Volume III

International Performance Measurement & Verification Protocol

Concepts and Practices for Determining Energy Savings in New Construction

Volume III, Part I

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Prepared by:

IPMVP New Construction Subcommittee

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Preface

As of January 1, 2006, the IPMVP Volumes will be numbered to indicate them as Efficiency Valuation Organization (EVO)-owned documents, and to specify their Volume Number (first digit in the initial 5-digit number), Part (if multiple) and Year of Publication. Any corrigendum issued will be so indicated by the "cor" number and year of issuance. Thereby, the present edition is numbered and should be cited as EVO 30000 - 1: 2006. The revisions herein reflect minor editorial rather than more substantive or technical changes to EVO 30000 - 1: 2003. All revisions were made to Table 1: Overview of New Construction M&V Options, page 11. A separate errata sheet was also issued and is numbered and should be cited as EVO 30000 - 1/Cor 1: 2003.

EVO is an international non-profit organization offering products and services which aid in:

- Measurement and Verification (M&V) of energy/water efficiency projects
- Financial risk management of energy savings performance contracts
- Quantifying emissions reductions from energy efficiency projects
- Promoting sustainable and green construction

To find out more about how EVO is making a reality of its vision of a global marketplace that correctly values the efficient use of natural resources and utilizes end-use efficiency options as a viable alternative to supply options, please visit www.efficiencyvaluation.org. To download IPMVP documents, including Volumes and Errata Sheets, visit www.ipmvp.org.

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- The IPMVP Technical Committee for reviewing the document for consistency with IPMVP Volume I and for providing valuable comments;
- The peer reviewers of the draft document for providing valuable comments.

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- Energy Foundation
- Federal Energy Management Program
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Chapter 1 Introduction

1.1 Purpose and Scope

Concepts and Practices for Determining Energy Savings in New Construction has been developed by the EVO (a non-profit organization) to provide a concise description of the best practice techniques for verifying the energy performance of new construction projects[1]. The objective is to provide clear guidance to

- professionals seeking to verify energy and demand savings at either component or whole building level in new construction.
- professionals seeking the M&V credit specified in the LEED™ rating system.

Although there is significant overlap between this document and IPMVP Volume I, the New Construction Subcommittee composed this document in a manner that minimizes the need for referral to IPMVP Volume I. This was done in recognition that many users of this protocol may be new to the field of M&V and would find a stand-alone document easier to use. While this document is broadly consistent with IPMVP Volume I and uses the same format and key terms, some concepts and definitions have been modified to suit new construction. These differences are identified either in the main text or through the use of footnotes. This protocol should not be applied to retrofit savings determination. This document also does not address sampling methodologies for large-scale programs involving multiple buildings.

A chapter on the measurement and verification of energy savings in new construction was first published in the 1997 IPMVP (Section 6), and since then has provided general guidance to the industry. However, experience gained from the application of the 1997 methods to several well-documented projects indicated a need to review the protocol and formed the basis for its further evolution. Additionally, the 2002 publication of ASHRAE Guideline 14, which addresses detailed procedures and instrumentation for calculating and verifying energy savings, provided additional supporting context for the advancement of the protocol. The result is this document, Concepts and Practices for Determining Energy Savings in New Construction, which supersedes Section 6 of the 1997 IPMVP.

IPMVP, in collaboration with US Green Building Council, will endeavor to ensure that this protocol will be referenced in future versions of LEED™ for new construction, commencing with LEED™ version 3.0.

1.2 Overview – Motivations for M&V

Chapter 1 of the IPMVP Volume I examines and identifies the various motivations for measurement and verification (M&V) in retrofit projects. Many of these motivations can be extended to new construction.

a) Increase energy savings – Accurate determination of savings gives facility owners and manager valuable feedback on the operation of their facility,

1. This is part of IPMVP Volume III, Part I document.

allowing them to adjust facility management to deliver higher levels of energy savings, greater persistence of savings and reduced variability of savings.

b) Operations and Maintenance Troubleshooting – M&V provides performance feedback, which can facilitate operations and maintenance troubleshooting. This is particularly valuable during the first year or two of operation of a new building.

c) Performance Contracting – Although performance contracting activity in new construction has been limited to date, in principle there is no reason why performance contract models cannot be adapted to new construction. While M&V is a key aspect of performance contracting in and of itself, greater experience with M&V in new construction in all contexts will provide a basis for increased knowledge of building performance and greater confidence in savings projections. This in turn will lead to lower perceived risk and greater acceptance of performance contracting in new construction.

d) Encourage better project engineering – M&V is the major validation vehicle for energy efficient design strategies at the component and at the whole building level.

e) Help demonstrate and capture the value of reduced emissions from energy efficiency and renewable energy investments – In addition to energy cost and resource consumption, emissions reduction is emerging as a new and important "currency" in the assessment of energy saving and environmental initiatives. New construction M&V provides a basis for determining emissions reductions and improvements in air quality associated with reduced energy consumption.

f) Help national and industry organizations promote and achieve resource efficiency and environmental objectives – The IPMVP is being widely adopted by national and regional government agencies and by industry trade organizations to help increase investment in energy efficiency and achieve environmental and health benefits in a retrofit context. Similar benefits can be realized through M&V in new construction.

Stimuli for M&V which are unique to new construction include:

a) Incentive-based design fee structures – Incentive-based design fees link design team compensation, at least in part, on the actual performance of the building. This fee model has been the subject of increasing interest as facility owners and managers seek to make building designers more accountable. Good M&V is an inherent component of these agreements.

b) Documentation of the performance of new buildings – The new construction industry as a whole has a pressing need, at all levels, for reliable, consistent, and ongoing data on the performance of new buildings. Initiatives in this regard to date have been hampered by the limited amount of quality M&V undertaken in new buildings. Certain performance/compliance programs (such as LEED™) provide incentives to do good for M&V at the system or whole building level or both.

1.3 Audience

The potential audience for this document includes:

– Project Developers

- Facility Owners and Managers
- Architects and Engineers
- Financial Institutions and Firms
- Government and Government Agencies
- Utilities
- Trade Organizations and other Non-Governmental Organizations
- ESCOs
- Researchers and Academics

While this protocol is intended to be a stand-alone document, it assumes a basic understanding of M&V concepts, and uses nomenclature and definitions similar to IPMVP Volume I.

It is also assumed that the reader has a working knowledge of new building design processes and technologies, energy efficient design strategies and systems/equipment, energy analysis, computer energy simulation, and monitoring and metering methods and technologies.

1.4 New Construction and Retrofit – Fundamental Differences in M&V

The fundamental difference between M&V in new and retrofit construction is related to the baseline. This issue presents challenges unique to new construction M&V.

The baseline in a retrofit project is usually the performance of the building or system prior to modification. This baseline physically exists and can therefore be measured and monitored before the changes are implemented. In new construction the baseline is usually strictly hypothetical - it does not physically exist, and therefore cannot be measured or monitored. A new construction baseline can be defined or characterized by code or regulation, common practice, or even the documented performance of similar constructed buildings. However, in all cases it is a hypothetical model, and the associated performance must be calculated or postulated in some manner. The model and associated performance projection methodologies usually must also be capable of accommodating changes in operating parameters and conditions as circumstances dictate.

Chapter 2: Baseline Definition and Development of this document addresses the issues and methodologies of baseline definition in greater detail.

1.5 Related Programs and Resources

As interest grows in building energy and environmental performance, programs and resources relevant to new construction M&V continue to emerge. Among these are the aforementioned LEED™ building rating system, US Department of Energy's High Performance Buildings Initiaitve, and ASHRAE Guideline 14. *Appendix B — Resources* provides a list of other programs and resources current at the time of production of this document.

