by case basis. Energy meters for large equipment such as chillers are often found, but few other examples exist. Following are commonly found points useful for systems level energy monitoring.

- **Chiller electric energy.** Many chillers are equipped with control panels that provide analog signals of chiller wattage or amps. This data may be recorded by the chiller's own control panel, or independently trended in the building's BAS.
- **Motors equipped with variable frequency drives (VFD).** Many VFD provide analog output signals of motor and inverter wattage or amperage that can be monitored in an BAS. Often, dip switches or programming on the VFD can be used to select the desired output. Before relying on the VFD output signal data, it should be checked against readings from a reliable watt or amperage meter.

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[29] Care must be taken to make sure temperatures and flows are aligned to the same time intervals before calculation.

[30] The Tool Lending Library's inventory may be found online: http://www.pge.com/mybusiness/edusafety/training/pec/toolbox/tll/

[31] "Metering Best Practices, A Guide to Achieving Utility Resource Efficiency," Federal Energy Management Program (FEMP), US Department of Energy, Energy Efficiency and Renewable Energy, Oct. 2007, available at: http://www1.eere.energy.gov/femp/operations_maintenance/om_resources.html.

- **Feedback signals.** Feedback signals are analog or digital input signals to the BAS that indicate the status of operating equipment. Binary value status signals describe the status of constant load equipment, while analog variable speed, position, or load signals describe the status of variable load equipment. Examples of constant and variable feedback signals are shown graphically in Figure 6-5. Both constant and variable load feedback signals can be made into "proxy" variables for energy use, as described below.

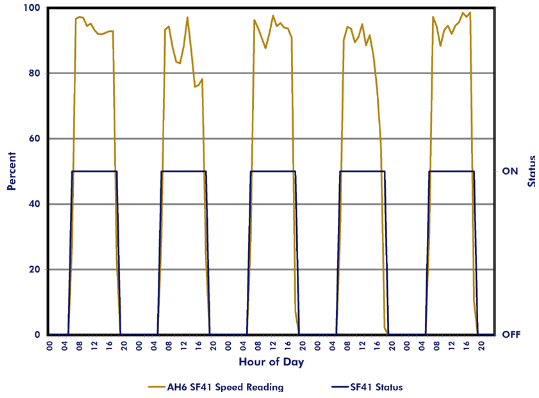

Figure 6-5: Examples of binary and analog feedback signals

  - Multiple measurements of instantaneous power may be made for equipment that is considered constant load. The degree to which a load is considered constant may be defined by the user; ASHRAE's Guideline 14-2002 indicates a 5% limit in the variance[32] of load to be considered constant. When the status signal shows that equipment is on, its power will then be known. Further measurements of power are unnecessary, and only the equipment status signal should be trended.
  - Variable load equipment power consumption must be logged with a true RMS power meter over time as the VFD varies through its range of loads. Usually a few full days of VFD modulation, at 5-minute intervals will suffice to capture data throughout its range of speeds. Simultaneously a characteristic variable load feedback signal (speed, frequency, etc.) for that equipment must be trended. The data is then collected and data sets merged. A relationship between the power and variable load signal is then developed. The form of the relationship between the two variables may be guided by known physical relationships, such as a cubic relationship between fan motor power and fan speed for variable speed applications. An example is shown in Figure 6-6.

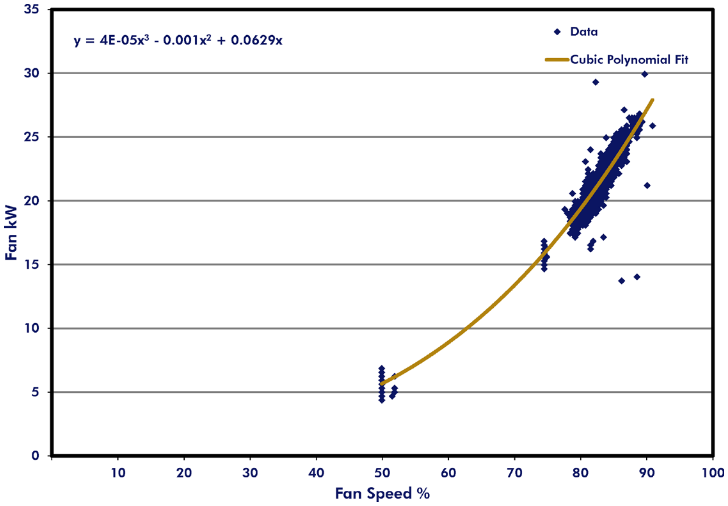

Figure 6-6: Cubic polynomial relationship between fan motor power and speed.

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[32] For the purposes of this protocol, this variance is defined as the coefficient of variation of the standard deviation: CV(STD). It is calculated by CV(STD) = $\sigma/\bar{x}$, where σ = standard deviation about the mean value, and $\bar{x}$ = mean of measured values.

6.3.2. Required Independent Variables and Sources

Data on independent variables that influence or "explain" the variation in energy use in a building or system must also be collected on a common time interval as the energy data. As most energy use in building HVAC systems is dependent on weather conditions, outdoor ambient temperature data are required. Other independent parameters may include: humidity, building occupancy, daily and weekly schedule, and other building internal heat loads, among others. Sources of independent variables include:

- **Local weather stations.** The National Oceanographic and Atmospheric Administration (NOAA) provide real weather data from most airports throughout the United States.[33] NOAA and other weather data websites are provided in Table 6-2 below. The weather data from these sources provide most of the information needed for ambient conditions, including dry-bulb temperatures and wet-bulb temperatures or relative humidity. Data intervals are usually hourly, but can be as frequent as 5 minutes. Generally over a year's worth of data is available, up to a few weeks behind the current date.
- **Building BAS.** The building's BAS can be a source for ambient temperatures, and sometimes relative humidity. Data on submetered chilled and hot water use may sometimes be found. Equipment feedback status signals that indicate equipment on/off schedules are usually available. This data should be used only after it has been validated, as often calibration and sensor placement problems exist with many temperature and relative humidity sensors, and feedback signals may be erroneous.
- **Date and time stamps from data files.** Monitored data are accompanied with date and time stamps. The date and time stamped data can be filtered by the hour-of-day and the day-of-week that the building is occupied or unoccupied. A useful spreadsheet add-in tool that helps develop these variables is described in ***Appendix C: Tools***.

Table 6-2: Weather Data Websites

Organization	Web Site
NOAA	www.ncdc.noaa.gov/oa/ncdc.html
GARD Analytics	www.gard.com/weather
Weather Underground	www.wunderground.com
USDOE EERE	www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm *

* Provides sources for weather data in a variety of formats, including real-time data.

6.3.3. Familiarity with Regression Analysis

Experience developing statistical regressions is recommended in order to use this method. The methods described in ***6.2. Analysis Methods*** (page 67) are extensions of the commonly applied least-squares regression technique. Users of this method should understand how to develop and test regressions for best fit to the data, and have a basic understanding of uncertainty analysis. ***Appendix C: Tools*** provides names of useful software to assist in the development of regression-based energy models. Use of these tools eliminates the tedious process of finding the best model and best fit to the data.

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[33] Available through: www.ncdc.noaa.gov/oa/ncdc.html.

7. Method 4: Calibrated Simulation

7.1. Description of Method

Calibrated simulation is a method for verifying the energy savings of ECMs implemented in buildings, or building subsystems using calibrated computer simulation models.

Building energy simulation software programs allow users to assess a wide variaty of ECM options in buildings. These software programs model the energy use required by the building's systems and equipment to maintain occupant comfort, lighting levels, and other building services. Because energy flows in buildings are numerous, complex, and highly interactive, building energy simulation software is often required to properly account for them. The most comprehensive simulation software programs model all of these flows within the building and its systems on at least an hourly basis.

Building simulation software is very useful for quantifying the savings impact of highly interactive and otherwise difficult to quantify ECMs such as improvements to the building envelope and reductions in unwanted air infiltration. Simulations are also used to estimate the savings for retrofits and upgrades to building central plants, air distribution and lighting systems. An advantage of using building energy simulations is that they can provide savings estimates for individual ECMs or the total savings, including interactions from multiple ECMs implemented within the building or a particular building subsystem.

However, developing and calibrating a building simulation model is time consuming, requires a lot of measured data for comparison and successful use takes intimate knowledge of and experience with the software. Calibrated simulation for verification of EBCx project savings should be performed by an experienced building simulation specialist only.

To calibrate a building-simulation model, much information about the building is needed. This information includes climate zone, size, use, envelope properties, details about system, equipment and efficiencies, building operations, number of occupants, and so on. The calibration process relies on use of extensive data sets collected from the building, including utility bills, time-of-use energy data, weather data, and temperatures. Information about control sequences and system operations is also needed. Much of this same information is collected in an EBCx investigation to determine where system operations are deficient and can be improved. The data collected can be used for each purpose.

A calibrated simulation is useful in the EBCx process because once it has been created, it may serve many purposes. As this chapter will demonstrate, it may be used to estimate energy savings of individual ECMs so that their cost-effectiveness may be determined prior to implementation. It may be used in two ways to verify that actual savings are achieved: by calculating the avoided energy use had the ECMs not been installed, or by calculating the annual energy savings under a common set of conditions ("normalized savings"). The calibrated simulation of the building in the post-installation period may be used to confirm the building's energy performance over time. This building model may also be used to evaluate other potential ECMs, including major improvements to lighting and HVAC systems.

7.1.1. Key Criteria for Calibrated Simulation

- Calibrated simulation requires a very accurate energy simulation of the baseline building model.
- The qualifications and experience of the simulator is a key factor, and subsequently calibrated simulation is intended for only the most qualified practitioners.
- Calibrated simulation is applicable when building details are known. Access to record documents such as: construction drawings, specifications, TAB reports, mechanical equipment schedules, submittals, architectural floor plans, architectural elevation drawings, envelope characteristics such as R and U values are required to limit the number of assumptions made in the model.
- Historical utility data should be available for at least one whole year in monthly format. Additional whole years of utility data may also be used. Hourly or 15-minute interval data will increase accuracy if used.
- Historical subsystem data should be available. The ability to trend through the BAS or with portable data loggers to provide additional baseline building model end-use breakdown for calibration purposes will increase accuracy.
- Configuring submetering systems to correlate to the analysis structure and end-use breakdown of the software being utilized allows direct comparison of metered and modeled energy use.
- Because simulation algorithms and equipment models assume “perfect” equipment operation, it can be difficult to model “broken” or “less than optimal” operation. The skill of the modeler and knowledge of the software are required to determine whether there is an appropriate “work around” to deal with these situations within the software.
- Some HVAC systems or control options cannot be easily modeled by the software. Common systems or control sequences are often easily modeled. However, public domain software may not be capable of modeling more complex systems or sequences. Examples include: DCV or under-floor systems where stratification occurs in the zone; any single zone that is served by two separate systems, such as dedicated outdoor air systems; building pressurization control; and variable refrigerant flow systems.

7.1.2. Terminology

- **Baseline Model:** The baseline model is a computer simulation of the building as it exists, prior to the installation of any ECMs. This model uses all the construction characteristics and current operational parameters of the building, such as: building geometry, construction materials, HVAC and lighting components, equipment sizes and efficiencies, operating schedules, control strategies, plug loads, etc.
- **Post-Installation Model:** The post-installation model is a computer simulation of the building as it would exist, if the proposed ECMs were installed. This model is typically generated by adding the proposed ECMs to baseline model and re-running the results. Only the parameters associated with the new ECMs are different between the baseline model and the post-installation model.
- **Calibrated Model:** A calibrated model is capable of predicting the whole-building, subsystem, or individual compnent energy consumption and demand, as compared to actual measured energy consumption and demand, to within certain statistical tolerances.
- **Adjusted Model:** Calibrated models may be adjusted to a common set of conditions so they may be compared to one another fairly. Common adjustments are to post-installation

conditions (weather, schedules, etc.) to calculate avoided energy use, or to a common set of weather conditions such as TMY, to calculate normalized savings.

- **Initial Savings Estimation:** The initial savings estimation is the difference between the energy consumption and demand of the calibrated baseline model and the post-installation model.
- **Verified Savings:** Also known as 'avoided energy use,' the verified savings estimation is the difference between the energy consumption and demand of the calibrated baseline model and the calibrated post-installation model (both under under post-installation conditions). It may also be determined from the difference in the calibrated baseline model (under post-installation conditions) and measured post-installation energy use or demand.
- **Normalized Savings:** The normalized savings estimation is the difference between the energy consumption and demand of the calibrated baseline model and the calibrated post-installation model, projected to a common set of conditions such as a typical meteorological year (TMY). This would then be the savings for a typical year, instead of a specific year.

7.1.3. Procedure

Figure 7-1 shows how Method 4's verification process is integrated with an EBCx project. In the baseline period, the simulation process begins with the development of a building model based on building plans and specifications, and discussions with the building operators, occupants, and maintenance personnel. Once the building shell, equipment and systems are described, its set-points, load shapes, and schedules are input, the model is then run with actual climate data corresponding to the utility data used for calibration.

