EVO

EFFICIENCY VALUATION ORGANIZATION

International Performance Measurement and Verification Protocol

Concepts and Options for Determining Energy and Water Savings
Volume 1

Prepared by Efficiency Valuation Organization
www.evo-world.org

January 2012

EVO 10000 – 1:2012

International Performance Measurement and Verification Protocol

Concepts and Options for Determining
Energy and Water Savings
Volume 1

Prepared by Efficiency Valuation Organization
www.evo-world.org

January 2012

EVO 10000 – 1:2012

EVO Vision

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

EVO Mission

To develop and promote the use of standardized protocols, methods and tools to quantify and manage the performance risks and benefits associated with end-use energy-efficiency, renewable-energy, and water-efficiency business transactions

January 2012

Dear Readers,

As the world is coming to recognize that energy efficiency is foundational to good environmental management, the importance of proper savings documentation has never been greater. It is certainly in everyone's interest that predicted savings are achieved and properly reported. Notably:

- **energy users** need to have robust methods of verifying achievement of their energy policy objectives, to get or maintain ISO 50001 certification for their management practices;
- **potential purchasers of energy efficiency products or services** want to know that their potential purchases have already proven themselves using widely recognized methods;
- **actual purchasers of energy efficiency products or services** need feedback on the effectiveness of their purchases, to help them fine tune performance and to inform further purchases;
- **governments and utilities** need to know that savings reported from energy efficiency programs are grounded in actual field-measured results following a widely accepted protocol.

Basically, the knowledge that energy savings can be transparently reported is vital to the acceptance of energy efficiency proposals.

EVO is the only organization dedicated to provision of tools for this purpose. This IPMVP, now in its seventh edition, **defines transparency in savings reports**, while assembling best practice from around the world. EVO also publishes the IEEFP (International Energy Efficiency Financing Protocol) to help energy efficiency investors indentify and invest in well managed energy cost saving projects.

IPMVP's flexible framework of M&V Options allows practitioners to craft the right M&V Plan for their building or industrial facility, inspiring confidence in those who wish to harvest their financial and/or environmental benefits. Clear definition of terms, and heavy emphasis on consistent and transparent methods are the core precepts of the IPMVP. Though application details are unique to each project, IPMVP's flexible framework has been successfully applied to all types of energy efficiency techniques, for thousands of projects and programs, large and small, around the world.

IPMVP is the work of numerous volunteers and sponsors, listed herein and in previous editions. I would like to thank all those shown in the Acknowledgments section herein. You can join this truly unique group of professionals by submitting comments, joining an EVO committee, or supporting the movement by subscribing to EVO. I encourage all readers to provide feedback, so we can continuously improve the IPMVP (email to: ipmvprev@evo-world.org).

John Cowan
Chair of the Board
Toronto, Canada

ACKNOWLEDGEMENTS

The IPMVP is primarily maintained by the following volunteers. EVO appreciates their work in receiving comments and developing changes for the 2011 edition. EVO appreciates the support and commitments made by the employers of all EVO volunteers.

EVO Board of Directors (2012)

John Cowan, Chair (Canada), Environmental Interface Limited

Thomas Dreessen, Vice Chair (USA), EPS Capital

John Stephen Kromer,Treasurer and Immediate Past Chair (USA), Independent Consultant

Anees Iqbal, Secretary (UK), Maicon Associates Ltd.

Timothy Hui (China), EcoTech International (ETI)

Jin Ruidong (China), Chiana National Center of Housing and Settlement Department

Patrick Jullian (France), GIMELEC

Satish Kumar (India), Schneider-Electric

Tienan Li (China), Center for Industrial Energy Efficiency (CIEE)

Pierre Langlois (Canada), Econoler

Steve Schiller (USA), Schiller Consulting

IPMVP Committee (2012)

David Jump, Chair (USA,) Quantum Energy Services & Technologies, Inc. (QuEST)

Ellen Franconi, Vice-Chair (USA), Rocky Mountain Institute

Thomas Adams (USA), AFCESA

Raja Chirumamilla (USA), Sain Engineering Associates, Inc.

LJ Grobler (South Africa), Energy Cybernetics Pty Ltd.

Sami Khawaja (USA), Cadmus Group Inc.

David Korn (USA), Cadmus Group Inc.

Ken Lau (Canada), BC Hydro

Daniel Magnet (Switzerland), IBTECH

Fernando Milanez (Brazil), INEE

Tracy Phillips (USA), 7th Gen Energy Solutions

Phil Voss (USA), National Renewable Energy Lab

Kevin Warren (USA), Warren Energy Engineering

Lia Webster (USA), Portland Energy Conservation Inc. (PECI)

Raj Khilnani (India), Freelance Energy Consultant

Shankar Earni (USA), Lawrance Berkeley National Laboratory

Vilnis Vesma (UK), Degrees Days Direct Limited

Max Zhang (China), SGS-CSTC Standards Technical Services Co., Ltd.