Chapter 2 Baseline Definition and Development

2.1 General Issues

Chapter 1.4 pointed out that the baseline for new construction M&V is usually hypothetical - it cannot be measured or monitored in the same way that a retrofit baseline can be physically documented. The baseline for new construction must therefore be postulated, defined, and developed.

In order to avoid unduly limiting the flexibility and application of this document, the protocol does not prescribe or proscribe any particular baseline. The definition and development of a baseline is therefore largely left to the discretion of the user. However, three key issues should be considered.

a) Appropriateness – If the baseline is to be meaningful it must be appropriate in the context of the overall project and the M&V objectives. Energy codes and standards can provide a convenient, clearly defined, and consistent baseline, and for this reason their use is encouraged whenever possible. Under certain circumstances, baselines reflecting “standard practice”, “market standards” may be more appropriate, if appropriately documentated.

Some projects may also require the use of more than one baseline to meet multiple M&V objectives. An example is a project which is pursuing the M&V credit under LEED™, which uses ANSI/ASHRAE/IESNA Standard 90.1-1999 for the energy performance baseline, while simultaneously applying for incentives under a utility energy efficiency program, which may use a different performance baseline.

b) Rigor – Once a baseline is defined in principle, it must be developed to a level of detail appropriate for the M&V methods and the analytical tools that will be used. If the ECMs involved can be isolated, then the baseline development consists of specifying baseline equipment or systems. Alternately, baseline development can be a significant undertaking if whole-building performance and design strategies are to be assessed. Whole building energy simulation tools in particular require a high level of design detail for proper analytical rigor, requiring a fairly well-developed design of the building.

c) Repeatability – Many of the M&V motivations presented in *Chapter 1: Introduction* inherently require baselines that are consistent and repeatable, or that can at least be readily adjusted to allow performance comparisons on a broader scale. This further supports the argument for deferring to energy codes and standards whenever possible and appropriate. Baselines which are unusual or specialized may meet the immediate needs of the M&V program, but have limited potential for broader application. Examples of such baselines include market standards that are specific to building function, size, and/or location.

2.2 Baseline Development Processes

The definition of a baseline usually occurs at the beginning of the building design and/or M&V planning. However, the development of the baseline is often an ongoing process. Many energy codes and standards derive their minimum allowable "baseline" from the proposed design, essentially "back-engineering" the baseline by applying prescriptive characteristics and requirements to the proposed general building configuration. The baseline therefore tends to evolve with the design and is not finalized until the design has reached a level of completeness, which addresses all pertinent building characteristics. Examples include ANSI/ASHRAE/IESNA Standard 90.1-2001 Energy Cost Budget Method and the Canadian Model National Energy Code for Buildings (MNECB) Performance Path. In the absence of codes or standards a baseline can be developed from a proposed design by removing the pertinent ECMs or design features.

In most cases the baseline development is made easier if energy analysis tools, and simulation in particular, are used as an integral part of the building design process. The insights provided into the performance dynamics of specific ECMs and design strategies can be invaluable in developing an M&V plan as well as resolving future M&V issues and problems. Analytical tools used in the course of building design are also usually readily adaptable for M&V purposes. In this regard, simulation models must be configured to match the systems or subsystems undergoing M&V.

2.3 Baseline Applications – Examples

Example 1 – Energy Codes/Standards

Project and M&V Context: A California utility pays incentives for efficiency improvements based on exceeding California Title 24 standard. A corporation decides to build a new head office building incorporating a number of energy efficiency features, and subsequently applies to the utility for incentives.

Baseline: The baseline is the Title 24 energy standard.

Comments: Title 24 energy standard address performance on a component basis for buildings constructed in California. Accordingly, documentation of the performance improvements must be made on a corresponding basis.

Example 2 – Design Standards

Project and M&V Context: A commercial developer wishes to build and monitor a “spec” office building incorporating a number of energy saving features which represent upgrades from their normal design standard. Energy codes or incentive programs will not apply to this project.

Baseline: The baseline is the projected energy performance of an equivalent building designed to the normal design standard.

Comments: The baseline can be readily developed by deleting the energy saving features from the as-built building. However, this is not a repeatable baseline.

Example 3 – Energy Codes/Standards

Project and M&V Context: The same developer in Example 2 wishes to compare the performance of their upgraded building to the minimum standards of the local energy code.

Baseline: The baseline is the projected energy performance of an equivalent building designed to the requirements of the code.

Comments: Although baseline development requires more effort than the design standard used in Example 2, the code baseline is a repeatable and common standard, which normalizes the building performance and allows comparison on a broader scale.

Chapter 3 M&V Processes and Planning

3.1 Basic Concepts

Energy savings in new construction M&V are determined by comparing measured or projected post-construction energy use to the projected energy use of a baseline under similar operating conditions. In general:

Energy Savings = Projected Baseline Energy Use – Post-Construction Energy Use Eq. 1

Post-Construction Energy Use is the energy use of the as-built equipment, system, or building.

This equation is analogous to the retrofit relationship Eq. 1 presented in Chapter 3.1 of the IPMVP Volume I, as follows:

Energy Savings = Baseline Energy Use – Post-Retrofit Energy Use Adjustments Eq. 2

In new construction the "adjustments" do not stand alone. Instead, the baseline is adjusted to account for operating conditions during the M&V period and the Projected Baseline Energy Use is generated. The adjustments are derived from identifiable physical facts such as weather, occupancy, and system operating parameters. The equation can also be used to estimate demand savings by substituting "energy" with "demand".

Measured Post-Construction Energy Use can be determined at the ECM, building system, or whole building level as required. This can be accomplished by one or more of the following methods:

- Utility invoices or meter readings
- System sub-metering

Projected Post-Construction Energy Use is determined by whole-building simulation calibrated to post-construction measured energy use. This is discussed further in *Chapter 4.5: Option D: Whole Building Calibrated Simulation*.

The method for determining Projected Baseline Energy Use depends on the M&V option, and is discussed further in *Chapter 4: M&V Methods* of this document.

The method of energy use measurement should not only be appropriate for the M&V option, but should also be thoroughly reliable. Missed data can never be replaced or recovered - it can only be interpolated or approximated in some other manner.

Adjusting for weather conditions is usually a key component of new construction M&V. Depending on the systems involved and the M&V option used, required weather data could range from simple factors such as mean temperature to full hourly recording of all weather conditions. Hourly energy simulation programs (which would be used for Option D) generally use normalized hourly weather data such as TMY. For the purposes of M&V, these normalized weather files must be replaced with weather data from the M&V period. Government weather agencies are the most reliable and verifiable source of weather information, but delays in availability, or complete lack of data availability in some instances may warrant on-site weather monitoring.

Operational data must be similarly compiled. Hours of operation, occupancy, imposed equipment loads, and system setpoints are some of the factors which must be monitored and documented. Admittedly this can be problematic, particularly in whole-building M&V. Potential data sources include building control/automation systems, security systems, occupant surveys and observations, and specialized sub-metering systems.

Analytical methods and tools for projecting baseline energy use are addressed in detail in *Chapter 4: M&V Methods*.

3.2 M&V Plan

General – Chapter 3.3 of the IPMVP Volume I states that, "the preparation of an M&V plan is central to proper savings determination and the basis for verification". Responsibility for the design, coordination, and implementation of the M&V program should reside with one entity of the building design team. The person or persons responsible for energy engineering and analysis are usually best-placed for this role.