At this point, the model results are compared to the monthly energy values obtained from historical energy bills. Comparison of electric consumption and demand between the model and the energy bills are determined. Typically, if large discrepancies (greater than 10%) exist for any month, further tuning is performed. Note that most building energy simulation software reports energy use by the hour and month, utility bills will need to be normalized to monthly totals for comparison to software output.

In addition to the normal procedure outlined above, detailed end-use data provided by submetering and/or building automation trends can be used as part of the calibration and fine-tuning process during the model's development. Simulation outputs of individual systems performance are compared against measured data from the BAS. Checks are made on simulated system operations assumptions and adjustments are made. The process is repeated until acceptable results are achieved.

Calibrated simulation can be used to estimate the savings from multiple ECMs on a facility at the whole building meter level. However, in contrast to whole –building meter level analysis, calibrated simulation can also be applied to estimate the savings of individual ECMs in a multiple ECM project by isolating the ECM and performing multiple runs within the model.

In the post-installation period, avoided energy use or normalized savings may be determined. The calibrated baseline model is adjusted to post-installation conditions to verify the actual savings achieved. Development and use of a calibrated post-installation model allows both baseline and post-installation energy use to be stated under a common set of conditions. This is often necessary when the post-installation monitoring period for the data used to calibrate the post-installation model is shorter than one year.

The step-by-step details of developing and calibrating the baseline model are provided below.

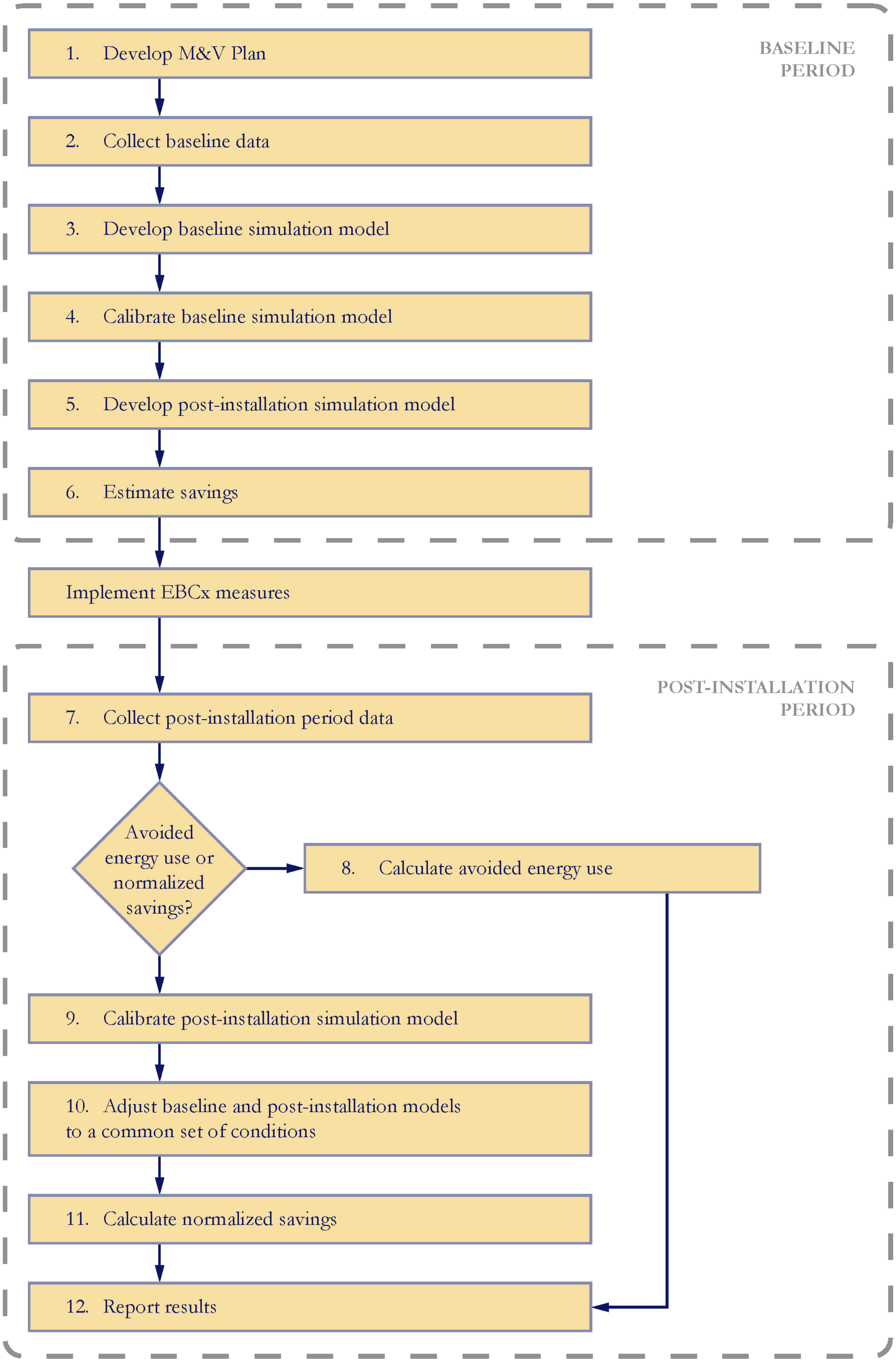


Figure 7-1: Method 4 process flow chart

Step 1: Produce a calibrated simulation M&V plan.

First, create a plan so that the basic parameters of the model calibration effort can be defined and documented. The plan should document the baseline scenario of the existing building prior to installation of the proposed ECMs, and the post-installation scenario with the ECMs installed.

Document the simulation software and version to be used and whether the model is to be calibrated using monthly and hourly energy use data, and measured building susbystem energy use data, or any combination of them.

The minimum amount of required baseline data includes 12 consecutive months of metered whole building energy use and the corresponding hourly weather data for the same billing periods. For the typical existing building project historical utility data is usually available. Depending on the systems improved by the EBCx project, short-term trend data of subsystem energy use and operational parameters should also be collected.

The plan defines the basis of comparison (whole-building energy use, subsystem energy use), time interval (hourly, daily, weekly, monthly) and the tolerance of the statistical calibration indices. ASHRAE compliance requires monthly calibration to a maximum 15% CV(RMSE) and 5% NMBE (and hourly calibration to a maximum 30% CV(RMSE) and 10% NMBE if used) is required. Refer to ***7.2 Analysis Methods*** (page 88) for more detail about statistical indices.

Though the effort adds cost, taking spot and short-term measurements can increase the accuracy of calibrated models by allowing for the detection and correction of possible off-setting errors within the model that would not be detected by monthly calibration. The plan should describe the selection and implementation of any spot and short-term measurements.

Step 2: Collect baseline data.

Obtain building plans.

Obtain the best building plans available and confirm as many construction and operating details as possible on-site. In an existing building retrofit project construction documentation may be complete and updated, or non-existent, or in some in-between state. As-built drawings are best but field confirmation of construction material and building geometry is required. Document any external conditions affecting the site such as shading from landscaping or adjacent structures.

Collect and review utility data.

Collect at least 12 consecutive months (and additional whole years if available) of metered whole building energy use (electric, natural gas, etc.). Additional hourly or smaller interval data can be requested from the utility (sometimes for a fee), or can be gathered through the BAS, utility meters (if capable), portable data logging equipment, or other permanently installed equipment.

Utility bill information will often have to be normalized into complete months for easy comparison with model output.

Prepare for data collection as defined in the simulation plan.

Since there is a large amount of data to collect from the site and since project budget or location may not allow for multiple visits, it is important to organize data collection forms, procedures, etc, ahead of time. A well developed plan helps identify the important information to be gathered in the field.

Conduct on-site surveys.

Conduct on-site surveys to characterize all energy using or energy influencing features and operations of the building including: lighting, plug loads, HVAC system, building envelope, and building occupancy. Collect all relevant information regarding sizes, capacities, schedules, control sequences, etc. Much of this information should already be documented as part of the EBCx project investigation. In completing this step, complete understanding of the rest of the building's systems and equipment that were not part of the EBCx project will be obtained.

A knowledgeable modeler or field engineer will know what inputs are required by the modeling software and will be sure to collect the most relevant information to adequately model the building and proposed ECMs.

Interview operators and occupants.

Interviewing operators and occupants is another area of overlap between the EBCx project, and setting up a calibrated simulation. Operator interviews can confirm schedules, occupancy, and other important details. These interviews will often provide insight about potential ECMs or other corrective action the building could benefit from, since the people working in and using the building daily are often most aware of ongoing problems and special conditions that may exist. However, it is often good practice to confirm whether this kind of antidotal evidence can be supported directly by data.

Conduct spot and short-term measurements.

System submetering facilitates the calibration process and substantially enhances calibration accuracy and is strongly recommended for more intensive M&V programs. Submetering facilitates the calibration of individual pieces of equipment, systems, or end uses. Due to the wide variety in types of measurements and their duration, the project specific plan should be based on the expertise and judgment of the modeler.

In addition to monthly or interval utility data, submetered energy data, or data from portable power loggers, or building automation trends provide the basis of additional calibration resolution. This end-use data is used to compare the model's prediction of building's subsystem performance with actual energy and operational data from the building.

The subsystem energy use data should be collected in a format that will be easily compared to the output of the modeling software. Typical end uses reported by modeling software may include: heating, cooling, ventilation, fans, pumps, lighting, plug loads, cooking, process loads, domestic hot water, refrigeration, etc. The measured and monitored subsystem data must be reported in comperable end-use categories and reporting frequencies.

Collect weather data.

Weather data for the baseline model may be available through historic building automation trends of ambient dry-bulb temperature, wet-bulb temperature, and/or relative humidity. Most modeling software can also use data for solar irradiance (which will impact predictions relating to solar gain). If on-site weather data is to be used, it should be recorded by the same equipment in the same location for both the baseline and post-installation periods. For on-site weather data collection it is useful to compare to data from the nearby weather station and check for sensor failure or calibration drift.

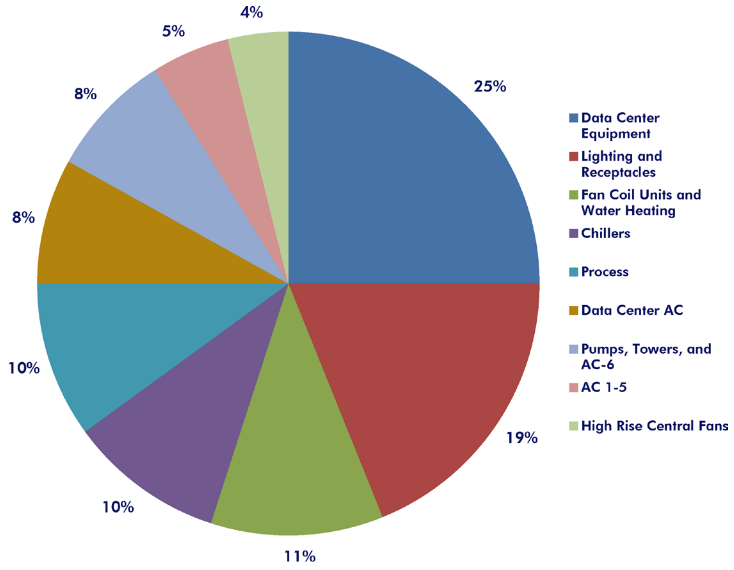


Figure 7-2: End-use breakdown

A "Class A" site as defined by the National Oceanographic and Atmospheric Administration (NOAA) is one employing measurement devices and techniques equivalent to those defined by NOAA. Typical sources of "Class A" site weather data may include local airports and military bases.

In the absence of reliable on-site weather data collection this data may come from a reliable source such as municipal airport or military base if the installation is close enough to the project site that the local weather conditions are considered identical.

Collection of actual site weather data is required so that the model can be calibrated to the energy use data and the corresponding weather data for that period. If the model is to be projected to a common set of conditions such as a typical meteorological year (TMY) to predict "normalized savings" this weather data is also required. Several sources of TMY weather data are available including: ASHRAE (WYEC2), and National Renewable Energy Laboratory (TMY2 and TMY3).

A custom weather file will need to be created from the collected weather data and applied in the simulation. At a minimum, an hourly weather file corresponding to the period of energy use data is required for model calibration.

Step 3: Develop baseline simulation model.

Most building simulation software programs have graphical user interfaces (GUIs) that facilitate development of building energy models. These GUIs allow users to describe the building's physical systems, orientation, location, and so on based on the software's library of information as well as information provided by the user. Other software programs allow the user to input this information through an extensive data input file, which is a much longer and laborious process. Even when the building description is assisted with GUIs, familiarity with the software is essential.

Correctly input as much model information as possible from known values or information, minimize the use of standard "default" values within the model inputs. Model the HVAC systems and zoning as closely as possible to the actual conditions. If the exact HVAC system is not available within the software program a "work around" may be required to model the system. In this case care should be taken to ensure the system is meeting the set-points. Comparison of simulated zone temperatures with actual readings can help confirm that the model is working properly and the HVAC system is meeting its requirements. Similarly, comparison of proper lighting levels and fixture types with physical observations should confirm the model is correctly representing lighting requirements. The modeler should be as thorough as possible when comparing model predicion of building system performance with actual measurements. The important variables or parameters used to describe proper system operation and should be measured should be identified in the M&V plan. Assumed values may be used when their influence is low.