M&V Plan Sub-Committee (2012)

Shankar Earni, Chair (USA), Lawrence Berkeley National Laboratory
Ellen Franconi, Vice-Chair (USA), Rocky Mountain Institute
Salil Gogte (USA), Nexant Inc.
David Korn (USA), Cadmus Group Inc.

IPMVP Fellows

Jeff Haberl (USA) Texas Agricultural and Mechanical University

John Stephen Kromer (USA), Independent Consultant

Steven R. Schiller (USA) Schiller Consulting Inc.

EVO is also grateful to its many individual subscribers around the world and its current organizational subscribers (also found at www.evo-world.org):

ADENE – Agencia para a Energia (Portuguese Energy Agency)
BC Hydro
Bonneville Power Administration
Dana Energy Services Company (DESCO)
EDF Electricite de France
Energy Decisions Pty Ltd.
EEVS – Energy Efficiency Verification Specialists
EU.BAC – European Building Automation and Controls Association
Gas Natural Fenosa
HEP-ESCO d.o.o.
ITE – Instituto de Tecnología EléctricaNexant, Inc.
North American Energy Standards Board
Navigant Consulting Inc.
Ontario Power Authority
Quantum Energy Services & Technologies, Inc.
Sabien Technology Ltd.
San Diego Gas & Electric Company
Schneider Electric
Services Industriels de Genève
SGS-CSTC Standards Technical Services Co., Ltd, China
Southern California Edison
Taiwan Green Productivity Foundation
Université de Genève
Vanguards Power (Hong Kong) Limited

CHANGES IN THIS EDITION

The 2012 edition makes the following changes to the 2010 edition:

1. Added content to Appendix C-1 sections for USA. Moved all references to ASHRAE to Annex C.
2. Moved detailed descriptions of users of IPMVP (Chapter 1.4) to a new Appendix D.
3. Formally modified requirements to include *"operational verification"* in addition to "savings verification" in Chapters 4 and 5. Consolidated former Chapters 4.4, 4.5 and 4.6 in the new Savings Verification Chapter 4.5, and renumbered subsequent sections of Chapter 4.
4. Included concept of "owner's project requirements for M&V" in Chapter 4.
5. Definition of baseline for new construction added.
6. The role of Equations 1f and 1g) were clarified in Chapter 4.9.3.
7. Concept of "Monitoring and Targeting," and its relationship to M&V added Its reference is made in a new Chapter 4.11 on Peristence of Savings.
8. Definitions of statistical and uncertainty concepts clarified in Appendix B.
9. Made minor corrections to typographical or wording errors and updated references made to this edition of IPMVP.
10. A Catalonian section was added to Appendix C-3 for Spain

PREFACE

Outline Of This Document

The International Performance Measurement and Verification Protocol (IPMVP) Volume I is a guidance document describing common practice in measuring, computing and reporting savings achieved by energy or water efficiency projects at end user facilities. The IPMVP presents a framework and four measurement and verification (M&V) Options for transparently, reliably and consistently reporting a project's saving. M&V activities include site surveys, metering of energy or water flow(s), monitoring of independent variable(s), calculation, and reporting. When adhering to IPMVP's recommendations, these M&V activities can produce verifiable savings reports.

The IPMVP is intended to be used by professionals as a basis for preparing savings reports. Each user must establish its own specific M&V Plan that addresses the unique characteristics of the project. The IPMVP is not a standard and thus there is no formal compliance mechanism for this document. Adherence with the IPMVP requires preparation of a project specific M&V Plan that is consistent with IPMVP terminology. It must name the IPMVP Option(s) to be used, metering monitoring and analysis methods to be used, quality assurance procedures to be followed, and person(s) responsible for the M&V.

IPMVP Volume I Chapters are organized as follows:

1. Introduces IPMVP and EVO.
2. Defines M&V, and lists eight uses for M&V techniques.
3. Lays the foundation of M&V by defining the underlying Principles of good M&V. The balance of the document summarizes common industry methods for implementing these fundamental Principles.
4. Defines the IPMVP Framework and its four Options. It presents the basic methodologies and adjustments to energy or water measurements needed to properly report savings. Tables 2 and 4, and Figure 4 summarize the Options and offer guidance in choosing amongst them for each application.
5. Lists the topics that should be contained in an M&V Plan and gives guidance on design decisions needed to make the M&V activity cost effective for all users of the savings reports.
6. Defines a means of specifying the use of IPMVP and of claiming adherence with it.
7. Presents key information that should be included in each savings report.
8. Lists many additional issues that commonly arise in M&V design or reporting.
9. Lists definitions of all italicized words in the document.
10. Provides a list of references and some useful other resources.