A complete M&V plan should include, but not be limited to:

- Documentation of the design intent of pertinent ECMs or energy performance strategies.
- Statement of M&V objectives and description of the project context of the M&V program eg. performance contract, incentive-based design fees, etc.
- Technical identification of the boundaries of savings determination eg. piece of equipment, system, or whole-building. The nature of any energy effects beyond the boundaries may be described and their possible impacts estimated.
- Clear statement describing M&V period.
- Documentation and specification of the baseline including a listing of all important assumptions and supporting rationale
- References to relevant sections of any energy efficiency standard or guide used in setting the baseline.
- Specification of the M&V Option or combination of Options, which will be used to determine savings, including a rationale for the choice. If Option D is to be used:
- Specification whether Method 1 or Method 2 will be used for savings estimation;
- Specification of the approach to be used if the estimation of long-term savings is required.
- Specification of analytical techniques, algorithms, and/or software tools (name and version number), including any stipulated parameters or operating conditions and the range of conditions to which the techniques,

algorithms, and/or software tools apply (eg. a simulation tool calibrated to summer conditions may not be valid for winter conditions).

- For Option A, description of the overall significance of stipulated parameters relative to the total expected savings with description of the uncertainty inherent in the stipulation.
- Final input/output files for software tools, including important assumptions and any unusual modeling techniques employed during the development of the model.
- Specification of metering points, equipment, equipment commissioning and calibration, and measurement protocols, including expected accuracy.
- Specification of the methods to be used to deal with missing or lost metered data.
- Identification of operational conditions that are to be monitored, and methods for monitoring and data collection eg. weather, occupancy, system operating parameters.
- For Option C, identification of similar buildings to be used to determine Projected Baseline Energy Use, including rationale for the choice with supporting data on building function, location, and operation.
- For Option D, specification of simulation calibration procedures, calibration parameters, frequency of measurement of calibration parameters, and calibration accuracy objectives.
- Specification of the set of conditions used for weather adjustments, including the period and/or weather data used, and any assumptions or interpolations made in the case of missing or incomplete data.
- Expected overall M&V accuracy and anticipated areas of error susceptibility and magnitude of the sensitivity.
- Description of Quality Assurance procedures.
- ·pecification for reporting format of the results.
- Specification of the information and data that will be available for third party verification, if required.
- Budget and resources for the entire M&V program, including long term costs, broken out into major categories.

Developing the M&V Plan – The development of the M&V plan is an ongoing process, which should begin in the early stages of building design for the following reasons:

- Technical analyses which are performed in support of design decisions provide a starting point in defining the M&V objectives and approach. Key elements of energy analyses are also usually important factors in M&V. Energy analyses should therefore be well documented and organized.
- M&V considerations can affect certain design decisions such as instrumentation, building systems organization, etc.

The M&V plan should progress with the building design, and can be finalized when the design has developed to a point where all M&V issues can be addressed and "signed off". In fact, it can be said that the development of the

M&V plan is integral with the design of the building and/or its systems. Proceeding in this manner ensures that the effectiveness and efficiency of the M&V program is optimized. It also avoids unforeseen or unexpected difficulties later in the process when they are more difficult to resolve. These can include missing instrumentation or inappropriate segregation or separation of systems and equipment.

3.3 Adherence With This Document

This protocol is a framework of definitions and methods for determining energy savings in new construction. It has been written to allow maximum flexibility in creating M&V plans that meet the needs of individual projects, while adhering to the principles of accuracy, transparency and repeatability. In the case where users are required to demonstrate adherence, or wish to claim adherence to this protocol, they must:

- Identify the organization/person responsible for implementing the M&V plan for the duration of the M&V project should be clearly identified.
- Produce a site-specific M&V plan, as outlined in *Chapter 3.2: M&V Plan*, using concepts and terminology consistent with this document.
- Maintain Quality Assurance procedures as specified in the M&V plan.

Chapter 4 M&V Methods

4.1 Overview

This document is intended to provide the basic framework for M&V for new construction. While some technical detail is offered, the reader is referred to two other key resources: IPMVP Volume I and ASHRAE Guideline 14, for guidance on specific topics such as statistical issues and instrumentation.

Table 1 below provides an overview of New Construction M&V Options. Options A and B focus on the performance of specific and easily isolated ECMs. Option C provides a method for estimating whole-building energy savings by comparing energy use in the newly constructed building with other buildings belonging to a control group. Option D provides a rigorous method for determining savings at the ECM, system, or whole-building level.

Table 1:Overview of New Construction M&V Options

M&V Option	How Baseline is Determined	Typical Applications
A. Partially Measured ECM Isolation Savings are determined by partial measurement of the energy use of the system(s) to which an ECM was applied, separate from the energy use of the rest of the facility. Some parameters are stipulated rather than measured.	Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under operating conditions during the M&V period.	Lighting system where power draw is periodically measured. Operating hours are stipulated.
B. ECM Isolation Savings are determined by full measurement of the energy use and operating parameters of the system(s) to which an ECM was applied, separate from the rest of the facility.	Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under measured operating conditions during the M&V period.	Variable speed control of a fan motor. Electricity use is measured on a continuous basis throughout the M&V period.
C. Whole Building Comparison Savings are determined at the whole-building level by measuring energy use at main meters or with aggregated sub-meters.	Projected baseline energy use determined by measuring the whole-building energy use of similar buildings without the ECMs.	New buildings with energy-efficient features are added to a commercial park consisting of buildings of similar type and occupancy.
D. Whole-Building Calibrated Simulation Savings are determined at the whole-building level by measuring energy use at main meters or sub-meters, or using whole-building simulation calibrated to measured energy use data.	Projected baseline energy use is determined by energy simulation of the Baseline under the operating conditions of the M&V period.	Savings determination for the purposes of a new building Performance Contract, with the local energy code defining the baseline.

Figure 1 below provides a guide to selecting an appropriate M&V option for new construction depending on the project context, circumstances, available resources, and objectives..