Once a working model is developed it typically needs to be run several times in order to debug errors in the input file. Carefully review the input and output files to ensure information was entered properly and results are reasonable.

Architectural Rendering

The geometry and representative zoning for an energy model is illustrated in Figure 7-3. It is important to confirm that the architectural rendering of the building using the model inputs is an accurate depiction of the actual building. Proper zoning is important for accurate HVAC simulation.

Software packages may include an architectural rendering package which allows for viewing of a 3-D model of the building as its input. This is particularly helpful in ensuring the modeled building is a good representation of the actual geometry, zoning, and construction of the real building.

However, it may be possible to avoid the inputting of large amounts of building data. An example would be a central plant feeding multiple buildings on a college campus. If appropriate historical data is available, such as the plant load, ambient temperature, etc., it may be possible to build the central plant within the software and apply an annual load profile on the plant based on the historical data. Plant ECMs energy impact could then be predicted without ever inputting the individual building characteristics.

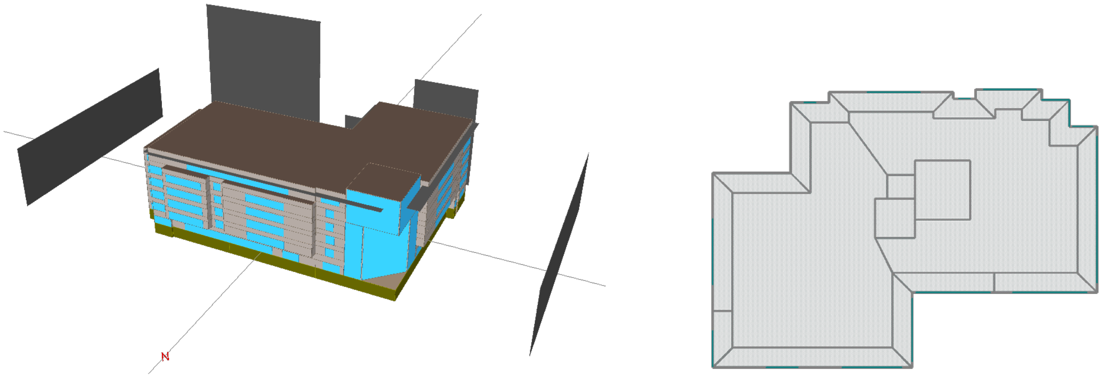


Figure 7-3: Graphic representation of the DOE-2 energy model

Converting Lighting and Receptacle Loads into Simulation Program Inputs

Information gathered in the field must be converted into a form that will be accepted by the modeling software. Values and schedules input into the energy model may be derived from spreadsheet analysis of submetered data. Daily schedules of diversity factors for typical loads are illustrated in Figure 7-4.

The graph shows the need for developing hourly schedules for lighting and plug load power density, they must be entered in at least an hourly format, as demonstrated in the graph, the simulation software will calculate the energy use typically based on a maximum density such as W/sqft multiplied by the percentage factor for the particular hour.

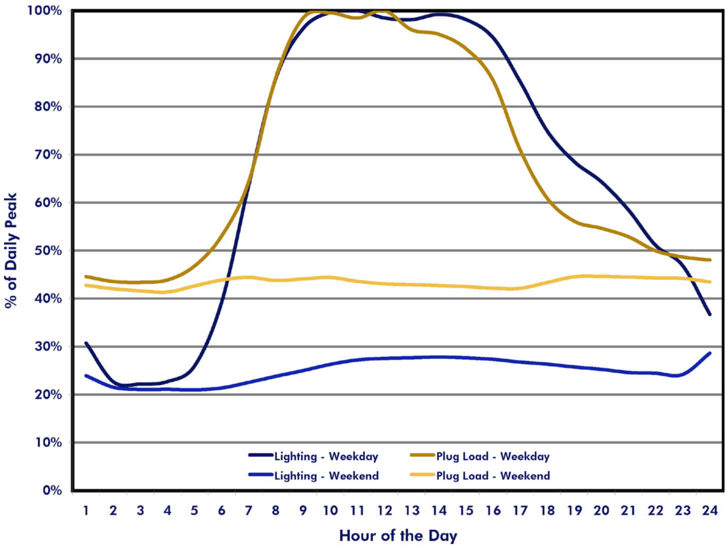


Figure 7-4: Internal loads and schedules

Debugging Models

Debugging models can be time-consuming so it is important to check both the simulation inputs and outputs for quality control. Parameters to check for simulation inputs include: building orientation, zoning, external surface characteristics, lighting and plug load power densities, operating schedules, HVAC system characteristics and plant equipment characteristics. For simulation outputs check that: HVAC systems satisfy heating and cooling loads, lighting and equipment schedules are appropriate, fan schedules are appropriate, ventilation air loads are appropriate, HVAC plant efficiencies are appropriate.

Step 4: Calibrate baseline simulation model.

Model calibration is achieved when the simulation's prediction of energy use matches, within specified criteria, the measured energy use. Calculation and application of these calibration criteria are described in ***7.2 Analysis Methods*** (page 88). The total building energy use and demand predicted by the simulation models may be calibrated to monthly utility bills, and the model's prediction of a building subsystem's energy use may be calibrated to measured energy use. Because monthly utility bill data is usually available, calibration at the whole-building level is the most common calibration method used.

When 15-minute electric data from building electric meters are available, additional levels of calibration may be achieved.

1. Hourly energy use of the building simulation may be compared with measured hourly energy use in the same way as for monthly data. Adjustments are made to the model inputs until the comparison is within the specified criteria.
2. Hourly whole-building energy use generated from the simulation for a typical day of operation may be plotted along with actual hourly energy use generated from the 15-minute data. A calibration requirement is met when the two profiles match within specified tolerances. This comparison of daily load profiles should be carried out for each characteristic operational day type of a building.

To increase confidence in the building simulation model's ability to estimate savings accurately, the model's prediction of building subsystem energy use may be calculated to measured data. This requires:

1. The energy using components included in the simulation's definition of subsystem be identified. Most simulations define energy end-uses, such as heating, cooling, and ventilation energy use, and so on. All components for each of these end-uses must be defined. For example, the ventilation end-use is defined as all air-handling fans in a building's air distribution system.
2. Energy use of each of the components must be measured over a period of time representative of its operation. This data must be compiled and normalized to the same time interval as the simulation output before it can be compared.

Requirements for calibration of the baseline energy simulation should be documented in the M&V Plan.

Step 5: Develop post-installation model.

The post-installation model is developed from the calibrated baseline model by modifying inputs that describe the building subsystem characteristics or operations that will improved by the EBCx project. EBCx projects improve building operations without requiring major retrofits. Changes may include:

- extending control system capabilities (I/O points, additional controllers, new sequences) to enable new control strategies and control capability,
- reprogramming control system sequences of operation,
- repairing disfunctional equipment such as linkages, dampers, valves, and actuator motors,
- rebalancing air flows in air distribution systems,
- adjusting operation schedules

The simulations inputs are modified to model the EBCx improvements, and saved in new input files. See Step 6 for the recommended modeling sequence for estimating savings for each ECM.

Step 6: Estimate savings.

The difference between the annual baseline energy use predicted by the calibrated baseline model, and the annual post-installation energy use as predicted by the post-installation model, are the estimated savings expected from the EBCx measures. This difference may be calculated for whole-building energy use as well as building subsystem energy use, depending on project requirements.

If the total energy savings is to be disaggregated to report on the impact of each individual ECM and its interaction with the other ECMs, several sequential runs will need to be made. The first run contains only one ECM and successive runs each add one more ECM until the last sequential run that contains all ECMs.

The estimated energy savings for each ECM identified in the EBCx project should be determined by successive runs of the post-installation model. In order to properly assess the contribution and interaction of the ECMs the order in which the ECMs are applied and bundled in the sequential runs is important. Typically the ECMs are ranked in order of either energy savings, or likeliness of being installed. In this way the results of the most likely installed project are calculated.

A logical order of EBCx ECMs is described as follows. Generally, changes affecting building loads such as adding widnow film, reducing lighting loads, or reducing occupancy schedules are modeled first. Next are modifications to systems that directly interact with the building loads, such as air handling systems. These changes may include repair of malfunctioning VFDs or elimination of simultaneous heating and cooling in the building zones or terminal boxes. Last are modifications to central systems that serve the air handlers, such as chilled or hot water systems. Central system changes may include modifications to chilled water supply temperatures, chiller staging sequences, or repair of non-functioning variable flow systems.

The procedure is to start with the calibrated baseline simulation and modify the input files to model the first ECM. Then run the model and save the output, which is the post-installation model's prediction of energy use including the first ECM. Subtract the annual energy use predicted by the calibrated baseline model from that of the post-installation model with the first ECM. This will yield the savings estimate for the first ECM.

For each successive ECM follow the same procedure, using the previous model's output as the baseline for the new simulation with the next ECM. Determine the savings for each ECM by subtraction of the new model run from the previous model run. Save each file generated in this process separately.

Each ECM's savings are used to determine their cost-effectiveness, and documented in a report to review with building owners and other involved parites. The list of measures for implementation is then selected. If this list includes fewer ECMs than were previously analysed, the savings estimation process is re-run without the unused ECMs to get the final estimated savings amount. The selected ECMs are then implemented.

Step 7: Collect post-implementation data.

After the ECMs are implemented and their operations verified as meeting their expected impacts, the same data used to identify the individual ECMs and calibrate the basline simulation model is collected. The conditions and duration of data collection under which savings are to be determined must be specified in the M&V plan.

The next step is based on whether the energy use will be stated as "avoided energy use" or "normalized savings." If avoided energy use is selected, proceed to Step 8. If normalized savings is selected, proceed to Step 9.

Step 8: Calculate avoided energy use.

Calculation of avoided energy use requires that the calibrated baseline model be re-run under post-installation conditions. These conditions usually include ambient temperture, and any changes to building occupany or equipment operation schedules. Actual temperatures must be used to determine the adjusted baseline energy use under post-installation conditions.

Avoided energy use, or savings are determined by subtraction of measured energy use from the adjusted baseline energy use from the simulation. This determination may be done at the whole-building level, or individually for separate end-uses, depending on the amount of sub metered data collected. Note that only the cumulative savings for all ECMs may be verified when using only whole-building energy use measurements. When building subsystem energy use is measured and compared with adjusted baseline model predictions of end-use energy, the collective savings of each end-use is determined. Separate verification of individual ECM savings isn't possible using this approach.

Determination of annual savings using this method requires that data be collected for one year. If this is not feasible, then a modified normalized savings approach should be used.

Step 9: Calibrate post-installation simulation model.

The post-installation model with simulation inputs for only the installed ECMs (as determined at the vey end of step 6) is calibrated to actual post-installation energy use data collected from the building. The calibration requires measured energy use and other data such as ambient temperatures, building occupancy, and equipment schedules.

For adherence to IPMVP, a year of data should be collected and used to calibrate the post-installation model. However, project schedule requirements often dictate that savings must be verified in a much shorter time perod. Often, only three or six months of data may be collected. The duration and extent of post-installation data collection required for calibration of the post-installation model must be proposed by the simulation expert, and agreed-upon by involved parties.

Post-installation model calibration is done in the same way as described for the baseline model. The model may be calibrated with whole-building monthly energy bills, or with measured building subsystem energy use. Use of available 15-minute data will help with the model tuning process.

Step 10: Adjust baseline and post-installation models to a common set of conditions.

Calculation of normalized savings requires that both the calibrated baseline model and the calibrated post-installation model each be adjusted to a common set of conditions and re-run. These conditions usually include ambient temperature, as provided in typical meterological year (TMY), but may also include building occupancy, equipment schedules, and other conditions as agreed in the M&V plan. Generally, a full year of TMY data is available for the climate zone where the building is located.

Step 11: Calculate normalized savings.

After the baseline and post-installation calibrated models have been re-run with a common set of conditions, the normalized energy savings may be determined. Normalized savings are determined by subtraction of the energy use predicted by the adjusted post-installation model from that of the adjusted baseline model. When the baseline or post-installation models have been calibrated with less than a full year of data, the normalized savings result is not adherent with IPMVP.

Savings may be calculated from the difference in whole-building energy use of each model, or they may be calculated individually for the separate end-uses of interest. Note that only the cumulative savings for all ECMs may be verified whether comparing only whole-building energy use or building subsystem energy use. Separate verification of individual ECM savings isn't possible using this approach.

Step 12: Report results.

The final step in the calibrated simulation process is to report the results in the format outlined by the plan. The report should contain an executive summary, baseline building conditions, measure descriptions, simulation plan, methodology, observations, results, and appendices.

7.1.4. Persistence

Depending on the owner's or program managers objectives, the owner's facility operations personnel or the commissioning provider may be engaged over a multiyear term to make sure energy savings last for their expected lifetimes. This is the basis for a persistence phase in the verification process. Should persistence phase activities be required, the tasks are essentially the same as in the post-installation phase. These tasks include verification of continued operational performance, tracking energy performance over time, and periodic savings reporting. Specific to this method, two additional steps representing the persistence phase are added. These steps are not shown on the flowchart in Figure 7-1.

Step 13: Verify equipment continued performance.