Appendix A provides 12 example applications of IPMVP, in varying levels of detail. It refers to EVO's website for detailed examples of M&V Plans and Savings Reports.

Appendix B summarizes basic uncertainty quantification techniques to guide decisions about the level of rigour suitable for each M&V process.

Appendix C contains region-specific materials for the United States of America, France, Spain (incl. Catalonia), Romania, Bulgaria, the Czech Republic, Croatia and Poland.

Appendix D is a Users Guide to help different types of readers understand common ways of applying the document

Efficiency Valuation Organization and IPMVP

This International Performance Measurement and Verification Protocol (IPMVP) is sponsored by the Efficiency Valuation Organization (EVO), a non-profit private corporation. EVO envisions a global marketplace that correctly values the efficient use of natural resources and utilizes end-use efficiency as a viable alternative to new energy supply. EVO's mission is to develop and promote standardized methods to quantify and manage the risks and benefits associated with business transactions on end-use energy efficiency, renewable energy, and water efficiency. EVO is a subscriber-based organization with supporters around the world.

EVO is grateful to its volunteers who develop and maintain EVO documents. Members of our current Board and Committees active in developing this document appear in the Acknowledgements section, above, along with Organizational Subscribers.

EVO maintains a website (www.evo-world.org) which contains:

- A subscribers' section with access to pre-release copies of some EVO documents, reference materials, newsletters, discussion forums, and links to other resources;
- Latest released editions of the documents, and archival editions;
- Lists of the current committee members and supporters;
- Invitation for comments on IPMVP documents to the email address of: ipmvprev@evo-world.org ;
- Information on EVO's training and certification programs;

EVO documents should include unique methods from around the world. Therefore, EVO is developing international, regional groups to document international M&V methods. To participate as a volunteer or subscriber, please visit the EVO website, www.evo-world.org, for current contact information.

EVO's current activities and plans are summarized below.

EVO's Current Publications

Currently EVO has four publications available on its website:

IPMVP Volume I Concepts and Options for Determining Energy and Water Savings

Volume I defines terminology and suggests good practices for documenting the effectiveness of energy or water efficiency projects that are implemented in buildings and industrial facilities. These terms and practices help managers to prepare M&V Plans, which specify how savings will be measured for each project. The successful M&V Plan enables verification by requiring transparent reports of actual project performance.

IPMVP Volume II Indoor Environmental Quality (IEQ) Issues

Volume II reviews IEQ issues as they may be influenced by an energy efficiency project. It highlights good project design and implementation practices for maintaining acceptable indoor conditions under an energy efficiency project. It advises on means of measuring IEQ parameters to substantiate whether indoor conditions have changed from the conditions of the baseline when determining savings. Volume II has been archived, and remains available in the archives section of the public library on EVO's website.

IPMVP Volume III Applications

Volume III contains specific application guidance manuals for Volume I. The two current applications manuals address new building construction (Part I) and renewable energy additions to exisiting facilities (Part II). This volume is expected to be an area of continued development as more specific applications are defined.

International Energy Efficiency Financing Protocol (IEEFP)

The IEEFP provides guidelines for local financing institutions around the world to evaluate and finance energy efficiency and savings-based renewable projects.

History Of Previous Editions

The first edition of IPMVP, entitled the North American Energy Measurement and Verification Protocol, was published in March 1996. It was modified in December 1997 then renamed the International Performance Measurment and Verification Protocol. Options A and B were changed substantially when IPMVP was re-published in 2001 and minor editorial changes were added in a 2002 edition. Volume II on Indoor Environmental Quality was published in 2002. Committees, sponsored by the United States' Department of Energy (DOE) wrote and edited these documents.

In 2002, IPMVP Inc. was incorporated as an independent non-profit corporation in order to include the international community and relieve the U.S. Department of Energy of its responsibilities as the organizer. IPMVP Inc. raised its own funds, created a website, and published the new Volume III Parts on New Construction and Renewables. In 2004, IPMVP Inc. was renamed Efficiency Valuation Organization as it expanded its focus.

In 2007, EVO updated IPMVP Volume I primarily for clarity, thought re-writing the uncertainty Appendix B. No substantive changes were made to the core concepts, though the titles of Options A & B were expanded along with their descriptive materials, to ensure proper understanding. In 2009, Volume I was modified to separate USA-specific references and to establish a structure for many region-specific materials in a new Appendix C for the USA and France. . In 2010, Volume I was modified to add more European references and Appendices, and updated the significant digitis presentation.