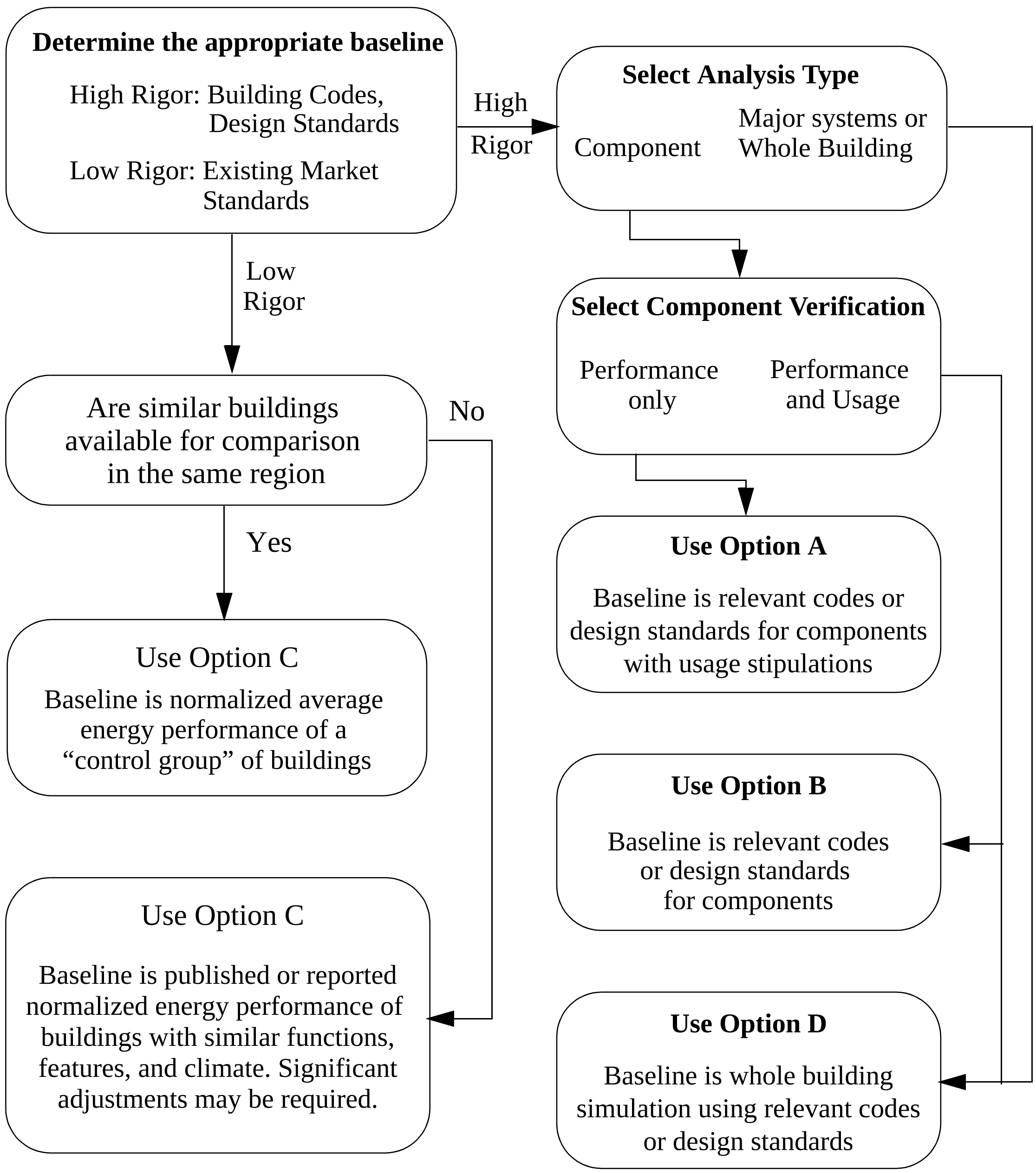

Figure 1: M&V Process Guide

4.2 Option A: Partially Measured ECM Isolation

Partially Measured ECM Isolation in new construction involves isolation of the Post-Construction Energy Use of the components affected by an ECM from the energy use of the rest of the building. Measurement equipment is used to isolate the relevant energy flows in the as-constructed facility. However, some parameters are stipulated rather than measured. These stipulations can only be made when the combined impact of the plausible errors from the stipulations will not significantly affect overall reported savings.

The Projected Baseline Energy Use is determined by calculating the hypothetical energy use of the baseline system or equipment under the post-construction operating conditions during the M&V period. The performance characteristics of the baseline system or equipment can be specified from energy efficiency standards or guidelines.

Option A is suitable for ECMs and systems with constant and/or predictable loads such as fixed-speed motors and lighting equipment and where the additional cost of performing a Whole Building Calibrated Simulation cannot be justified.

4.2.1 Option A: Isolation Metering

Metering of the ECM should reflect the objectives of M&V and the associated boundary between equipment which is affected by the ECM and equipment which is not. For example, if the M&V focus is strictly on lighting, then measurement of lighting energy use is all that is necessary.

4.2.2 Option A: Measurement vs. Stipulation

The decision regarding which parameters to measure and which to stipulate should consider the significance of the impact of all such stipulations on the overall reported savings. The stipulated values and analysis of their significance should be included in the M&V Plan.

An example of a stipulated parameter is operating hours for a piece of equipment. The significance of any variance or error is determined by calculating the estimated savings at the possible extreme values of the parameter eg. 2000 hours per year operation vs. 2400 hours. The impact of all such potential stipulations should be added before determining if the stipulation is defensible.

The identification of parameters to stipulate should also be considered relative to the M&V objectives. For example, if the M&V objective is to determine savings for the purposes of a performance guarantee for a piece of equipment, then only parameters significant to assessing the equipment performance should be measured. Factors beyond the control of the equipment manufacturer and not relevant to the performance guarantee (eg. operating hours) should be considered for stipulation.

4.2.3 Option A: Installation Verification

The potential of the equipment to perform as assumed or promised must be verified. This can often be incorporated into commissioning procedures, but may also have to be periodically performed through the M&V period. Examples include verifying that as-designed control sequences and settings have not be overridden, or that lighting fixtures are being properly re-lamped or are not being removed.

4.2.4 Option A: Measurement Interval

The expected amount of variation in a parameter will dictate the frequency of measurement. If a parameter is not expected to change, it may be measured immediately after installation and then periodically re-measured to verify that it is remaining constant. Alternately, parameters that change daily or hourly may warrant continuous metering. Lighting systems and constant-load motors are examples of systems that generally require infrequent measurement. By contrast HVAC systems often require continuous metering.

4.2.5 Option A: Sampling

Some ECMs involve multiple installations of the same component or piece of equipment. In these cases statistically significant samples may be used as measurements of the total parameter. Motors and lighting fixtures are typical examples. Appendix B of IPMVP Volume I addresses statistical issues associated with sampling.

4.2.6 Option A: Projected Baseline Energy Use

ECM energy savings estimates are usually performed as part of the design process to support the evaluation of design options. Analytical tools associated with individual ECMs are usually relatively simple, consisting of manual engineering calculations, computer spreadsheets, or rudimentary computer software packages. However, as pointed out in *Chapter 2.2: Baseline Development Processes*, these tools should be selected with future M&V requirements in mind.

Assumptions regarding the operating parameters under which design savings estimates are made should be reasonable and well-documented. A sensitivity analysis of changes in these assumptions for future reference is often advisable.

4.2.7 Option A: Uncertainty

Chapter 4.2 of the IPMVP Volume I and ASHRAE Guideline 14 address issues associated with uncertainty of savings determination. However, general factors affecting the uncertainty of Option A methods include:

- The magnitude of effects beyond the boundary of the ECM isolation. For example, the significance of the mechanical cooling energy associated with a reduction in lighting power is dependent on the duration of the cooling season and the schedule of operation of the cooling system.
- The error in Post-Construction Energy Use introduced by variation between the stipulated and true values of parameters. This can be controlled by careful review of the ECM design, prudent selection of stipulated parameters, and periodic review of the veracity of stipulated parameters.
- Measurement interval. If less than continuous measurement is employed, then potential variances between measurement intervals must be considered. This can be controlled through increased measurement frequency at the beginning of the M&V period. Frequency may be subsequently reduced as variances become characterized.
- The degree to which a sample measurement represents the total parameter.

- The flexibility and accuracy of analytical tools used to determine Projected Baseline Energy Use.

4.2.8 Option A: Cost

The cost of implementing Option A is variable and dependent on a number of factors:

- The complexity of the ECM and the number of energy flows crossing the isolation boundary.
- Stipulation vs. measurement. Stipulating parameters is often less costly than measuring them. However, in some cases the cost of deriving a good stipulation can exceed the cost of direct measurement.
- Meter type and installation.
- The frequency of measurement and/or verification.
- Commissioning and maintenance of metering systems.
- The complexity and rigor of analytical tools for determining Projected Baseline Energy Use.
- Collating, processing, and reporting of savings data.

The cost of savings determination should reflect the magnitude of the expected savings as well as the significance of potential error. The need for greater M&V rigor should be evaluated relative to the higher cost that it usually incurs.

4.2.9 Option A: Best Applications

Option A is best applied where:

- The performance of only the systems affected by the ECM is of concern.
- Interactive effects between ECMs or with other building equipment can be measured or assumed to be insignificant.
- The parameters that affect energy use are not complex or excessively difficult or expensive to monitor.
- The uncertainty created by stipulations is acceptable.
- The veracity of stipulations can be readily reviewed and confirmed.
- The potential of the ECM to perform can be readily verified.
- Stipulation is a less costly and preferable alternative to measuring certain parameters or simulating operation under Option D.
- Meters can serve a dual purpose eg. sub-metering for operational feedback or tenant billing.
- Projected Baseline Energy Use can be readily and reliably calculated.

4.3 Option B: ECM Isolation

The savings determination methods of Option B are identical to Option A except that no stipulations are allowed under Option B. Measurement of all energy flows and operating parameters is required on a continuous or periodic basis.