Once the EBCx project is complete, the operational verification steps taken in the post-installation phase should be repeated in regular, predefined intervals such as quarterly to insure continued performance. Requirements for verifying improved operation depends on each individual recommendation that was installed, and may include simple visual inspection, trending and analysis of operational data, or functional testing. These activities were described in ***4.3 Field Verification Approaches***. Meters and sensors should also be periodically inspected and calibrated to ensure accurate data is collected.

Step 14: Verify continued energy savings.

The calibrated baseline energy simulation model may be used to account for savings over time. This requires that the input parameters used to determine baseline energy use under post-installation conditions be input into the calibrated baseline model. Such parameters may include: ambient temperature, building operation schedule, and building occupancy characteristics. The adjusted baseline energy model is re-run to determine baseline energy use under these conditions, and periodic savings reports are generated from the comparison of baseline energy use and measured energy use. Savings calculations are performed in the same way as described in Step 8. This process may be done for both whole-building energy use as well as system energy use, depending on the project's objectives. Savings should be reported at least on an annual basis.

Alternatively, the post-installation model may be used for checking and maintaining ongoing energy performance of the building. In this case, the measured parameters are input into the post-installation model and the predicted energy use of the building, or of its systems, are compared with measured energy performance. Significant negative deviations (that is, when measured energy use is greater than simulated energy use) indicate a need to investigate why energy performance has degraded. When comparing simulated system energy use with measurements, the poorly performing systems are immediately identified.

7.2. Analysis Methods

The process of developing a whole-building or a building system energy simulation model requires intimate knowledge of the building in order to model it properly, and close familiarity with the available energy and operational data in order to properly calibrate the model. The following section describes the criteria that may be applied to check and improve model calibration.

7.2.1. Calibration Methods and Criteria

Using graphical comparison techniques is often helpful in determining where a divergence between the metered data and the simulation model exists. For example, a comparison between the measured data and the simulation may show a consistent over-prediction in morning warm-up heating. This can lead the modeler to refine inputs that influence morning warm-up heating, and create a better representative model.

Though these graphical techniques are important in indentifying the areas of the model that are not in good agreement with the measured data, the ultimate judgment of whether the model is calibrated or not comes down to meeting the tolerances of the statistical indices as defined in the plan.

Common statistical indices defining model calibration are outlined in ASHRAE Guideline 14-2002, 5.2.11.3, p.15. They are: Coefficient of variation of the standard deviation (CVSTD), Coefficient of variation of the root mean square error (CVRMSE), and Normalized mean bias error (NMBE). These indices represent how well a mathematical model describes the variability in measured data when comparing the results of a calibrated simulation to the utility data.

Equation 7-1: Common Statistical Indices Defining Model Calibration

$$CVSTD = 100 \times [\sum (y_i - \bar{y})^2 / (n-1)]^{1/2} / \bar{y}$$

$$CVRMSE = 100 \times [\sum (y_i - \hat{y}_i)^2 / (n-p)]^{1/2} / \bar{y}$$

$$NMBE = \frac{\sum^{n} (y_i - \hat{y}_i)}{(n-p) \times \bar{y}} \times 100$$

where:

n = number of data point or periods in the baseline period

p = number of parameters or terms in the baseline model, as developed by a mathematical analysis of the baseline data

y = dependent variable of some function of the independent variable(s)

$\bar{y}$ = arithmetic mean of the sample of n observations

$\hat{y}$ = regression model's predicted value of y

Source: ASHRAE Guideline 14-2002

Energy model results are compared to the monthly energy consumption and demand values obtained from historical energy bills and/or detailed end use from the submetering as part of the calibration and fine-tuning process during the model's development. Calibration plots that demonstrate the monthly correlation of electric consumption and demand between the energy model simulation and utility bills are presented in Figure 7-5.

The calibration process steps are as follows:

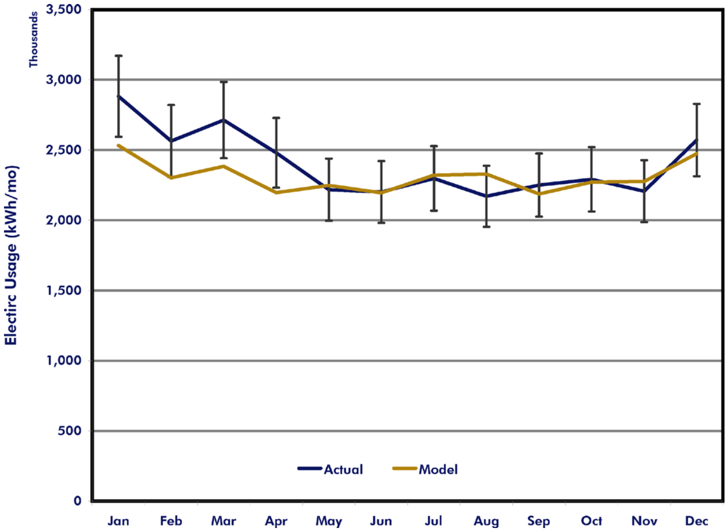
1. Collect as much relevant calibration data as possible. 12 months of utility data is the minimum. Hourly or interval utility data provides greater accuracy. Additional information

such as user-defined part load curves generated from trend data help to calibrate specific end uses or individual pieces of equipment.

2 Assume and document any other inputs required. It may be necessary to assume certain parameters that are difficult or cost prohibitive to measure directly, building infiltration being an example.

3 Run the simulation and verify that the results are reasonable. Typically a room or zone is examined in detail to assure that the simulation is providing accurate results.

4 Compare simulated energy consumption and demand to the utility data at a monthly or hourly basis. Actual weather data must be used. Time-series graphing and the use of error bars are helpful here, refer to Figure 7-5. Calculate statistical indices and compare with prescribed limits. If these values exceed the limits, make adjustments to the model and try again.



Note: Error bars indicate +/-10% deviation in monthly consumption

Figure 7-5: Electrical consumption comparison

5 Compare simulated energy consumption of selected building subsystems to measured energy use data. Compare the energy use of the simulation and the measured data over a representative time period, such as a week. Calculate the statistical indices and compare with the prescribed limits. Make model adjustments and repeat the process if the indices are not within specifications.

6 Repeat the process by iteratively replacing assumed or stipulated conditions with actual building operating data until the level of agreement between the predicted and actual energy use are with the acceptable calibration tolerances.

7.2.2. Refine Model Until an Acceptable Calibration is Achieved

Model calibration often involves numerous iterations to achieve the required calibration tolerances. It is often better to calibrate from the system/zone/equipment level up rather than from the whole building level down. This is because if calibration to the monthly level is done first and the results are not within tolerances, there is not a clear direction for the modeler to pursue the portion of the model that is not a good prediction of the measured values. Whereas calibration of subsystems or equipment first identifies the portion of the model that is not performing and corrections can be made to improve the model before aggregating end uses and eventually the whole building energy use.

7.3. Requirements and Costs

7.3.1. Hourly Simulation Programs

An energy baseline for the whole building or subsystem can be established through the use of an 8,760 hourly simulation program such as DOE-2.2, eQuest, EnergyPlus, or similar software capable of modeling the whole building or subsystem using hourly weather files. A complete list of available energy simulation programs is maintained by the Department of Energy and can be found at http://apps1.eere.energy.gov/buildings/tools_directory/

The hourly simulation program calculates hour-by-hour facility energy consumption and demand over an entire year (8,760 hours) using actual hourly climate data for the location under consideration. Inputs consist of detailed descriptions of the buildings being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. Programs are capable of accurate simulation of such building features as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air-conditioning system types and controls.

Other aspects to consider when choosing an appropriate software include: whether the software is commercially available, well documented, and supported; it is capable of modeling the building and desired ECMs; it can be calibrated to an acceptable level of accuracy, and the calibration can be documented; and whether the software libraries of equipment, systems, and control strategies are a good match for the building and ECMs in question.

7.3.2. Personnel

Two main skill sets are needed for the proper application of calibrated simulation from a labor resource perspective. The project will require both a skilled retrocommissioning field engineer, and an experienced modeler familiar with the simulation software to be used. They may be, but are rarely the same person.

A skilled field engineer is required to identify the appropriate ECMs, and to specify their intent, and methods for implementation, commissioning, and verification. This engineer should be familiar with the project building's equipment, operating parameters, specific control strategies and sequences. The field engineer also needs to be skilled at collecting additional building information that the modeler may need for calibration. Data collection skills can include: setting up and retrieving building automation trends, setting up and retrieving portable data logger's trends, post processing of data, and development and execution of functional performance tests.

As model calibration can be difficult and time consuming, the skill level of the modeler is an important consideration. A competent and experienced modeler will be able to determine if the building construction and operation can be reliably modeled within the simulation program. As well, the modeler needs to understand how to model the proposed ECMs and that they can be reasonably predicted by the simulation software chosen.

A strong working relationship between the field engineer and modeler is also useful. The modeler may know what information is needed to improve the accuracy of the model, but may rely on a field engineer to collect the required information.

7.3.3. Costs and Budget

The cost of implementing calibrated simulation is dependent on the following factors:

- The size and complexity of the ECMs, system, or building.
- The required degree of accuracy in the savings determination.

- The simulation software utilized and its associated complexity.
- The extent and sophistication of the submetering.
- Cost of the building simulation expert and any other field engineering support.

As with other M&V options the rigor and associated cost must be balanced against expected savings and the significance of potential error. It is important to realistically anticipate cost and effort associated with completing metering and data analysis activities. In most cases, improving accuracy by any means increases M&V cost. Such extra cost should be justified by the value of the improved information.

Depending on the scale of the project and its complexity a calibrated simulation will require several man-weeks to several man-months of labor to complete. This can result in a project cost of tens of thousands of dollars or more.

Appendix A: List of Acronyms

Acronym	Meaning
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BAS	Building automation system
BCA	Building Commissioning Association
BHP	Brake horsepower
BTU	British thermal units
CCC	California Commissioning Collaborative
CFM	Cubic feet per minute
CLCH	Constant load, constant hours-of-use
CLVH	Constant load, variable hours-of-use
CV	Coefficient variation
CVSTD	Coefficient of variation of the standard deviation
CWST	Condenser water supply temperature
DCV	Demand controlled ventilation
DOE	Department of Energy
EBCx	Existing building commissioning
ECAM	Energy charting and metrics
ECM	Energy conservation measure
EIS	Energy information system
EMCS	Energy management and control system
EVO	Efficiency Valuation Organization
FEMP	Federal Energy Management Program
GPM	Gallons per minute
HHWST	Heating hot water supply temperature
HVAC	Heating, ventilation, air conditioning
IPMVP	International Performance Measurement and Verification Protocol
kW	Kilowatt
kWh	Kilowatt hour
M&V	Measurement and verification
MAT	Mixed air temperature
NBE	Net determination bias error
NMBE	Net mean bias error
NOAA	National Oceanographic and Atmospheric Administration
OAT	Outside air temperature
RAT	Return air temperature
RMSE	Root mean squared error
SAT	Supply air temperature
TAB	Test and Balance
TMY	Typical meteorological year (or typical mean year?)
TOU	Time of use
VFD	Variable frequency drive

Acronym	Meaning
VLCH	Variable load, constant hours-of-use
VLVH	Variable load, variable hours-of use

Appendix B: Data Sources and Management

BAS as a Source of Data

The building's building-automation system (BAS) is a primary focus of most commissioning projects. During EBCx investigations, providers identify and gather the list of control and monitoring points, and identify the sequences of operations. EBCx providers often test that these sequences are fully operational as part of the commissioning process, through examination of data collected with control system trending functions. Before establishing trends, or after an initial set of data is collected, monitored points should be checked for calibration to ensure that the collected data are accurate.

A BAS's ability to trend and store data varies widely depending on the manufacturer, installed capabilities, and vintage of the system. EBCx providers are well aware that programming trends and recovering trend data on many BASs can be a very cumbersome process, requiring a controls technician familiar with the system. Trends are seldom stored in a database format that is accessible without use of proprietary software. There may be data storage limits to a system's trending capability, requiring frequent downloading of data before the trend file is halted, reset, or overwritten. Establishing many trend functions may slow down the BAS's ability to perform its prime function. While use of trended BAS data is a rich source of data, these real limits often hinder the effort for both EBCx and M&V purposes. As these issues with the BAS's trending capabilities are discovered, EBCx providers can assess its reliability as a source of data for energy analysis. This can also provide motivation for upgrading BAS capabilities.

More recently manufactured BASs are responding to the market's need for more trending capability, more storage capability, and easier access to the data. BASs not only provide valuable data, but may also serve as an energy tracking system to help maintain good energy performance, and roll up achieved savings, long after the commissioning provider has completed the EBCx project.

- For short time interval data, such as 15-minute data, a large amount of data must be collected. This can tax a BAS's capabilities, both in the number of simultaneous trends required, and the amount of data to be stored. This can slow down the clock speed on many BASs, resulting in poor control of the building's systems, inhibiting its ability to satisfy its primary function. Many BASs are more robust and can handle this task without detrimental effects. Issues to watch for are:
  - Overwriting of data after a specified limit of data is reached. Some BAS trend files are limited in size, and will be set to override the initial values after the size limit is reached. Many systems default to this method of data collection.
  - Limited number of points included in trend files. Many systems only record one point at a time, others can record up to ten points at a time. For system M&V approaches, multiple such files may be needed.
  - Some BASs record data in proprietary formats, unreadable to most common software. Check to verify that the BAS can export data in readable formats.