Training And Certification

EVO recognizes that documents alone will not improve the valuation of energy efficiency in the world. Therefore EVO and its world wide partners introduced awareness and training programs about measurement and verification. These programs educate professionals on methods and recent developments in M&V.

EVO also has a Certified Measurement and Verification Professional (CVMP) program for professionals who pass a test demonstrating their knowledge of IPMVP and have appropriate knowledge experience or training. CMVP®s should be competent to develop M&V Plans and to manage M&V programs for straightforward applications. For more information on the CMVP® program, and for the names of designated CMVP®s, visit www.evo-world.org .

EVO's Future Plans

EVO's subscribers, and volunteers determine its future plans to create new educational efforts and documents about efficiency valuation. EVO welcomes IPMVP readers to become EVO subscribers, provide recommendations, and participate in new and existing EVO activities.

In light of its international focus, EVO is in the process of:

- Developing active regional affiliates who contribute to the development and maintenance of EVO publications;
- Conducting additional training and certification programs around the world;
- Preparing its latest documents in a variety of languages; and

- Encouraging its internet-based community of subscribers to share efficiency-valuation ideas.

EVO welcomes feedback and suggestions. Please direct your comments by email to ipmvprev@evo-world.org. All comments will be considered, though EVO will not necessarily reply directly. The latest English version and certified translations of EVO documents will always be available for internet download at www.evo-world.org. EVO plans to revise this document every year. Please let us know how our services can be improved or expanded.

CHAPTER 1 INTRODUCTION TO IPMVP

1.1 Purpose And Scope Of IPMVP

Efficiency Valuation Organization (EVO) publishes the International Performance Measurement and Verification Protocol (IPMVP) to increase investment in energy and water efficiency, demand management and renewable energy projects around the world.

The IPMVP promotes efficiency investments by the following activities.

- IPMVP documents common terms and methods to evaluate performance of efficiency projects for buyers, sellers and financiers. Some of these terms and methods may be used in project agreements, though IPMVP does not offer contractual language.
- IPMVP provides methods, with different levels of cost and accuracy, for determining savings[1] either for the whole facility or for individual energy conservation measures (ECM)[2];
- IPMVP specifies the contents of a Measurement and Verification Plan (M&V Plan). This M&V Plan adheres to widely accepted fundamental principles of M&V and should produce verifiable savings reports. An M&V Plan must be developed for each project by a qualified professional[3].
- IPMVP applies to a wide variety of facilities including existing and new buildings and industrial processes. Chapter 1.4, User's Guide, summarizes how different readers might use IPMVP.

IPMVP Volume I defines *M&V* in Chapter 2, presents the fundamental principles of *M&V* in Chapter 3, and describes a framework for a detailed *M&V Plan* in Chapter 4. The details of an *M&V Plan* and *savings* report are listed in Chapters 5 and 6, respectively. The requirements for specifying use of IPMVP or claiming adherence with IPMVP are shown in Chapter 7. Volume I also contains a summary of common M&V design issues, Chapter 8, and lists other *M&V* resources. Twelve example projects are described in Appendix A and basic uncertainty analysis methods are summarized in Appendix B. Region-specific materials are in Appendix C. Specific guidance for different types of users is in Appendix D.

IPMVP Volume II provides a comprehensive approach to evaluating building indoor-environmental-quality issues that are related to ECM design, implementation and maintenance. Volume II suggests measurements of indoor conditions to identify changes from conditions of the baseline period.

IPMVP Volume III provides greater detail on M&V methods associated with new buiding construction, and with renewable energy systems added to existing facilities.

IPMVP Volumes I and III are a living suite of documents, with the latest modifications available on EVO's website (www.evo-world.org). Volume II is now found in the archives of the EVO website.

1.2 Benefits Of Using IPMVP

IPMVP's history since 1995 and its international use brings the following benefits to programs that adhere to IPMVP's guidance.

---

[1] Words in italics have the special meanings defined in Chapter 8.

[2] Although there is some debate over the differences between two terms — energy conservation measure (ECM) and energy efficiency measure (EEM) — the common ECM term is defined to include both conservation and efficiency actions. See Chapter 8.

[3] www.evo-world.org contains the current list of Certified *M&V* Professionals (CMVP®s), persons with appropriate experience and who have demonstrated their knowledge of IPMVP by passing an examination.