Since Option B involves full measurement of the impact of the ECM, there is less need to verify the potential to perform compared to Option A. In general, ongoing re-inspection is unnecessary after commissioning or initial verification.

The savings associated with most types of ECMs can be determined using Option B, with the limiting consideration being the cost associated with increased metering complexity. However, less uncertainty in savings determination, particularly with variable loads and savings, often warrants the higher cost.

This option is suitable for ECMs and systems with variable loads such as variable speed fan and pump drives, chillers, boilers, etc. and where the additional cost of performing a whole building calibrated simulation cannot be justified.

4.3.1 Option B: Best Applications

Option B is best applied where:

- The performance of only the systems affected by the ECM is of concern.
- Interactive effects between ECMs or with other building equipment can be measured or assumed to be insignificant.
- The parameters that affect energy use are not complex or excessively difficult or expensive to monitor.
- The uncertainty created by stipulations is unacceptable.
- Measurement of parameters is a less costly and preferable alternative to simulating operation under Option D.
- Meters can serve a dual purpose eg. sub-metering for operational feedback or tenant billing.
- Projected Baseline Energy Use can be readily and reliably calculated.

4.4 Option C: Whole Building Comparison

Option C involves the use of utility meters or aggregated sub-meters to determine the Post-Construction Energy Use of the facility at the whole-building level. The Projected Baseline Energy Use is the energy use of a "control group" of similar buildings without the ECMs or design enhancements. In this regard the Projected Baseline Energy Use is a stipulation.

Option C is suitable only for projects, which do not require a high level of savings accuracy and where there are existing buildings available for comparison which are physically and operationally similar except for the ECMs of the subject building. Even then, *the potential for error renders this option suitable for only the most cursory M&V programs.*

4.4.1 Option C: Baseline Stipulation

The successful application of Option C is predicated on identifying buildings that are as similar as possible to the subject building. Although engineering analysis can sometimes be used to make minor adjustments to the energy use of potential Baseline buildings in order to compensate for differences in design or operation, major adjustments compound the substantial uncertainty already inherent in this option and should be avoided. Valid adjustments can only be made if the pertinent characteristics of the buildings being used for comparison are fully understood.

Minimum considerations in identifying Baseline buildings should include:

- Location and/or climate
- Use, occupancy, and operational scheduling
- General configuration e.g. floor area, shape, orientation
- Envelope configuration and construction e.g. R-value, fenestration type and area, mass
- Lighting, plug, and miscellaneous electrical power densities
- HVAC configuration and operation
- Operational stability

Weather adjustments are particularly difficult to make, so local buildings and energy data from the same time period should be used whenever possible.

The identification of buildings for comparison will tend to be least subject to error if the buildings are owned and operated by the same owner or management group, and with the same type of occupancy as the subject building.

Larger Baseline sample sizes may offer greater statistical significance. However, this can be offset by greater unknowns and variances in the Baseline buildings from the subject building. Adjustments to individual buildings are therefore more difficult in larger sample sizes. Smaller sample sizes sacrifice statistical significance for potentially greater flexibility in making Baseline adjustments.

Possible sources for building construction, energy use, and operational data include building association directories, utility or government databases, and building research establishments.

4.4.2 Option C: Installation Verification

The potential of the subject building to perform as assumed must be verified. As with Options A and B, initial verification can be incorporated into commissioning procedures, although this must be done on a much larger scale. However, whole-building M&V also introduces the added complication that facilities often experience a period of troubleshooting and tuning during the first year or two of operation, regardless of how rigorous the commissioning process. Often the "final" long term state of tune differs materially from the design intent. There is no general solution to this problem other than to recommend that initial operational instabilities as well as deviations in the long term operational condition from the design intent be recognized and considered in the application of this M&V option.

4.4.3 Option C: Measurement Interval

Measurement interval for the subject building is dictated by the availability of data from the Baseline buildings. In most cases this means monthly utility data at best, with annual data more the norm. Monthly data, if available, provides a more rigorous comparison as well as insights into potential adjustments to the Baseline.

4.4.4 Option C: Uncertainty

Factors affecting the uncertainty of Option C include:

- The size and quality of the sample of Baseline buildings, with similarity being the primary criterion.
- The magnitude of the savings being measured relative to the building energy use - the variance in energy use between the comparison buildings should not be statistically significant relative to the savings which the M&V program is attempting to estimate.
- The rigor and accuracy of any engineering adjustments applied to the Baseline buildings.
- The error introduced by operational instability or changes to the Design building during the M&V period – this uncertainty can be reduced by monitoring building use and operation through the M&V period.
- The uncertainty introduced by operational instability of the Baseline buildings during the M&V period – This is usually difficult to monitor, but error can be controlled through careful selection of the Baseline sample.
- Measurement interval.

4.4.5 Option C: Cost

The cost of implementing Option C is variable and dependent on a number of factors:

- The availability of quality Baseline building data and cost of procurement.
- The required accuracy of savings determination – Greater accuracy requires larger Baseline building samples and/or more rigorous Baseline building adjustments.

4.4.6 Option C: Best Applications

Option C is best applied where:

- The M&V focus is on whole building performance rather than individual ECMs.
- A high level of savings accuracy is not required. Seemingly small variances in building function, occupancy, or operation can lead to significant variances in energy use.
- An appropriate population of potential Baseline buildings is available.
- The budget for M&V is limited.

4.5 Option D: Whole Building Calibrated Simulation

Option D involves of computer simulation of whole building energy use. The Post-Construction Energy Use is determined by utility metering and/or sub-metering or by using an energy simulation model of the as-built building calibrated to metered energy use data. The Projected Baseline Energy Use is determined by energy simulation of the Baseline under the climatic and operating conditions of the M&V period.

As with the other options, this section provides the general framework for applying Option D. Section 6.3 of ASHRAE Guideline 14 is a source of further detailed information on many of the technical aspects of whole building calibrated simulation.

Whole Building Calibrated Simulation requires a very accurate energy simulation model of the as-built building as well as a similarly detailed simulation model of the Baseline. (In practice the initial Baseline model is often developed from the as-built simulation model). The as-built energy use projections are compared to the measured Post-Construction Energy Use. Significant deviations are investigated and addressed, and corrections and adjustments are applied to the as-built model in order to achieve calibration. These same corrections and adjustments, to the greatest extent possible, are also applied to the Baseline simulation. The objective of the calibration process is not only to calibrate the as-built simulation, but also develop a calibrated and defensible Baseline simulation, thereby minimizing the error in the Projected Baseline Energy Use.

System sub-metering facilitates the calibration process and substantially enhances calibration accuracy and is strongly recommended for more intensive M&V programs.

Option D is most suited to buildings with numerous ECMs that are highly interactive or where the building design is integrated and holistic, rendering isolation and M&V of individual ECMs impractical or inappropriate. The requirement for whole-building simulation distinguishes Option D from Options A and B.

4.5.1 Option D: Types of Simulation Programs and Simulation Issues

The 2001 ASHRAE Handbook (Fundamentals) provides information on different types of building simulation models. DOE also maintains a current list of public domain and proprietary building energy simulation software. This information can be obtained at www.eren.doe.gov/buildings/tools_directory.

Whole building simulation programs usually involve hourly calculation techniques. However, in some cases less rigorous methods such as ASHRAE's simplified energy analysis procedures using modified bin methods and simplified HVAC models may be suitable.

Special-purpose software may be used to simulate energy use of individual components or systems. HVAC and other component models are available from ASHRAE and other organizations (see *Appendix B — Resources*). *In some cases it may be necessary to combine the results of more than one simulation tool to fully assess energy use.*

The accuracy of computer simulation is a subject of ongoing debate. The qualifications and experience of the simulator is a key factor, and subsequently Option D is intended for only the most qualified practitioners.