Data Management

The M&V methodologies described in this guideline require large amounts of data. For example if baseline energy models are based on hourly data for an entire year, there will be at least 8,760 data points for each variable in the analysis. When working with large data sets it is important to have good quality control procedures so that the analysis is based on the best datasets available. Following is a brief list of the major issues that should be anticipated and addressed when working with large data sets.

- **Data Gaps.** Gaps in data occur often when continuously monitoring data. Such gaps arise due to sensor failures, transmission interruptions, or other issues that are particular to the data collection system. Data gaps can be addressed in two ways.
  - If the gap does not last excessively long, for example it lasts only a few measurement intervals, the missing data can be "filled in" by interpolating between the data points of the two bordering intervals. This generally applies for both energy and temperature variables.
  - If the gap is longer and interpolation would not yield representative data values, consider eliminating the missing time interval from the analysis. If too much data is removed however, the monitoring period should be extended.
  - Please consult the CPUC's "Direct Access Metering and Data Handbook"[34] for further information.
- **Erroneous Data.** Erroneous data is data that are clearly outliers from expected values, long series of duplicate data values when variations are expected, corrupted or null value data, and data from sensors that are clearly out of calibration, and so on. The data should be checked to make sure their values are consistent with what is expected. For example, when monitoring power the data can be corrupted temporarily if a voltage lead becomes disconnected, or an ambient temperature sensor can be affected by direct sunlight. There are various techniques to identify erroneous data.
  - The data can be screened to determine maximum and minimum values. Comparison of these values with what is expected can identify problems.
  - Applying a summation or mathematical function to the data in a spreadsheet program can identify the presence of non-numerical information.
  - The data can be graphed, and erroneous data identified.

  Similar to the treatment of data gaps, the erroneous data should be eliminated and interpolated values used in their place. The data can also be removed from the analysis altogether. Often, the cause of the erroneous data should be identified and removed, and the monitoring period extended in order to obtain reliable data for analysis. This is costly as it can require returning to the site to collect more data, and emphasizes the importance of good planning and monitoring techniques.

It is rare that one monitoring system will collect all the required data streams, and neatly pair them for each time stamp. Often the monitoring time interval is not uniform for each data stream. In addition, the data must be prepared for the time interval used in the analysis. This requires for example that shorter time interval energy data (15-minute) be summed to the total for the selected analysis time interval (an hour or a day), and the shorter time interval temperature data be averaged over the analysis time interval period. To use the methods described in this guideline, the data must be neatly aligned with the same time stamp for the selected analysis time interval.

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[34] Pacific Gas and Electric Company, San Diego Gas & Electric, Southern California Edison, February 23, 2005 Available at: www.pge.com/includes/docs/pdfs/b2b/customerchoice/espresourcecenter/handbook_directaccessmetering.pdf

Transparency of all collected data and calculations is a guiding principle of the IPMVP. This means that due diligence review of all data collected, data quality control procedures performed, baseline model development, savings and uncertainty calculations must be able to be reviewed by knowledgeable parties. These parties include an owner's representative, or an energy efficiency program manager's in-house technical team. In California, the data and analysis may also be reviewed by the evaluation measurement-and-verification (EM&V) contractor in a process which ultimately determines the cost-effectiveness of publically funded energy efficiency programs.

Transfer of the collected data, quality control processes, and all analysis used to calculate savings creates a diverse set of requirements. These requirements can be fulfilled with some common software applications. Three common applications and their ability to address the requirements of data storage, analysis, and transferability are described below.

- **Spreadsheet Programs:** Most common spreadsheet programs are capable of handling large data sets, and many of the quality control procedures listed above. Microsoft Excel™ can include over 65,000 data records, and has mathematical and statistical functions, as well as graphing tools that are very useful for identifying data gaps and erroneous data. Most quality control processes, data set merging, and time stamp alignment requirements are performed manually within the spreadsheet, unless programming through macros or Visual Basic™ can be developed. Spreadsheet programs allow annotations and summaries of analysis steps to be described within the spreadsheet so that they can be reviewed when opened. This facilitates third-party review of data and calculations, as most reviewers have access to the same spreadsheet software. However, multiple manipulations of data sets in spreadsheets rapidly increase its size. This slows down the spreadsheet's performance. Spreadsheets also take up large amounts of electronic storage space.
- **Database Programs:** Databases are designed to store large amounts of data and minimize impact on the available storage space. However database programs do not typically include analysis tools. Many required tools can be purchased separately or programming environments within the database application can be used to create the required tools and procedures. Descriptions of data, merging and quality control procedures should be documented separately. While databases are logical choices for storing data, third parties are not likely to have the same software and tools to review them. The EBCx service provider would have to summarize the data and calculations so that reviewers could follow the analysis steps.
- **Statistical Analysis Software:** Commercially available statistical analysis software, such as SPSS, SAS, and STATA, were developed to analyze large data sets. They provide standard statistical analysis tools, and programming environments for users to create their own algorithms. Analysis procedures can be documented within the programs so that others can follow the steps. Such software environments can compute and analyze data sets as large as the computer's active memory, which can be multiple gigabytes, without adverse impact on processing speed. They can store data in open protocol or proprietary formats, minimizing file sizes. As with database software however, it is unlikely that third-party reviewers will have the same software to be able to perform the review within the same environment. The EBCx service provider would have to summarize the data and calculations separately to facilitate the review process.

Appendix C: Tools

Data Preparation

Energy Charting and Metrics (ECAM): A free Microsoft Excel based add-in that can set up flag variables for parameters such as occupancy, hour of day, day of week, and holidays. Data can also be displayed in various predefined pivot charts for easy visualization and anaysis. ECAM was developed with funding from the California Commissioning Collaborative, and is available through its website at http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.

Universal Translator (UT): PG&E's Universal Translator is a free downloadable software capable of working with data in several different formats and various sources such as data loggers, BAS trends, and NOAA weather files. The output from Universal Translator can then be manipulated in spreadsheets or statistical analysis software. A power feature of UT is the ability to align different timestamps from the various data sources. UT is available through www.utonline.org.

Utility Consumption Analysis Tool: This tool calculates average daily energy consumption for each month based on monthly utility bills and the dates the meter was read. Energy use is prorated when billing dates do not coincide with the with calendar months. Additional data processing capabilities and graphical presentation are included. The Utility Consumption Analysis Tool is avaible through the California Commissioning Collaborative's website at http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.

Custom Calculators

Building Optimization Analysis (BOA) Tool: A Microsoft Excel-based tool that uses a few user inputs to present previously calculated energy and demand savings from several common EBCx measures in California climate zones. This tool is designed to streamline the calculation process for common measures with relatively low savings, and thus, low risk. The BOA Tool can be downloaded for free at http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.

Fan and Pump Workbooks: Inlcudes two separate workbooks designed to calculate savings from a few measures associated variable flow fan or pump systems. The fan and pump workbooks are available for free through the California Commissioning Collaborative at http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.

Custom Building Optimization Analysis (C-BOA) Tool: A Microsoft Excel-based tool that calculates custom savings using a binned approach for nine common RCx measures. This tool was funded through the 2009-2012 Public Interest Energy Research (PIER) and is available through the California Commissioning Collaborative's website at http://www.cacx.org/resources/rcxtools/spreadsheet_tools.html.

Regression Analysis

ASHRAE Modeling Toolkit (IMT): The Inverse Modeling Toolkit (IMT), developed as part of ASHRAE Research Project 1050, is available to assist in development of the linear and multivariate change-point regression models. The IMT tool kit accompanies the final report for ASHRAE's Reasearch Project-1050 which can be purchased from http://www.techstreet.com/cgi-bin/detail?product_id=1717813.

Energy Explorer: A commercially available tool that allows users to create mean, median and linear change point regression models. This software is capable of producing 3 ,4, and 5 parameter change-point models and includes a graphical environment to assist with data analysis. Energy Explorer can be purchased from Prof. Kelly Kissock, University of Dayton (http://academic.udayton.edu/kissock/Default.htm).

QuEST Energy Modeling Spreadsheet (QuEMS): A commercially available tool that allows users to create linear regressions as well as 3 or 4 parameter change-point regression models using a single independent variable. This software calculates fractional savings uncertainty in accordance to ASHRAE Guideline 14 as well as additional statistical metrics. QuEMS can be purchased at http://www.quest-world.com/engineering/software/ for $425.

Custom Spreadsheet Tools: Most spreadsheet programs provide basic functions or analysis tool packages that allow users to develop average, linear, and polynomial regression models. In Microsoft Excel, the data analysis tool pack includes a regression tool that can develop linear regressions between a dependent variable and one or more independent variables. This regression tool allows users to test the validity of each regression coefficient for each variable in the model, and helps users in the model development process. Using Visual Basic™, Excel can be programmed to determine change points and ultimately the model that best represents the data.

Simulation Tools

eQuest: A freely available front-end user interface that comes with the common DOE-2 simulation platform. Various wizards are included to help users establish the required input files for a relatively sophisticated analysis of building energy use. Various versions of this software are available at http://doe2.com/equest/.

EnergyPlus: The newest freely available whole building energy and water simulation platform. EnergyPlus was developed to address some of the shortcomings of other available building simulation tools. This software is available at http://apps1.eere.energy.gov/buildings/energyplus/.

Vendor Simulation Platforms: There are many other simulation platforms that are available for purchase from specific vendors that can be used to estimate energy savings from EBCx improvements.

Data Collection

PG&E's Tool Lending Library and SCE's instrument lending library has many hand-held instruments and metering technologies that collect energy or performance data. These tools are funded through the Public Goods charge and are available freely for use in short term energy efficiency projects.

- www.pge.com/pec/tll/
- http://asset.sce.com/Documents/Business – Services for Your Business/TLL7_2010Catalog.pdf

Other

EBCx Guidance: Several guides are available that provide information related to EBCx benefits, best practices and processes. A few of these guides are listed below:

- **Building Commissioning Association:** Best Practices in Commissioning Existing Buildings. http://www1.eere.energy.gov/femp/pdfs/bcabestpractices.pdf
- **California Commissioning Collaborative:** California Commissioning Guide: Existing Buildings, http://www.cacx.org/resources/documents/CA_Commissioning_Guide_Existing.pdf \
- **Federal Energy Management Program:** Continous Commissioning(SM) Guidebook, http://www1.eere.energy.gov/femp/pdfs/ccg01_covers.pdf

Appendix D: Data-Driven Regression Models and Statistical Indices

This appendix provides more detailed descriptions of the linear models introduced in Chapter *6. Method 3: Energy Models Using Interval Data*. It provides brief discussions on when the models are applied, and what important statistical indexes should be used to determine that the model that best represents the data.

One-Parameter Model

The simplest model is the one-parameter model shown in Figure D-1, in which the energy use does not vary with any independent variable. The energy use is a constant when the equipment or system is in use, or it has less than a 5% variation,[35] in which case an average is used. This can apply to constant speed pumps and fans, and lighting circuits and similar equipment. These models can also be used, with caution, if an independent variable cannot be found that explains the energy use, and the energy use has larger than 5% variation. One-parameter models have a simple equation:

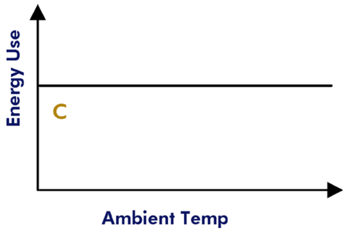

Figure D-1: Average (one-parameter) model

Equation D-1: One-Parameter Model

$$E = C$$

where:

C = the constant or average energy use

Two-Parameter Model

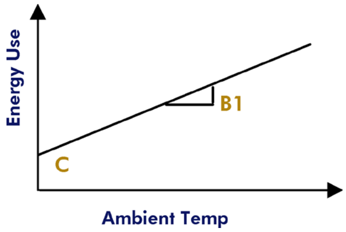

Figure D-2: Two-parameter model

Two-parameter models, as shown in Figure D-2, are equivalent to simple linear regressions with one independent variable. These models types are appropriate for buildings that require cooling or heating for the entire year, such as in extremely cold or warm climates. Selected building systems can be modeled with two-parameter models: Haberl and Culp[36] cite dual-duct, single-fan, constant volume systems without economizers. When using this model, as with most models, care should be taken to gather as much data over the entire range of conditions as possible, in order to avoid extrapolating energy use to conditions outside the data range. While higher parameter models mentioned below have

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[35] This variance is defined as the coefficient of variation of the standard deviation: CV(STD). It is calculated by CV(STD) = $\sigma/\bar{x}$, where σ = standard deviation about the mean value of all measurements, and $\bar{x}$ = mean of the measured values.

[36] Haberl, J.S., and C. H. Culp, "Review of Methods for Measuring and Verifying Savings from Energy Conservation Retrofits to Existing Buildings," Energy Systems Laboratory, Texas A&M University System, report no. ESL TR-03/09-01.

bounds at least at the lower end, two-parameter models are unbounded and can easily yield erroneous results not far outside their data limits. Two-parameter models have equations in the form:

Equation D-2: Two-Parameter Model

$$E = C + B_1 T$$

where:

C = a constant

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature

Three-Parameter Change-Point Models

Figure D-3 and Figure D-4 show three-parameter linear change point heating and cooling models, respectively. Three-parameter models are applicable to many types of buildings and systems. Each type is a change-point model, where the change point indicates a change in the dependence of energy use on the independent variable.