- Substantiation of payments for performance. Where financial payments are based on demonstrated energy or water *savings*, adherenece to IPMVP ensures that *savings* follow good practice. An IPMVP-adherent *savings report* allows a customer, an energy user or a utility, to readily accept reported performance. *Energy service companies* (*ESCOs*) whose invoices are supported by IPMVP-adherent *savings reports*, usually receive prompt payments.
- Lower transaction costs in an *energy performance contract*. Specification of IPMVP as the basis for designing a project's *M&V* can simplify the negotiations for an *energy performance contract*.
- International credibility for energy *savings reports*, thereby increasing the value to a buyer of the associated energy *savings*.
- Enhanced rating under programs to encourage or label sustainably designed and/ or operated facilities.
- Help national and industry organizations promote and achieve resource efficiency and environmental objectives. The IPMVP is widely adopted by national and regional government agencies and by industry organizations to help manage their programs and enhance the credibility of their reported results.

1.3 IPMVP's Relationship To Other *M&V* Guidelines

Chapter 9 lists other interesting resources for readers of IPMVP. Appendix C lists other guidelines, protocols, and documents from different regions of the world that are applications of IPMVP, or provide references to relevant codes, standards, and programs that reference IPMVP.

1.4 Who Uses IPMVP?

IPMVP presents common principles and terms that are widely accepted as basic to any good *M&V* process. It does not define the *M&V* activities for all applications. Each project must be individually designed to suit the needs of all readers of energy or water *savings reports*. This individual design is recorded in the project's *M&V Plan* and s*avings* are reported as defined therein.

This document is written to progressively provide greater levels of definition of *M&V* practice as it progresses through the Chapters as summarized below.

- Chapter 2 defines M&V and descibes eight different applications for *M&V* techniques.
- Chapter 3 present the six foundational principles of good *M&V* practice and the IPMVP. They are useful for guiding *M&V* design details where IPMVP is silent.
- Chapter 4 presents the general framework and *savings* computation equations needed to properly express *savings*. Table 2 summarizes four M&V design Options and Chapters 4.7 - 4.9 describe each of them. Chapter 4.10 offers guidance and a logic diagram for selecting the right Option for any application. Appendix A provides example applications of IPMVP's methods to 12 typical projects.
- Chapter 5 lists the topics and data which should be included in an *M&V Plan* and offers some suggestions on key issues which might be discussed under each topic. Readers can use this as a checklist for describing the *M&V* design for a particular project.
- Chapter 6 lists the topics and data that should be included in *savings* reports.
- Chapter 7 shows the requirements for claiming adherence with IPMVP and suggests terms for specifying the use of IPMVP in contracts.

- Chapter 8 reviews a variety of common *M&V* issues that need to be considered in any *M&V* program. A key issue governing the design and operation of an *M&V* system is the competing needs for reasonable accuracy and reasonable cost. Each user must find its own balance between the accuracy and cost of reporting. Chapter 8.5 particularly focuses on the factors involved in this tradeoff. Appendix B provides an overview of some uncertainty and statistical methods, but this overview is not a definitive text on the topic. Users are advised to seek appropriate statistical design help for any *M&V* program data normalization, sampling or uncertainty evaluation techniques they may use. Chapter 8 also presents design issues surrounding metering for *M&V* programs, though it is not a definitive text on metering.
- Chapter 9 contains the definitions of key terms used in this document. The terms are italicized throughout the document to indicate that they have the special meanings given in Chapter 9.
- Chapter 10 lists useful readings, references, and other sources of useful material.

Though the application of IPMVP is unique to each project, certain types of users will have similar methods in their *M&V Plans* and implementation. Appendix D.1 through D.10 point out some of the key ways this document may be used by the following user groups:

- Energy performance contractors and their building customers
- Energy performance contractors and their industrial process customers
- Energy users doing their own retrofits and wanting to account for *savings*
- Facility managers properly accounting for energy budget variances
- New building designers
- New building designers seeking recognition for the sustainability of their designs
- Existing building managers seeking recognition for the environmnetal quality of their building operations
- Utility demand side management program designers and managers
- Water efficiency project developers
- Emission reduction trading program designers
- Energy user's seeking ISO 50001 certification

Financial backers and purchasers of emission credits from any of the above applications will find the key ways to use this document under these same headings.

This Chapter uses terms explained in subsequent Chapters as noted in brackets, or as defined in Chapter 9 for italicized words.

CHAPTER 2 DEFINITION AND PURPOSES OF *M&V*

"*Measurement and Verification*" (*M&V*) is the process of using measurement to reliably determine actual *savings*[4] created within an individual facility by an energy management program. *Savings* cannot be directly measured, since they represent the absence of *energy* use. Instead, *savings* are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions.

M&V activities consist of some or all of the following:

- meter installation calibration and maintenance,
- data gathering and screening,
- development of a computation method and acceptable estimates,
- computations with measured data, and
- reporting, quality assurance, and third party verification of reports.