4.5.2 Option D: Metering

Sub-metering of the Post-Construction Energy Use is invaluable to the process of simulation calibration. It facilitates calibration down to specific system levels as well a provide feedback on the operational state of equipment and systems.

Sub-metering systems should be configured to correlate to the analysis structure and end-use breakdown of the software being utilized in order to allow direct comparison of metered and projected energy use. With sophisticated hourly simulation software this can be done at the various system levels such as individual spaces, HVAC secondary zones, and HVAC plant.

4.5.3 Option D: Measurement vs. Stipulation

The decision regarding which parameters to measure and which to stipulate is often driven by purely practical considerations. Parameters related to occupant use of the facility are particularly difficult to directly monitor or measure, and therefore must often be stipulated. However, as with Option A, stipulations should have some basis in fact or observation and must be well documented. The effect of variances should also be tested and quantified in the form of a sensitivity analysis if the resulting error is pertinent to the M&V objectives.

4.5.4 Option D: Installation Verification

Using Option D for large systems or whole-building M&V presents the same challenges as Option C in the respect that buildings are often unstable in their first year or two of operation. Frequent post-commissioning re-verification of operational status and the associated potential to perform is usually necessary. However, Option D presumably has the advantage of sub-metering to help track and document these instabilities. This information can subsequently be incorporated into the simulation calibration process.

4.5.5 Option D: Measurement Interval

The amount of variation in a parameter, expected or otherwise (see *4.5.4* above) will dictate the frequency of measurement. As with Options A and B, if a parameter is not expected to change, it may be measured immediately after installation and then periodically re-measured to verify that it is remaining constant. Alternately, parameters that change daily or hourly may warrant continuous metering.

Consideration should also be given to how continuous metering data is collated. Hourly simulation programs are only capable of resolving calculations to one hour intervals. Consequently, data from continuous meters must be averaged to a one hour period if it is to be used for comparison with simulation results and calibration.

4.5.6 Option D: Design and Baseline Development

A requirement for Option D is a whole building simulation model which accurately reflects the as-built building. If such a model is not produced in conjunction with the building design process, then it will have to be independently developed for M&V purposes.

The Baseline simulation model can often be developed from the as-built model. This may involve removing the ECMs or altering system and building characteristics to a prescribed configuration or level of performance. *However, care must be taken when removing individual ECMs or changing building characteristics to ensure that all secondary impacts resulting from the ECM removal or building change are considered and incorporated in the model. Otherwise the simulation will not accurately represent the full effect of the alterations*. A simple example is the "backing out" of high performance glazing. In real practice this would result in a number of secondary changes to the design, including changes in heating and cooling loads, chiller plant size, and heating plant size. These changes must be incorporated in the revised simulation model to arrive at a true assessment of the impact of the ECM removal. Moreover, the changes must be incorporated by essentially re-designing the affected systems to suit. Simply allowing the simulation program to default or auto-size/respond in response to the ECM removal can result in significant savings estimation error.

If a Baseline simulation model is to be developed independently as opposed to developed from the as-built model, then the cautions of 4.5.6 also apply. The Baseline simulation must accurately reflect what would actually be designed if the Baseline building were to be constructed.

4.5.7 Option D: Simulation Calibration

Option D requires the calibration of both as-built and Baseline simulation models. However, because the Baseline is hypothetical and has no direct relationship or reference to reality, the only available approach is to first calibrate the as-built simulation. This first requires adjusting the as-built simulation inputs and parameters to reflect the conditions of operation of the facility during the M&V period. Most of these adjustments will consist of changing stipulations such as schedules and occupancy, but others may result from measurements which uncover variances in parameters such as equipment performance curves or system control. Again, sub-metering can be invaluable in providing the necessary feedback to recognize and quantify these variances.

A crucial parameter which must usually be adjusted is weather. Local weather data for the M&V period must be acquired and collated in a format suitable for the software package employed. Most hourly simulation packages include utilities specifically for this purpose. Government weather agencies are the most reliable and verifiable sources of weather data, although in some cases on-site weather measurement may be warranted.

After the required operational and weather adjustments to the as-built simulation model have been made, the model is re-run and the results compared to the metered Post-Construction Energy Use for the M&V period. The comparison should include energy end uses for all system levels for which metered data is available. Variances are then investigated and reconciled, with further changes to the as-built simulation model being made as necessary to achieve acceptable calibration.

Some variances are more significant than others, and it may not be practical to correct all deviations due to constraints in the software being used. The simulator must rely on training and experience to assess and address these situations. Many software packages provide user support systems which can be helpful. Significant deviations which cannot be corrected within the software must be dealt with through adjustments which are external to the simulation. In some cases the calibration investigation may also uncover under-performance of as-built equipment or systems. Depending on the objectives of the project, these as-built deficiencies can be incorporated in the as-built simulation as a calibration measure or can be corrected prior to continuing the calibration process.

The acceptable margin of error for simulation calibration depends on the requirements and objectives of the M&V program as well as the magnitude of the savings that are involved. ASHRAE Guideline 14 provides suggested ranges of error for various calibration situations.

After the as-built model has been satisfactorily calibrated, to the greatest extent possible all adjustments made to the as-built model should be incorporated into the Baseline model. It should be noted that the similarity between the as-built building and Baseline in terms of physical configuration, systems, and other key features will dictate how many as-built calibration adjustments are applicable to, and can be transferred to the Baseline model. In extreme cases where the two buildings are completely dissimilar, the as-built calibration may have little or no value beyond providing a quality control check for the as-built model.

4.5.8 Option D: Savings Estimation

Savings with Option D are estimated by one of two methods:

Method 1 – Subtract the energy use of the calibrated as-built model from the energy use of the calibrated Baseline model.

or

Method 2 – Subtract the metered post-construction energy use from the energy use of the calibrated Baseline model.

The choice of which method is used depends on the objectives of the M&V program and is related to the control of savings estimation error.

- Method 1 can conceivably minimize the effects of systemic simulation error. However, this only applies if the nature of the error is understood and can be reasonably assumed to be consistent between the as-built and Baseline simulations. In that case the error does not affect the savings calculation since the net difference in energy projections between the simulations is unaffected.
- Method 1 does not readily identify long term post-calibration physical failure or degradation in equipment or system performance unless the simulations are re-calibrated to metered data for each subsequent M&V period. This is because the simulation algorithms and equipment models assume "perfect" equipment operation.
- Method 2 more readily allows identification of post-calibration performance degradation without complete re-calibration since savings deterioration will be evident through unexplained increased metered energy use.
- Method 2 requires a highly accurate Baseline simulation model and a thorough understanding of potential simulation error. The savings estimation must be adjusted to account for any simulation error.

While savings estimation is usually focused on a limited M&V period, in some cases it may be desirable to estimate subsequent long term savings. This can potentially be accomplished by one of three approaches:

- If savings estimation Method 1 is being used, completely re-calibrate the as-built and Baseline simulation models for each subsequent M&V period. This will allow detection of physical degradation in equipment or system performance since the deterioration will be identified in the calibration process.
- If savings estimation method 2 is being used, adjust the Baseline simulation model to reflect operational and weather conditions for each subsequent

M&V period. Significant physical equipment or system performance degradation will be evident through savings deterioration.

- Use the energy use of the as-built building from the first "stable" or acceptable year of operation as the new baseyear energy use, and apply the regression methods of IPMVP Volume I to correlate the baseyear energy to weather and other operational variables for subsequent periods. Essentially the as-built energy use and operating conditions of the first M&V year become the baseline for subsequent M&V periods, and subsequent savings are estimated relative to this new baseline.