Three-Parameter Heating Model

In the heating mode, the energy use (e.g., natural gas, etc.) has a decreasing dependence on ambient temperature as it increases, until the change point is reached. As the ambient temperature increases beyond it, the heating energy use remains constant. Three-parameter change-point heating models have equations in the form of Equation D-3.

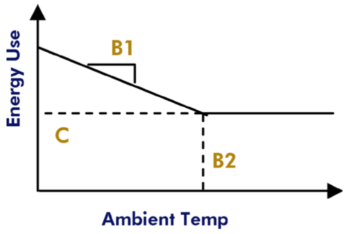


Figure D-3: Three-parameter heating model

Equation D-3: Three-Parameter Heating Model

$$E = C + B_1(B_2 - T)^+$$

where:

C = the constant energy above the change point

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature

B_2 = the heating change point temperature

$^+$ indicates that only positive values may be taken inside the parenthesis

Three-Parameter Cooling Model

Equation D-4.

Equation D-4: Three-Parameter Cooling Model

$$E = C + B_1(T - B_2)^+$$

where:

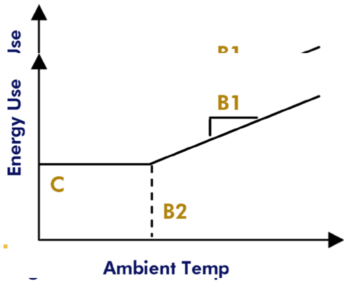
C = the constant energy below the change point

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature

B_2 = the cooling change point temperature

$^+$ indicates that only positive values may be taken inside the parenthesis



cooling model

Figure D-4: Three-parameter cooling model

Four-Parameter Change-Point Models

Figure D-5 and Figure D-6 show four-parameter linear change point heating and cooling models, respectively. Four-parameter models are applicable to buildings and systems that display different linear dependence of energy use on the independent variable in different ranges. For example, a building with a chilled water plant, and variable volume air distribution systems equipped with economizers will display different electric energy dependence on ambient temperature when the air handling unit is economizing at mild temperatures, than in warmer temperatures when the building will rely exclusively on mechanical cooling.

Four-Parameter Heating Model

Four-parameter change-point heating models have equations in the form of Equation D-5.

Equation D-5: Four-Parameter Heating Model

$$E = C + B_1(B_3 - T)^+ - B_2(T - B_3)^+$$

where:

C = the energy use at the change point

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature below the change point

B_2 = the coefficient that describes the linear dependence on temperature above the change point

B_3 = the change point temperature

$^+$ indicates that only positive values may be taken inside the parenthesis

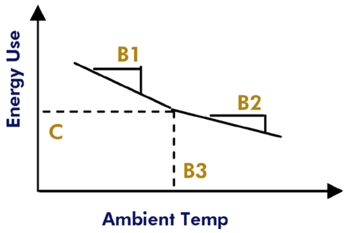
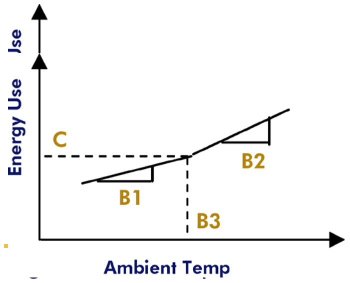


Figure D-5: Four-parameter heating model

Four-Parameter Cooling Model

Equation D-6.



cooling model

Figure D-6: Four-parameter cooling model

Equation D-6: Four-Parameter Cooling Model

$$E = C - B_1(B_3 - T)^+ + B_2(T - B_3)^+$$

where:

C = the energy use at the change point

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature below the change point

B_2 = the coefficient that describes the linear dependence on temperature above the change point

B_3 = the change point temperature

$^+$ indicates that only positive values may be taken inside the parenthesis

Five-Parameter Model

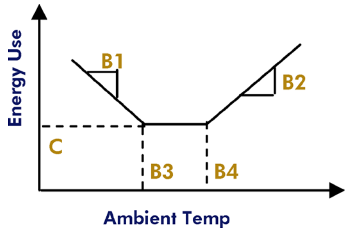


Figure D-7: Five-parameter model

Figure D-7 shows a five-parameter linear change-point model. Five-parameter models are useful for modeling building energy use when the same energy source provides both heating and cooling, such as a building with air conditioning and electric heating. Five-parameter models are also useful for modeling the weather-dependence of energy use in variable volume air distribution systems. Five-parameter models display a linear dependence of energy use on ambient temperature below the heating change point and above the cooling change point, and constant energy use between the heating and cooling change-points. Five-parameter change-point heating models have equations in the form of Equation D-7.

Equation D-7: Five-Parameter Model

$$E = C + B_1(B_3 - T)^+ + B_2(T - B_4)^+$$

where:

C = the energy use between the heating and cooling change points

T = the ambient temperature

B_1 = the coefficient that describes the linear dependence on temperature below the heating change point

B_2 = the coefficient that describes the linear dependence on temperature above the cooling change point

B_3 = the heating change point temperature

B_4 = the cooling change point temperature

$^+$ indicates that only positive values may be taken inside the parenthesis

Multivariate Models

Each of the preceding linear modeling techniques assumes a predominant dependence on one independent variable – the ambient temperature. It is well known that there are many other influencing parameters in a building or a system's energy use. Examples include daily and weekly building schedule, and ambient wet-bulb temperature for humid climates.

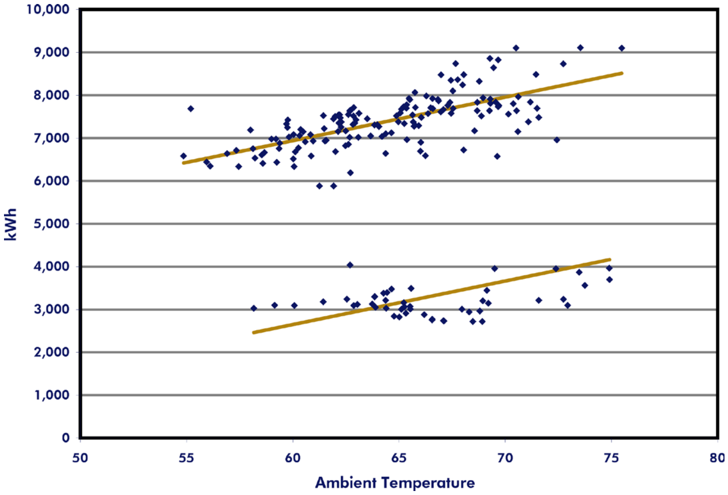


Figure D-8: Multivariate model – example 1

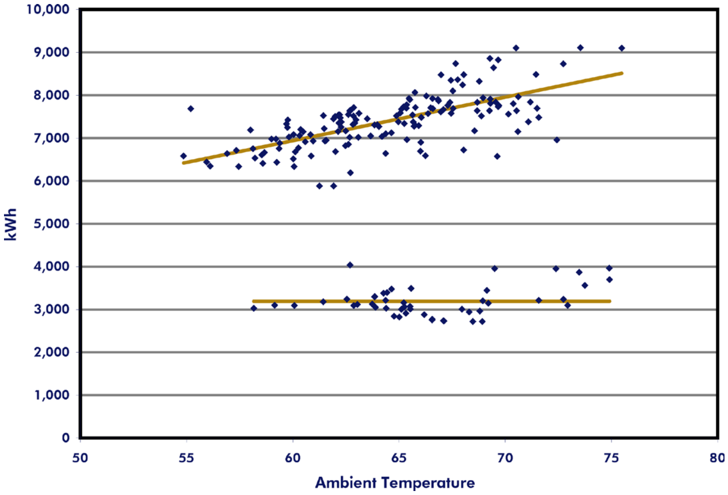


Figure D-9: Multivariate model – example 2

For example, a building may have occupancy and HVAC operations only during working hours on non-holiday weekdays, and minimal occupancy and HVAC use on holidays and weekends. If the building energy use on weekends and holidays is constant, a day-of-week schedule variable may be introduced into the energy model that effectively makes the energy use constant during weekends and holidays.

If there are minimal HVAC loads on weekends and holidays, but enough to show a variation in energy use with ambient temperatures, a day-of-week schedule variable may be introduced into the model that accounts for the variation in energy use for weekend and holiday periods only.

Figure D-8 shows a scatter plot of a building's daily energy use versus average daily ambient temperature. A two-parameter, two-variable model fits the data well. This model is shown in Equation D-8, and indicates a constant difference in energy use between the weekdays and weekends/holidays.

Equation D-8: Multivariate Model – Example 1

$$E = C_1 + B_1 T + C_2(Workday)$$

where:

T = the ambient temperature

$Workday$ = 1 for Monday through Friday, 0 for weekends and holidays

Note that when categorical variables are used, it is advantageous to develop models for each category separately. The models do not have to be of the same type (e.g., constant, two-parameter, three-parameter, and so on). This assures that the characteristic energy use of each period is correctly modeled. Figure D-9 shows the same data with a two-parameter model for the weekday energy use and an average for the weekend/holiday energy use.

Additional independent variables may be included in the energy use models only where it makes physical sense.

Equation D-9: Multivariate Model – Example 2

$$E = Workday[C_1 + B_1 T] + C_2(Weekend)$$

where:

$Workday$ = 1 for Monday through Friday,
0 for weekends and holidays

$Weekend$ = $1 - Workday$

Important Statistical Indexes

There are several important statistical indices that help users determine the model type and fit that best represents the measured data. These statistical indicies can be used to evaluate regression based energy models that are developed using any of the four methodologies described in this guidebook.

Coefficient of Determination

The coefficient of determination, R^2, is an indicator of how well the independent variables "explain" the variation in the dependent variable. For our purposes, it can be interpreted as the fraction of variation in energy use that is explained by the variations in the independent variables (e.g., ambient temperature). R^2 falls between 0 and 1. When R^2 is 0, the independent variable used does not explain any of the observed variations in energy use. When R^2 is 1, the independent variable used explains all of the observed variations in energy use. Note that R^2 should not be used as the sole criteria for determining the best model for the data. Linear models with steep slope coefficients generally have higher R^2 values than linear models with low slope coefficients. Best fit models are determined by those that minimize variation and bias from the measured data.

Equation D-10: Coefficient of Determination

$$R^2 = 1 - \frac{\sum_i (E_i - \hat{E}_i)^2}{\sum_i (E_i - \bar{E}_i)^2}$$

Coefficient of Variation

The coefficient of variation of a model is an indication of how much variation or randomness there is between the data and the model. It measures the variation in energy use relative to the average energy use, and is dimensionless. The higher it is, the more variation there is relative to the average, and therefore it is more difficult to discern changes in energy use. For a one-parameter model, it is called the coefficient of variation of the standard deviation, CV(STD). For a multiparameter model it is called the coefficient of variation of the root-mean squared error CV(RMSE). The mathematical definitions are provided below. All terms are defined at the end of the equations.

Equation D-11: Coefficient of Variation of the Standard Deviation

$$CV(STD) = 100 * \frac{\left[\sum_i (E_i - \overline{E}_i)^2 \Big/ (n-1) \right]^{1/2}}{\overline{E}}$$

Equation D-12: Coefficient of Variation of the Root-Mean Squared Error

$$CV(RMSE) = 100 * \frac{\left[\sum_i (E_i - \hat{E}_i)^2 \Big/ (n-p) \right]^{1/2}}{\overline{E}}$$

Net Mean Bias Error

The net mean bias error is used to determine the amount of bias error in the model:

Equation D-13: Net Mean Bias Error

$$NMBE = 100 * \frac{\sum_i \left(E_i - \hat{E}_i \right)}{(n-p)\overline{E}}$$

For all equations:

E = the dependent variable (energy use or demand), which is some function of the independent variable(s)

$\overline{\mathrm{E}}$ = the arithmetic mean of the sample of n observations

$\hat{\mathrm{E}}$ = the regression model’s prediction of E

i = the *i*th data interval

n = the number of data points or intervals in the baseline period

p = the number of parameters or terms in the baseline (regression) model

These indexes are used to determine the best fit of the model to the data. Generally, the model with the lowest CVs and bias errors of all the regression models tested represents the best fit. ***Appendix E: Uncertainty Analysis*** shows how to use these indexes in assessing savings uncertainty, selecting an M&V approach, and determining the uncertainty associated with the verified savings results.

Appendix E: Uncertainty Analysis

The following discussion is based on the excellent treatment of savings uncertainty found in ASHRAE's Guideline 14-2002, Annex B: Determination of Savings Uncertainty. In Annex B, the basis for calculating uncertainty is provided, and its sources and treatment are described. The uncertainty analysis described in Annex B was developed for an approach akin to***Method 3: Energy Models Using Interval Data***.