When there is little doubt about the outcome of a project, or no need to prove results to another party, applying *M&V* methods to calculate savings may not be necessary. However, it is still wise to verify (initially and repeatedly) that the installed equipment is able to produce the expected savings. Verification of the potential to achieve *savings* is referred to as *operational verification*, which may involve inspection, commissioning of equipment, functional performance testing and/or data trending (see Section 4.4. below). IPMVP-adherent *M&V* includes both *operational verification* and an accounting of *savings* based on site energy measurements before and after implementation of a project, and adjustments, as described above.

M&V is not just a collection of tasks conducted to help a project meet IPMVP requirements. Properly integrated, each M&V task serves to enhance and improve facility operation and maintenance of savings. As shown in Figure 1, M&V activities overlap with other project efforts (e.g. collecting data to both identify ECMs and establish energy baselines, commissioning and operational verification of installed ECMs, and installing monitoring systems to track and maintain savings persistence, etc.). Identifying these project synergies and establishing roles and responsibilities of involved parties during project planning will support a coordinated team effort. This can leverage complementary scopes and control M&V-related costs.

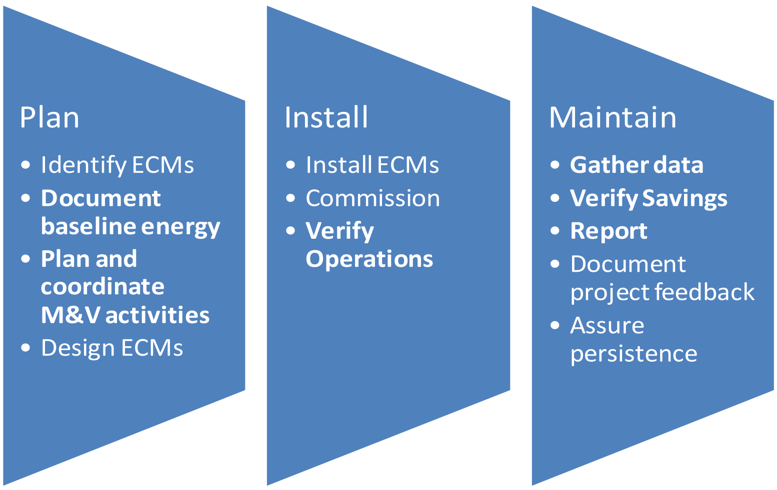


Figure 1 Process Timeline (M&V activities in bold)

[4] Words in italics have the special meanings defined in Chapter 9.

2.1 Purposes Of M&V

M&V techniques can be used by facility owners or *energy* efficiency project investors for the following purposes:

a) Increase *energy savings*

Accurate determination of *energy savings* gives facility owners and managers valuable feedback on their *energy conservation measures (ECMs)*. This feedback helps them adjust *ECM* design or operations to improve *savings*, achieve greater persistence of *savings* over time, and lower variations in *savings* (Kats et al. 1997 and 1999, Haberl et al. 1996).

b) Document financial transactions

For some projects, the energy efficiency savings are the basis for performance-based financial payments and/or a guarantee in a performance contract. A well-defined and implemented *M&V Plan* can be the basis for documenting performance in a transparent manner and subjected to independent verification.

c) Enhance financing for efficiency projects

A good *M&V Plan* increases the transparency and credibility of reports on the outcome of efficiency investments. It also increases the credibility of projections for the outcome of efficiency investments. This credibility can increase the confidence that investors and sponsors have in *energy* efficiency projects, enhancing their chances of being financed.

d) Improve engineering design and facility operations and maintenance

The preparation of a good *M&V Plan* encourages comprehensive project design by including all *M&V* costs in the project's economics. Good *M&V* also helps managers discover and reduce maintenance and operating problems, so they can run facilities more effectively. Good *M&V* also provides feedback for future project designs.

e) Manage *energy* budgets

Even where *savings* are not planned, *M&V* techniques help managers evaluate and manage *energy* usage to account for variances from budgets. *M&V* techniques are used to adjust for changing facility-operating conditions in order to set proper budgets and account for budget variances.

f) Enhance the value of emission-reduction credits

Accounting for emission reductions provides additional value to efficiency projects. Use of an *M&V Plan* for determining energy *savings* improves emissions-reduction reports compared to reports with no *M&V Plan*.

g) Support evaluation of regional efficiency programs

Utilty or government programs for managing the usage of an *energy* supply system can use *M&V* techniques to evaluate the savings at selected *energy* user facilities. Using statistical techniques and other assumptions, the *savings* determined by *M&V* activities at selected individual facilities can help predict savings at unmeasured sites in order to report the performance of the entire program.

h) Increase public understanding of energy management as a public policy tool

By improving the credibility of energy management projects, *M&V* increases public acceptance of the related emission reduction. Such public acceptance encourages investment in energy-efficiency projects or the emission credits they may create. By enhancing *savings*, good *M&V* practice highlights the public benefits provided by good *energy* management, such as improved community health, reduced environmental degradation, and increased employment

CHAPTER 3 PRINCIPLES OF *M&V*

The fundamental principles of good *M&V*[5] practice are described below, in alphabetical order.