4.5.9 Option D: Uncertainty

ASHRAE Guideline 14 provides technical guidance for statistical analysis of simulation error. However, general factors affecting the uncertainty of Option D include:

- The complexity of the ECMs, systems, or building.
- Operational stability or changes to the as-built building through the M&V period.
- The simulation software utilized and it's ability to model the ECMs, systems, or building.
- The rigor and accuracy of the as-built and Baseline simulation models.
- The extent and sophistication of sub-metering.
- The accuracy of stipulated parameters.
- The degree of calibration achieved.
- Similarity between the as-built and Baseline buildings.
- Capabilities and experience of the practitioner.

4.5.10 Option D: Cost

The cost of implementing Option D is dependent on the following factors:

- The size and complexity of the ECMs, systems, or building.
- The required degree of accuracy in savings determination.
- The simulation software utilized and its associated complexity.
- The extent and sophistication of sub-metering.

As with other M&V options, rigor and associated cost must be balanced against expected savings and the significance of potential error.

4.5.11 Option D: Best Applications

Option D is best applied where:

- The M&V focus is on interrelated ECMs and systems, or whole building performance rather than simple individual ECMs.
- A high degree of accuracy in savings determination is required.
- The budget for M&V is generous.
- Meters can serve a dual purpose e.g. sub-metering for operational feedback or tenant billing.

Appendix A Definitions

Baseline – A complete set of assumed conditions of design, use, operation, and occupancy (typically based on an energy efficiency standard or guideline).

Model – A mathematical representation or calculation procedure that is used to predict the energy use and demand in a building or facility. Models may be based on equations that represent the physical processes or may be the result of statistical analysis of measured energy use data.

Measurement – The process of using an instrument to determine a physical quantity.

M&V Period – Any period or time, following commissioning of the building, which will be used for determining savings.

Projected Baseline Energy Use – The Baseline energy use or demand calculated using post-construction operating conditions.

Simulation Model – An assembly of computerized algorithms that calculate energy use for specified time intervals at the systems and at the whole building level based on engineering equations and user-defined parameters.

Appendix B Resources

1 ASHRAE Guideline 14 (2002)

The purpose of this document is to provide guidelines for reliably measuring the energy and demand savings due to building energy management projects. It introduces generic M&V approaches and describes detailed analysis procedures associated with completing M&V. In addition, it presents instrumentation and data management guidelines and describes methods for accounting for uncertainty associated with models and measurements.

The guideline can be ordered directly from ASHRAE:

Mailing address: 1791 Tullie Circle, N.E., Atlanta, GA 30329.
Toll-free: (800) 527-4723 (U.S. and Canada only)
Phone: (404)636-8400
Fax: (404)321-5478
URL: www.ashrae.org

2 ASHRAE 90.1 (2001): Energy Standard for Buildings Except Low-Rise Residential Buildings

The purpose of this standard is to provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings.

This standard provides minimum energy-efficient requirements for the design and construction of:

- new buildings and their systems,
- new portions of buildings and their systems, and
- new systems and equipment in existing buildings.

The standard can be ordered directly from ASHRAE.

3 ASHRAE Handbook Chapters on Data Acquisition and Recording and Life Cycle Costing

ASHRAE Handbook, 2001 Fundamentals, Data Acquisition and Recording, Chapter 14, pp. 14.31-14.32.

ASHRAE Handbook, 1999 HVAC Applications, Economic Analysis Techniques, Chapter 35, pp. 35.6-35.12.

4 California's Energy Efficiency Standards for Residential and Nonresidential Buildings

The California Building Code (Title 24) establishes building energy efficiency standards for new construction (including requirements for entire new buildings, additions, alterations, and in nonresidential buildings, repairs).

Electronic copies of the standard can be downloaded from http://www.energy.ca.gov/title24/standards/index.html. Printed copies of Title 24 can be obtained by calling 916-654-5200.

5 The Canadian Model National Energy Code for Buildings (MNECB)

The MNECB establishes prescriptive equipment/system and performance-based whole-building energy efficiency standards for new buildings and major renovations. A number of provincial and municipal jurisdictions in Canada have adopted, or are in the process of adopting the Code.

The MNECB can be obtained in printed or electronic version by calling:

Natural Resources Canada Publications
Phone: 1800-387-2000
URL: http://oee.nrcan.gc.ca.

6 Federal Energy Management Program (FEMP)

The US Department of Energy operates the Federal Energy Management Program (FEMP) that assists federal agencies reduce their energy and operating costs through performance contracting. As part of the ESPC program, FEMP developed and maintains a set of measurement & verification guideline to be used for all ESPC and Super ESPC projects. Although based on the IPMVP, the FEMP guidelines (currently at version 2.2) offer specific direction for many common measures. Printed copies of the FEMP M&V guidelines can be obtained by calling 1-800-363-3732 (DOE-EREC) or can be downloaded from the FEMP web page at
http://www.eren.doe.gov/femp/financing/espc/contract_tools.html.

7 International Performance Measurement & Verification Protocol (IPMVP)

International Performance Measurement & Verification Protocol – Volume I, 2002. “Concepts and Options for Determining Energy and Water Savings.” Washington, DC.: US Department of Energy.

International Performance Measurement & Verification Protocol – Volume II, 2002. "Concepts and Practices for Improved Indoor Environmental Quality." Washington, DC.: US Department of Energy.

The International Performance Measurement and Verification Protocol (IPMVP) provides an overview of current best practice techniques available for verifying results of energy efficiency projects.

Copies of IPMVP are available from:

Phone: 800-363-3732 (for hard copies)
URL: http://www.ipmvp.org (for electronic copies)

8 The Model Energy Code (MEC)

Published and maintained by the International Code Council (ICC) as the “International Energy Conservation Code” (IECC), contains energy efficiency criteria for new residential and commercial buildings and additions to existing buildings. It covers the building's ceilings, walls, and floors/foundations; and the mechanical, lighting, and power systems.

Copies of the MEC/IECC are available from the model code organizations:

a) Building Officials Code Administrators International, Inc. (BOCA) (708) 799-2300

b) International Conference of Building Officials (ICBO) (562) 699-0541

c) International Code Council (ICC) (703) 931-4533

d) Southern Building Code Congress International Inc. (SBCCI) (205) 591-1853

9 US Department of Energy's High Performance Building Initiative (HPBi)

The High Performance Buildings initiative (HPBi) is a research program sponsored by the U.S. Department of Energy that works to create and deploy commercial buildings that use substantially less energy than typical practice--50% or less--by changing how commercial buildings are designed, built, and operated. By 2025, the HPBi will establish the technical capability to combine energy efficiency with renewable energy sources, enabling the construction of net-zero energy buildings (ZEB) at low incremental cost.

URL: http://www.eere.energy.gov/buildings/highperformance/

10 US Green Building Council's Leadership in Energy & Environmental Design (LEED™)

The LEED™ (Leadership in Energy and Environmental Design) Green Building Rating System™ is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED™ provides a complete framework for assessing building performance and meeting sustainability goals. LEED™ was created to: a) define "green building" by establishing a common standard of measurement; b) promote integrated, whole-building design practices. LEED™ rating systems (e.g., for new construction, existing buildings, core and shell projects, and commercial interiors) reward use of the IPMVP for the Measurement and Verification credit under the Energy and Atmosphere category.

The LEED™ Rating System can be downloaded for free from the US Green Building Council web site (http://www.usgbc.org). Supporting documents can be purchased directly from US Green Building Council:

Mailing address: 1015 18th Street, NW, Suite 805, Washington, DC 20036
Phone: (202)828-7422
Fax: (202)828-5110
URL: www.usgbc.org

11 Weather Data

Information on weather data formats and weather data can be found at the following web sites:

- http://rredc.nrel.gov/solar/pubs/tmy2/
- http://gundog.lbl.gov/dirsoft/d2weather.html

12 Citations and references regarding Stipulations

- US Department of Energy, 2000. FEMP Option A Detailed Guidelines (http://ateam.lbl.gov/mv)

13 Citations and references regarding calibrated simulation

- Stein JR; Raychoudhury A; Eley C, 2000. "The Jury Is (Halfway) In: New Building Performance Contracting Results," Panel 4, pp. 4.315 - 4.326, Proceedings of the 2000 American Council of Energy Efficient Economy ACEEE) Summer Study on Energy Efficiency in Buildings, Asilomar, CA.
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4th Quarter Report and Annual DOE 2.1e Simulation Reconciliation – 1998", under contract to Canadian CANMET CETC Buildings Group, Standing Offer # 23341-6-2006/001-SQ, Order 23229, Ser. #3104.