Identifying sources of uncertainty, quantifying, and propagating them in savings calculations is often viewed by energy engineers as a cumbersome process with little reward or justification. In Guideline 14's Annex E, a streamlined approach that enables practitioners to gain a reasonable estimate of uncertainty, that can both help select an appropriate M&V approach and enable savings to be stated within confidence bounds is described. The Annex E approach was used to inform the development of ***Method 2: System or Equipment Energy Measurement***.

For more detailed discussion on the definition of uncertainty, description of uncertainty sources, and development of uncertainty formulae, the reader is referred to Annex B of ASHRAE Guideline 14-2002.

Objective

An owner's decision to implement an energy savings measure in their facility is based on an evaluation of the financial risks involved. An energy efficiency program manager has goals to produce cost-effective savings in the program's targeted market sector, and faces program evaluation risk. Such risks include the risk that estimated savings will not be realized. For both owners and program managers, EBCx providers are responsible not only for recommending the technical solutions that result in savings, but also for assessing their feasibility, so that managers can properly assess the savings risk. Savings risk involves an assessment of its uncertainty. Financial managers factor savings uncertainty, along with other sources of risk, into their investment analysis. Program managers may use uncertainty estimates to assess progress toward goals, anticipate evaluation risks, or to design better programs.

The objective of this appendix is to provide some of the fundamental concepts in calculating uncertainty, and to assist EBCx providers in selecting a proper M&V approach as well as in stating savings within confidence limits. The concept of uncertainty is defined, its relevant sources for this M&V approach are identified, and formulae for determining it are provided.

Definition of Uncertainty

Often, the terms *error* and *uncertainty* are used interchangeably. *Error* is the difference between a measured or predicted value and the true value. *Uncertainty* is used when the exact value is unknown. Therefore, the relevant term to express incomplete knowledge about a value is uncertainty. Uncertainty is a probabilistic statement about the confidence one has that the actual value of some expression is within certain limits of the predicted value. Confidence limits define the range of values in which the true value is expected to be, with a stated probability. For example, one can state that the 95% confidence limits for a savings prediction are 465,000 and 515,000 annual kWh. This implies that one is 95% confident that the actual savings is between these two values, or that in 95 of 100 predictions, the actual savings will be between these values.

A statement of the accuracy of a prediction is meaningless without an accompanying statement of its confidence level. For example, one can state that the savings are 500,000 kWh "plus or minus 5%." However without confidence limits, one would not have an idea what the potential risks involved would be. If the confidence limits were 68%, then this could be considered a very risky savings estimate, as the uncertainty statement would be: "we are (only) 68% confident that the true savings is between 475,000 and 525,000 kWh." This means that one third of the time, the savings may be outside this range. Contrast this with a statement at the 95% confidence level: "we are 95% confident that the true savings is between 475,000 and 525,000 kWh." In this case, it is far more likely that the actual savings is in this range.

Two different predictions of the same value can only be compared at the same confidence level. An uncertainty estimate of a prediction at one confidence level can be determined at a different confidence level by the ratio of their t-statistics. Student's t-statistic is a common factor defined in most statistics books. The number of data points, n, used in a model developed to predict the value, and the number of independent parameters, p, in that model must be known. Table E-1 shows t-statistics for different confidence levels and n-p values. Assume the 68% confidence level prediction described above was determined from a model built from a year of 15-minute interval data. The number of points would be very large (>25,000 points), and assuming a three-parameter model was used, n-p is still very large. For a 68% confidence level at infinite n-p values, the t-statistic is 1.00. At 95% confidence, the t-statistic is 1.96. The 50,000 kWh interval for the 68% confidence level prediction described above would then become (1.96/1.00)*50,000 kWh = 98,000 kWh at the 95% confidence level. The first statement says we're 68% confident that the savings are between 475,000 and 525,000 kWh, while the second statements says that we are far more certain (95%) that the savings is between 451,000 and 549,000 kWh. Clearly, from the perspective of a building owner or a program manager, the second prediction described above is superior to the first.

Table E-1: t-Statistics at Various n-p Values and Confidence Levels[37]

n-p	Confidence			
	68%	80%	90%	95%
5	1.00	1.48	2.02	2.57
10	1.00	1.37	1.81	2.23
15	1.00	1.34	1.75	2.13
20	1.00	1.33	1.73	2.09
25	1.00	1.32	1.71	2.06
infinite	1.00	1.28	1.65	1.96

Sources of Uncertainty

While there are multiple sources of uncertainty, the two primary sources described in this appendix are measurement errors and model prediction uncertainty. Many M&V strategies utilize sampling of similar ECMs to reduce costs, but this also introduces uncertainty to the savings calculation. Sampling and its impact on uncertainty will not be discussed here. See Annex B of ASHRAE Guideline 14-2002 for a detailed discussion of uncertainty introduced by sampling.

This guideline describes development of models for predicting adjusted baseline energy use for comparison with post-installation measured energy use to determine savings. Such models can have the form: $E = a_0 + a_1X_1 + a_2 (a_3 - X_2)^+$, where the X_i are the measured independent parameters (ambient temperature, time of day, etc.), and the a_i are model coefficients, or parameters, with values developed from statistical regression techniques. Uncertainty in the energy use, E, can be derived from measurement and model prediction uncertainty.

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[37] Reference: p. 14, ASHRAE Guideline 14-2002, and selected values from most statistics textbooks.

Measurement Uncertainty For cases where the coefficients a_i are known with zero uncertainty, such as in an equation based on physics where the coefficient values can be looked up in reference tables, the only source of uncertainty on the energy use is measurement uncertainty of the independent variables X_i. The uncertainty in E, denoted ΔE, is determined by the well-known propagation of error formulae (with the rule that uncertainties are combined only if they are expressed at the same confidence interval) found in most experimental methods textbooks, and not repeated here. Measurement errors are further identified as calibration errors, data acquisition errors, and data reduction errors. Two types of error are derived from these sources: random errors and bias errors (sometimes referred to as systematic errors). As a general practice, bias errors should be removed from measurements before the data are collected, as bias errors are cumbersome to analyze. This leaves random errors as the only source of measurement uncertainty. However, it is not always possible to eliminate bias errors.

Model Prediction Uncertainty When the X_i have zero or very small uncertainty, but the coefficients a_i are derived from regressions of measured data, they will invariably have some inherent uncertainty. Unless the regression is perfect, the coefficient of determination, R^2, will be less than 1. This means that the model is incapable of explaining the entire variation in the dependent variable. The models discussed in ***Appendix E: Uncertainty Analysis***, in which the ambient temperature is used to predict energy, are examples of models with this source of uncertainty. If the error in measuring the ambient temperature is small in comparison, then the model prediction uncertainty will be the largest source of uncertainty in the resulting calculated savings. This is a well-treated subject in the literature.[38] Annex B of ASHRAE Guideline 14-2002 classifies the various sources of modeling uncertainties into three categories, as described below.

1. Uncertainty arising from an incorrect model functional form: models are usually approximations of the true functional form of the relationships between the independent and dependent variables. This can be compounded by:
   - The inclusion of inappropriate, or absence of appropriate independent variables; for example, neglecting building schedule affects, or
   - Assuming an inappropriate model form, such as a three-parameter change point model when physical considerations suggest a four-parameter model is appropriate, or
   - Using an incorrect model order, such as when a second order polynomial is used when physical considerations suggest a lower order model is correct.
2. Model prediction uncertainty due to randomness in the dependent and independent variables: regression models are never perfect, and some amount of variation in the dependent variable cannot be explained by the variation in the independent variables.
3. Model extrapolation uncertainty that arises when the model is used to predict values outside the range of data that the model is based on: models developed from data sets that do not cover the entire range of operations are subject to this source of uncertainty.

The most effective way to minimize these sources of uncertainty are to calibrate the instruments used to collect the data, increase the number of data points collected and analyzed, and collect data over the entire range of variation in operating conditions that affects the energy use. ASHRAE Guideline 14-2002 recommends that at least nine months of data covering the annual extremes in climate variation be collected in order to minimize bias errors in the analysis.

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[38] Kissock, J.K., T.A. Reddy, D. Fletcher, and D. Calridge, "The Effect of Short Data Periods on the Annual Prediction Accuracy of Temperature-Dependent Regression Models of Commercial Building Energy Use." Proc. ASME International Solar Energy Conference, p.455-463, Washington, D.C, April, 1993.

Phelan, J., M. J. Brandemuehl, and M. Krarti, " "In-Situ Performance Testing of Fans and Pumps for Energy Analysis," ASHRAE Transactions, v.103, pt.1, 4040, (RP-827), 1997.

Uncertainty Formulae

This guideline describes how to determine actual savings, or avoided energy use, in the reporting period, as opposed to normalized savings. Actual savings over *m* reporting period time intervals are calculated using Equation E-1 and Equation E-2.

Equation E-1: Actual Savings

$$E_{save,m} = \hat{E}_{base,m} - E_{post,m}$$

Equation E-2: Actual Savings

a: $$E_{save,m} = \sum_{j=1}^{m} E_{save,j}$$

b: $$\hat{E}_{base,m} = \sum_{j=1}^{m} \hat{E}_{base,j}$$

c: $$E_{post,m} = \sum_{j=1}^{m} E_{post,j}$$

where:

$\hat{E}_{base}$ = the baseline energy use as predicted by the baseline model with post-installation conditions

E_{post} = is the measured post-installation period energy use

Annex B of ASHRAE Guideline 14-2002 derives the fractional savings uncertainty, which is defined as the energy saving uncertainty over *m* post-installation periods, divided by the energy savings over *m* periods. Please refer to the development of fractional savings uncertainty in Annex B. It develops a computationally useful form of the fractional savings uncertainty, which is shown in Equation E-3.

Equation E-3: Fractional Savings Uncertainty

$$\frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{\left[\Delta\hat{E}_{base,m} + \Delta\left(m \cdot \overline{E}_{post}\right)^2\right]^{1/2}}{m \cdot \overline{E}_{base} \cdot F}$$

where:

$\Delta\hat{E}_{base,m}$ = the uncertainty in the adjusted baseline model over m post-installation periods

$\overline{E}_{base}$ = the average adjusted baseline energy use over *m* post-installation periods

F = the fractional savings, as given by Equation E-4.

Equation E-4: Fractional Savings

$$F = \frac{\left(\hat{E}_{base,m} - E_{post,m}\right)}{\hat{E}_{base,m}}$$

where:

$\Delta\overline{E}_{post,m}$ = the uncertainty in measuring the mean post-retrofit energy use over m periods.

In the case where the measurement uncertainty is very small, such as when electric energy use is measured, where errors are on the order of 1–2%, the fractional savings uncertainty equation is simplified as shown in Equation E-5.

Equation E-5: Fractional Savings Uncertainty – Simplified

$$\frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{\left(\Delta\hat{E}_{base,m}\right)}{m \cdot \overline{E}_{base} \cdot F}$$

In Annex B, assumptions are made to simplify this equation in the case of weather-based regression models on hourly and daily-based time interval data that have serial correlation. This is the type of models described in this guideline. Without reproducing the discussion in Annex B, a simplified equation for use with models built on hourly or daily data is shown in Equation E-6.

Equation E-6: Fractional Savings Uncertainty – Simplified – Detailed Data

$$\frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{1.26 \cdot CV\left[\frac{n}{n'}\left(1+\frac{2}{n'}\right)\frac{1}{m}\right]^{1/2}}{F}$$

where:

CV = the coefficient of variation of the root mean squared error, as given in ***Appendix E: Uncertainty Analysis***,

n, m = the number of observations in the baseline and post-installation period, respectively,

n' = the number of independent baseline period observations, and

1.26 = an empirical coefficient.

Equation E-7 shows how the number of independent observations, n', of n observations are related by the autocorrelation coefficient, ρ.

Equation E-7: Independent Observations

$$n' = n \cdot \frac{1-\rho}{1+\rho}$$

The autocorrelation coefficient provides a measure of the extent to which an observation is correlated with its immediate successor. It is easily determined by duplicating the time series data of model residuals ($e_i = \hat{E}_{base,i} - E_{meas,i}$) onto another column and offsetting it by one time interval, then determine the R^2 between these data streams by simple regression. The autocorrelation coefficient is the square root of this R^2 value. This is expressed mathematically in Equation E-8.[39]

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[39] This equation was obtained from the final report for ASHRAE Research Project 1050.

Equation E-8: Autocorrelation Coefficient

$$\rho = \frac{\sum_{i=2}^{n} e_{i-1} e_i}{\sum_{i-2}^{n} \left(e_{i-1}\right)^2}$$

Examples

Equation E-6, Equation E-7, and Equation E-8 provide a logical means to evaluate the ability of a baseline model to determine savings within acceptable uncertainty limits. Keep in mind that it was developed under the assumption that the uncertainty of the measured post-installation energy use is very small. Table E-2 provides values of the fractional savings uncertainty, multiplied by the savings fraction, F, for different values of CV(RMSE) and correlation coefficient, for an example model based on daily energy use. Note that the number of model parameters, *p*, and degrees of freedom, *n-p*, are important factors in determining CV and values of the t-statistic at values other than at the 68% confidence level, but do not play a role for the purposes of this example.