Accurate *M&V* reports should be as accurate as the *M&V* budget will allow. *M&V* costs should normally be small relative to the monetary value of the *savings* being evaluated. *M&V* expenditures should also be consistent with the financial implications of over- or under-reporting of a project's performance. Accuracy tradeoffs should be accompanied by increased conservativeness in any estimates and judgements.

Complete The reporting of *energy savings* should consider all effects of a project. *M&V* activities should use measurements to quantify the significant effects, while estimating all others.

Conservative Where judgements are made about uncertain quantities, *M&V* procedures should be designed to under-estimate *savings*.

Consistent The reporting of a project's *energy* effectiveness should be consistent between:

- different types of *energy* efficiency projects;
- different *energy* management professionals for any one project;
- different periods of time for the same project; and
- *energy* efficiency projects and new *energy* supply projects.

'Consistent' does not mean 'identical,' since it is recognized that any empirically derived report involves judgements which may not be made identically by all reporters. By identifying key areas of judgement, IPMVP helps to avoid inconsistencies arising from lack of consideration of important dimensions.

Relevant The determination of *savings* should measure the performance parameters of concern, or least well known, while other less critical or predictable parameters may be estimated.

Transparent All *M&V* activities should be clearly and fully disclosed. Full disclosure should include presentation of all of the elements defined in Chapters 5 and 6 for the contents of an *M&V Plan* and a *savings* report, respectively.

The balance of this document presents a flexible framework of basic procedures and four Options for achieving *M&V* processes which follow these fundamental principles. Where the framework is silent or inconsistent for any specific application, these *M&V* principles should be used for guidance.

---

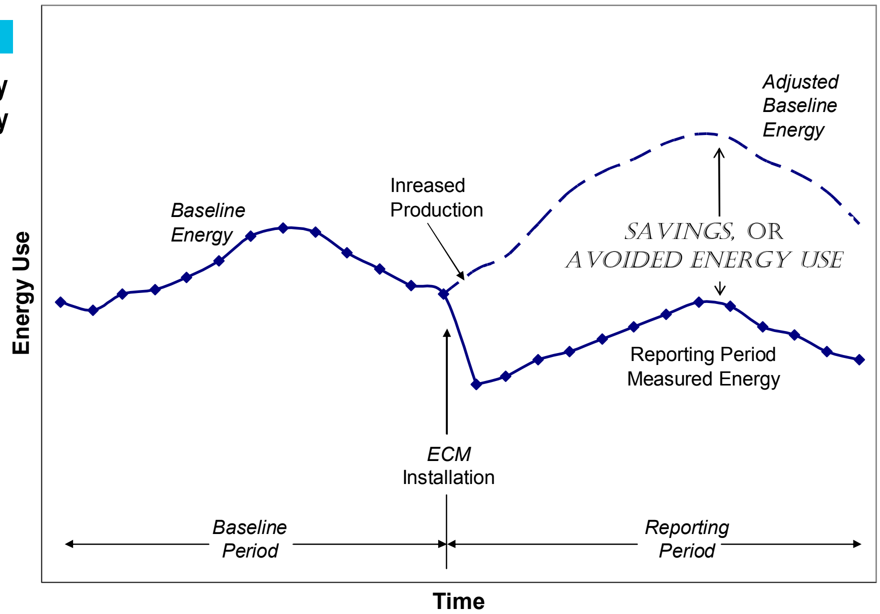
[5] Words in italics have the special meanings defined in Chapter 9.

CHAPTER 4 IPMVP FRAMEWORK AND OPTIONS

4.1 Introduction

Energy, water or demand *savings*[6] cannot be directly measured, since *savings* represent the absence of energy/water use or demand. Instead, *savings* are determined by comparing measured use or demand before and after implementation of a program, making suitable adjustments for changes in conditions.

Figure 2 Example Energy History



As an example of savings determination process, Figure 2 shows the energy-usage history of an industrial boiler before and after the addition of an *energy conservation measure (ECM)* to recover heat from its flue gases. At about the time of *ECM* installation, plant production also increased.

To properly document the impact of the *ECM,* its energy effect must be separated from the energy effect of the increased production. The "*baseline energy*" use pattern before *ECM* installation was studied to determine the relationship between energy use and production. Following *ECM* installation, this *baseline* relationship was used to estimate how much energy the plant would have used each month if there had been no *ECM* (called the "*adjusted-baseline energy*"). The *saving*, or '*avoided energy use'* is the difference between the *adjusted-baseline energy* and the energy that was actually metered during the *reporting period*.