- Haberl J; Bou Saada T, 1998. "Procedures for Calibrating Hourly Simulation Models to Measured Building Energy and Environmental Data", ASME Journal of Solar Energy Engineering, Vol. 120, pp. 193-204, (August).
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- Sylvester K; Song S; Haberl J; Turner D, 2002. "Sustainability Assessment of the Robert E. Johnson State Office Building," Proceedings of the Thirteenth Symposium on Improving Building Systems in Hot and Humid Climates, Texas A&M University, Houston, Texas, pp. 103-109.
- Kreider J and Haberl J, 1994. "Predicting Hourly Building Energy Usage: The Great Energy Predictor Shootout: Overview and Discussion of Results," ASHRAE Transactions Technical Paper, Vol. 100, Pt. 2 (June).
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Appendix C Case Studies

Crestwood Corporate Centre Building 8, Vancouver, BC, Canada

Project Description – Crestwood Corporate Centre Building 8 is a three storey 80,000 sq. ft. multi-tenant office building constructed in 1997. The project participated in the Canadian CANMET C-2000 Program for Advanced Commercial Buildings which required, among a range of environmental performance criteria, energy use no more than 50% of that of a Baseline building derived from ASHRAE/IES Standard 90.1-1989. Both the Baseline and the Design were the subject of ongoing simulation through the design process using DOE 2.1e.

M&V Objectives – The building was subjected to a broad monitoring program to validate all aspects of performance, including energy use, indoor air quality, and occupant satisfaction. The specific objectives of the energy use M&V were:

- To estimate as-built energy savings at the ECM and at the whole building level relative to the Baseline under actual operating conditions.
- To assess and validate the simulation methodologies employed and the simulation accuracy.
- To test the validity of the ASHRAE/IES 90.1-based operating and occupancy assumptions which were used in the design process simulations.

M&V Baseline – The Baseline developed for the project was essentially a hybridization of the ASHRAE/IES 90.1-89 Energy Cost Budget Method, using the Reference Building but applying HVAC systems as specified by the Prototype Building approach.

M&V Methodology – The M&V methods utilized were Option B – ECM Isolation and Option D – Whole Building Calibrated Simulation. Option B was directed at isolating the performance of certain key pieces of equipment such as the chillers and condensing boilers.

The M&V period consisted of 18 months spanning 1997-98. The first six months of M&V was a trial period which allowed testing and debugging of monitoring systems as well as stabilization of the building operation. The formal M&V period was the subsequent 12 months, which coincided with the 1998 calendar year.

The building was equipped with a comprehensive sub-metering system that monitored electrical use of all major equipment as well as lighting and plug power circuits. Additional meters monitored heating and cooling hydronic systems, natural gas consumption, and service water use. Measurement intervals were 15 minutes for electrical meters and continuous pulse for fluid meters. Surveys were used to determine occupancy schedules. Local weather data for the M&V period was obtained from Environment Canada.

Results and Lessons Learned –

- The as-built simulation model was calibrated to within 5% of monitored total annual building energy use (net underestimation), with monthly variances within +/- 10%. The underestimation was attributed to deficiencies in the software algorithms which could not be addressed within the simulation, rendering external adjustments necessary to achieve full correlation with as-built energy use. Most of these deficiencies were related to the inability of the software to model energy losses associated with equipment cycling and low part-load operation.

- The ASHRAE/IES 90.1 occupancy schedules grossly underestimated building occupancy schedules. This particular building also demonstrated an inordinately high plug load due to the high-tech tenancies. Consequently the Design building energy use was much higher than anticipated. However, the occupancy schedules and plug load also had a similar effect on the Baseline, significantly elevating Baseline energy use.
- The simulation calibration demonstrated that the Design building was essentially performing as-designed with some minor variances.
- The most significant simulation calibration issues were the inability of DOE 2.1e to capture the full inefficiency of boilers and chillers operating a very low part-load. This required the imposition of surrogate loads to mimic the losses.
- Reliability of the sub-metering and data logging systems was also an issue from time to time, requiring the interpolation of data during certain down-time periods.

References

G. F. Shymko & Associates Inc., DukeSolutions Canada Inc., 1999. “Energy Use Monitoring, Crestwood Corporate Centre - Building 8, Richmond, BC, 4th Quarter Report and Annual DOE 2.1e Simulation Reconciliation - 1998", under contract to Canadian CANMET CETC Buildings Group, Standing Offer # 23341-6-2006/001-SQ, Order 23229, Ser. #3104.

Robert E. Johnson State Office Building, Austin, TX, USA

Project Description – The Robert E. Johnson State Office building is a five storey 303,389 sq. ft. office building constructed in 2000-2001. The facility houses a variety of legislative departments and support staff. As a leading example of sustainable design, the building was the subject of a comprehensive M&V program.

M&V Objectives – The objectives of the M&V program were:

- To estimate as-built energy savings at the ECM and whole building level relative to the Baseline under actual operating conditions.
- To test simulation calibration methodologies and techniques.

M&V Baseline – Two Baselines were utilized for this project:

- The Design building with a number of ECMs removed from the design.
- Other state office buildings in the LoanSTAR database.

M&V Methodology – The M&V methods utilized were Option D - Calibrated Simulation method 1, and an extrapolated version of Option C - Whole Building Comparison. Option D concentrated on evaluating the impact of low-e glazing and the performance of major systems such as the HVAC air handling system, chillers, lighting, and lighting controls.

The M&V period for Option D consisted of 10 months in 2001. A sub-metering system was installed which monitored electrical use of the major systems under consideration as well as lighting and plug power circuits for a typical floor. Additional meters monitored heating consumption and HVAC operating parameters. Measurement intervals were one hour. Occupancy profiles for incorporation in the calibrated simulation were developed from recorded lighting and plug data for a typical floor. Weather data for the M&V period was obtained from the National Weather Service and was supplemented by on-site ambient solar measurements.

A DOE 2.1e simulation of the as-built building was developed specifically for the M&V program and calibrated to monitored data. Individual ECMs were then removed from the calibrated simulation to estimate the individual and collective savings they generated.

The extrapolated Option C M&V consisted of comparison between: a) the actual utility data of the building for six months after commissioning, extrapolated using the calibrated simulation model to annual performance through all seasons of a standard year and then converted to an annual energy index, and b) the annual energy index data registered for 11 comparable buildings in the LoanSTAR database.

Results and Lessons Learned –

- Satisfactory calibration of the Design simulation was achieved at a most M&V levels, with variances generally within ± 20%.
- Limitations in the modeling capabilities of the version of DOE2.1e utilized presented some simulation difficulties. Limitation included the inability to simulate certain systems as well as limits on the number of building elements and zones which could be inputted. Simplifications were applied to the simulation to circumvent these problems.

- Uncertainty regarding operational parameters and variables such as temperature setpoints also presented calibration difficulties.
- The buildings in the LoanSTAR database varied in energy performance from 100 to over 200 kBtu per sq. ft. per year. By comparison the performance extrapolated from the first six months' worth of data showed an energy use of 148 kBtu per sq. ft. per year. This wide variance in the comparison database illustrates the inherent shortcomings of Option C.

References

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