Table E-2: Values of Fractional Savings Uncertainty Multiplied by Savings Fraction – Daily Data

CV	**Correlation Coefficient, ρ**				
	0.00	**0.50**	**0.75**	**0.85**	**0.95**
0.05	0.003	0.006	0.009	0.012	0.023
0.10	0.007	0.012	0.018	0.024	0.045
0.15	0.010	0.017	0.027	0.036	0.068
0.20	0.013	0.023	0.036	0.048	0.091
0.25	0.017	0.029	0.044	0.060	0.113
0.30	0.020	0.035	0.053	0.072	0.136

Note: 68% Confidence interval after one year, baseline model developed from daily monitored data (n and m = 365)

Note that $\frac{\Delta E_{save}}{E_{save}} \cdot F$ increases as ϱ increases, for constant savings fraction at a given CV. The fractional savings uncertainty increases as the data exhibits more serial autocorrelation. Table E-3 provides values of the $\frac{\Delta E_{save}}{E_{save}} \cdot F$ for different values of CV(RMSE) and correlation coefficient, for a model based on hourly energy use. Note that more data, even though it has much higher serial autocorrelation, has lower overall savings uncertainty.

As an example, assume a model is developed from daily data, for a project that is expected to save 10% of its annual electricity use. Assume the model CV(RMSE) to be 10%, and there is light serial autocorrelation of ϱ = 0.3. For a complete year of post-installation data, $m = n = 365$. In this case, the fractional savings uncertainty is $\Delta E_{save}/E_{save}$ = 9.1% by Equation E-6. This compares marginally well with the savings fraction, 10%. This model would be acceptable for verifying the energy savings.

Table E-3: Values of Fractional Savings Uncertainty Multiplied by Savings Fraction – Hourly Data

CV	Correlation Coefficient, ρ				
	0.00	0.50	0.75	0.85	0.95
0.05	0.001	0.001	0.002	0.002	0.004
0.10	0.001	0.002	0.004	0.005	0.008
0.15	0.002	0.003	0.005	0.007	0.013
0.20	0.003	0.005	0.007	0.009	0.017
0.25	0.003	0.006	0.009	0.012	0.021
0.30	0.004	0.007	0.011	0.014	0.025

Note: 68% Confidence interval after one year, baseline model developed from hourly monitored data (n and m = 8760)

In another example, assume that 15-minute electric energy use data is available, and it is converted to an hourly analysis time interval. In this case, the best fit model is likely to have a higher CV(RMSE) and serial autocorrelation coefficient. Assume these are 18% and 0.75. For the same savings fraction of 10%, $\Delta E_{save}/E_{save}$ = 3.2%. The model would be an improvement over the model based on daily energy use as described above, despite a higher root mean squared error, and higher serial autocorrelation.

For the example presented in ***Definition of Uncertainty*** (page 108), the fractional savings uncertainty can be restated at the 95% confidence level, which would be 0.032×1.96/1.00 = 0.0627, or approximately 6.3%, which is still acceptable in comparison with the expected savings fraction.

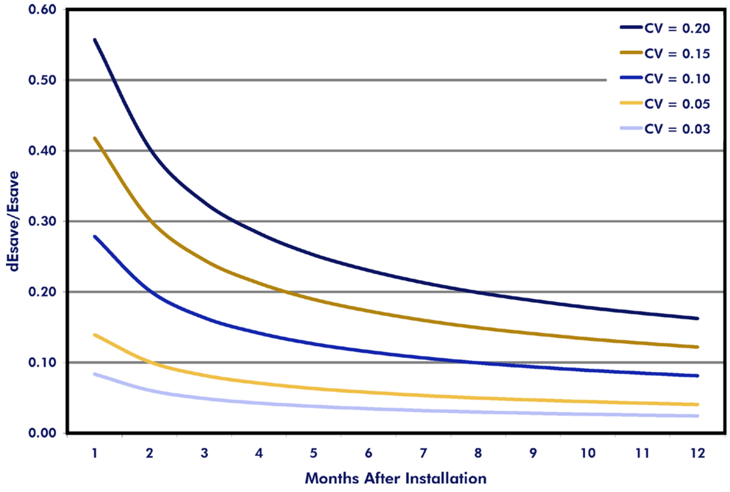

Figure E-1: Fractional savings uncertainty decreases as monitoring period increases

This equation can also be used to assess how long data must be collected in the post-installation phase in order to verify savings. Notwithstanding the seasonal impacts of when certain savings occur, the length of the monitoring period until the fractional savings uncertainty drops below the savings fraction can be determined. Figure E-1 shows the drop in fractional savings uncertainty at the 95% confidence interval for an hourly model and different levels of CV(RMSE), and 10% savings fraction. From this chart, one could assess that even with a CV of 20%, a little over six months of data is required for the fractional savings uncertainty to drop below the savings fraction. Tighter models (i.e., those with lower CV) require less data. If the reporting period is a full year, this figure shows the final savings uncertainty that would result from this baseline model.

There will be cases when the measurement uncertainty in the post-installation period is no longer negligible. At the whole-building level, this applies to non-revenue meters, such as steam, chilled, and hot water meters, and at the systems level for non-electric energy use measurements, such as energy use derived from proxy variables, or calculated from multiple measured points, such as chilled or hot water BTU. Note that the random error in baseline measurements is taken up in the random error of the baseline model, so there is no need to introduce it in the baseline model again. The measurement uncertainty factor, $t \cdot \Delta\overline{E}_{post,m} / \left(\overline{E}_{base} \cdot F\right)$ must be added back into Equation E-6. $\Delta\overline{E}_{post,m}$ is the uncertainty in measuring the mean post-installation energy use over m periods, and depends on the type of instrument used. Remember that uncertainties may only be combined at the same confidence interval. ASHRAE Guideline 2-2005[40] recommends using the 95% confidence interval in uncertainty calculations. Manufacturer specifications of uncertainty may be assumed to be developed from the results of multiple measurements and have a normal distribution, and be reported at the 95% confidence interval if not explicitly stated.

Another important factor in assessing savings uncertainty is the amount of data and length of monitoring period in the baseline period. Both of these factors determine the number of baseline model data points, n. Similarly Equation E-6 can be used to assess these issues.

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[40] ASHRAE Guideline 2-2005, "Engineering Analysis of Experimental Data," available at www.ashrae.org.

Appendix F: Algorithms for Peak-Period Demand Savings

Definitions of Peak Demand Period

The two principal methods of calculating peak demand reduction are average peak demand reduction in a defined peak demand period, and actual demand reduction coincident with a defined event such as the building's billing peak, or a utility distribution system peak. Each of these definitions relies on the definition of peak demand period by the local utility.

Many utilities define the peak period as the hours from noon to 6 P.M. during non-holiday weekdays during the summer months of the year. In some regions, the summer months may extend from May through October, in others the summer months include only June, July, August, and September. Electric utilities may also define the peak hours of the weekday differently, such as from 3 P.M. to 6 P.M. rather than from noon to 6 P.M. Table F-1 provides definitions of California utility peak demand periods.

Energy efficiency programs may also prescribe how to calculate peak demand reduction, which means that specific definitions of the algorithm must be obtained. For example, one such calculation for an EBCx program in California requires using a specific three-day demand period from 2 P.M. to 5 P.M. (nine hours total) that is defined for each climate zone.[41] Table F-2 shows the specific three-day peak period for each climate zone in 2008.[42]

EBCx programs in California offer incentives for peak demand reductions that result from implementation of EBCx measures, just as incentives are offered for retrofits under other energy efficiency programs. The algorithms for calculating demand reduction incentives for individual EBCx measures are average peak demand reduction algorithms. Therefore this guideline recommends that average peak demand calculations be used for engineering calculation and systems verification approaches (Methods 1 and 2), while both average peak demand and coincident peak demand reduction calculations are applicable for whole building approaches (Methods 3 and 4).

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[41] 2009 SPC Procedures Manual, available at: http://www.sce.com/b-rs/small-medium/spc/application-software-manual.htm#manual

[42] 2008 DEER Update - Summary of Measure Energy Analysis Revisions, December 2008, Version 2008.2.05 for 2009-2011 Planning/Reporting, available at http://www.energy.ca.gov/deer/.

Table F-1: California Utility Peak Demand Periods

Sacramento Municipal Utility District

Reference: GS TOU-2

Summer

- 2 P.M. – 8 P.M. (Super Peak)
- 12 P.M. – 2 P.M. and 8 P.M. – 10 P.M. (On-Peak)
- Monday – Friday (excl. holidays)
- June 1 – September 30

Winter

- 12 P.M. – 10 P.M. (On-Peak)
- Monday – Friday (excl. holidays)
- October 1 – May 31

San Diego Gas & Electric

Reference: A6-TOU

Summer

- 11 A.M. – 6 P.M.
- Monday – Friday (excl. holidays)
- May 1 – September 30

Winter

- 5 P.M. – 8 P.M.
- Monday – Friday (excl. holidays)
- October 1 – April 30

Pacific Gas & Electric

Reference: E-19 Summer Peak

- 12 P.M. – 6 P.M.
- Monday – Friday (excl. holidays)
- May 1 – October 30

Southern California Edison

Reference: TOU-8 On-Peak Period

- 12 P.M. – 6 P.M.
- Monday – Friday (excl. holidays)
- June 1 – September 30

California Public Utilities Commission

Reference: "CPUC Energy Efficiency Policy Manual, Version 2." CPUC, 2003, San Francisco

- 12 P.M. – 7 P.M.
- Monday – Friday
- June – September

Table F-2: Peak Demand Period Used for DEER 2008

Climate Zone	Start Date of 3-Day Period			Peak Temp (°F)	Average Temp (°F)	12p-6p Avg Temp (°F)
	Month	Day	Weekday			
CZ01	Sep	30	Mon	80	58	65
CZ02	Jul	22	Mon	99	78	93
CZ03	Jul	17	Wed	89	65	79
CZ04	Jul	17	Wed	97	71	87
CZ05	Sep	3	Tue	93	68	80
CZ06	Jul	9	Tue	85	69	77
CZ07	Sep	9	Mon	92	70	78
CZ08	Sep	23	Mon	98	78	89
CZ09	Aug	6	Tue	101	78	92
CZ10	Jul	8	Mon	104	83	99
CZ11	Jul	31	Wed	104	81	98
CZ12	Aug	5	Mon	103	81	100
CZ13	Aug	14	Wed	106	87	102
CZ14	Jul	9	Tue	106	90	103
CZ15	Jul	30	Tue	114	96	108
CZ16	Aug	6	Tue	96	73	89

Average Peak Demand Reduction

Average peak demand reduction is the permanent on-average reduction (kWh/hr) in demand over a defined peak period. The procedure to calculate it is straightforward. A baseline model of energy use is required to determine the peak period energy use under post-installation conditions. This is called the adjusted baseline energy use.

- The cumulative total adjusted baseline energy use for the defined peak period (occurring in the post-installation period) is determined under conditions in the post-installation period.
- The cumulative total energy use for the defined post-installation peak period is determined from post-installation period measurements.
- The peak period post-installation energy use is subtracted from the adjusted baseline energy use, and this amount is divided by the total number of hours in the defined peak period.

Methods 2, 3, and 4 of this Guideline describe how to develop baseline energy models that may be used in this algorithm. Method 1 describes how engineering calculations may be used to estimate energy use under peak conditions.

For example, for the three day, 2 P.M. to 5 P.M. peak period definition in Table F-2, apply the post-installation conditions (e.g., ambient temperature, occupied hours, etc.) to the baseline model and add up the total energy consumption for the nine hours of the defined peak period. Measure the post-installation period energy use during the peak period and subtract it from the adjusted baseline energy use. Divide this result by the nine peak period hours to get the result.

Coincident Peak Demand Savings

Coincident peak demand reduction is the permanent demand (kW) reduction at the time of a defined event. The defined event may be the time of the building's monthly billing peak demand, it may be the time when the utility's distribution system experiences a system-wide peak demand for power, or some other event. Peak power demand often, but not always, occurs in the warmest periods of summer months when air conditioning loads are highest.

Calculation of coincident peak period demand reduction requires a baseline model of power be developed. This model will be used to estimate what the adjusted baseline power would have been at the time of the post-installation period peak event. Baseline power models may be developed in the same way as energy models as described in Method 3 and 4. Note that the analysis time interval for coincident peak demand calculations should be hourly, not daily.

Actual building peak demand reduction is determined with the baseline peak demand model, and (post-installation) time of day that the building's peak demand occurred. The post-installation time of day when the peak occurred are used to determine what the baseline peak demand would have been had there been no changes to the building. The difference between the baseline peak demand and measured post-installation peak demand is the building's actual peak demand reduction.

Baseline peak demand models are more difficult to create and use, for the following reasons:

- Empirical baseline models (as described in Method 3) generally relate demand to one independent variable – ambient temperature, while factors that influence peak demand in a building can be more random and difficult to measure, such as unanticipated chiller operation in a building, increased occupancy, and similar events.
- Peak demand is usually driven by cooling loads, which increase with ambient temperatures and humidity, causing them to occur at the highest temperatures in the data range. There are

always fewer data points at the limits of the data range, as there are relatively few hours of the year when these conditions occur. Often the models need to be extrapolated to these conditions, which can overstate baseline demand and resulting savings.

- Coincident peak demand reduction should be calculated at the whole-building level. This requires electric meter interval data at the whole building level, which may not always be available.