Without the adjustment for the change in production, the difference between *baseline energy* and *reporting period* energy would have been much lower, under-reporting the effect of the heat recovery.

It is necessary to segregate the *energy* effects of a *savings* program from the effects of other simultaneous changes affecting the *energy* using systems. The comparison of before and after energy use or demand should be made on a consistent basis, using the following general Equation 1):

[6] Words in italics have the special meanings defined in Chapter 9.

Savings = (*Baseline-Period Use* or Demand - *Reporting-Period Use* or Demand) ± Adjustments 1)

The "Adjustments" term in this general equation is used to re-state the use or demand of the *baseline* and *reporting periods* under a common set of conditions. This adjustments term distinguishes proper *savings* reports from a simple comparison of cost or usage before and after implementation of an *energy conservation measure* (*ECM*). Simple comparisons of utility costs without such adjustments report only cost changes and fail to report the true performance of a project. To properly report "*savings*," adjustments must account for the differences in conditions between the *baseline* and *reporting periods*.

The baseline in an existing *facility* project is usually the performance of the *facility* or system prior to modification. This baseline physically exists and can be measured before changes are implemented. In new construction, the baseline is usually hypothetical and defined based on code, regulation, common practice or documented performance of similar *facilities*. In either case, the baseline model must be capable of accomodating changes in operating parameters and conditions so "adjustments" can be made.

The balance of this Chapter defines basic methods in these measurement and adjustment processes. If these methods do not cover all matters that arise in your project, consult the Principles of *M&V* (Chapter 3) for further guidance.

4.2 Energy, Water and Demand Terminology

The processes of determining *savings* in energy are analogous to those for determining *savings* in water or demand. To simplify the descriptions in this document, the italicized word *energy* will commonly be used to mean energy and water use or demand. Similarly the word *Energy Conservation Measure* (*ECM*) will commonly be used to mean measures to improve efficiency or conserve energy or water, or manage demand.

4.3 The *M&V* Design and Reporting Process

The *M&V* design and reporting process parallels the *ECM* design and implementation process. The *M&V* processes should involve the following steps:

1. Consider the needs of the user of the planned *M&V* report(s). If the user is focused on overall cost control, Whole-Facility methods may be most suited. If user focus is on particular *ECM*s, Retrofit Isolation techniques may be most suited (see Chapter 4.4).
2. While developing the ECM(s), select the IPMVP Option (see Chapters 4.7 - 4.11) that best suits the ECM(s), the needs for accuracy and the budget for M&V. Decide whether adjustment of all *energy* quantities will be made to the *reporting period* conditions or to some other set of conditions (see Chapter 4.6). Decide the duration of the *baseline period* and the *reporting period* (Chapter 4.5) (These fundamental decisions may be written into the terms of an *energy-performance contract*.)
3. Gather relevant *energy* and operating data from the *baseline period* and record them in a way that can be accessed in the future.
4. Prepare an *M&V Plan* (Chapter 5) containing the results of steps 1 through 3 above. It should define the subsequent steps 5 through 9.
5. As part of the final *ECM* design and installation, also design, install, calibrate and commission any special measurement equipment that is needed under the *M&V Plan*.

6. After the ECM is installed, ensure it has the potential to perform and achieve savings by conducting operational verification. This may include inspecting the installed equipment and revising operating procedures as needed to conform to the design intent of the *ECM*. This requirement may be fulfilled by a formal "commissioning" process as part of the project .

7. Gather energy and operating data from the *reporting period*, as defined in the *M&V Plan*.
8. Compute *savings* in *energy* and monetary units in accordance with the *M&V Plan*.
9. Report *savings* in accordance with the *M&V Plan* (see Chapter 6).

> ***Interactive Effects* - Example**
>
> For an ECM, which reduces the power requirements of electric lights, the *measurement boundary* should include the power to the lights. However lowering lighting energy may also lower any mechanical cooling requirements and/or raise any heating requirements. Such heating and cooling energy flows attributable to the lights cannot usually be easily measured. They are *interactive effects* which may have to be estimated, rather than included within the measurement boundary.

Steps 7 through 9 are repeated periodically when a *savings* report is needed.

A third party may verify that the *M&V Plan* adheres to IPMVP, and possibly a performance contract. This third party may also verify that *savings* reports comply with the approved *M&V Plan* (see Chapter 8.6).

4.4 Operational Verification

Operational Verification should be performed as part of any project M&V program. It serves as a low-cost initial step for realizing savings potential and should precede savings verification activities. A range of operational verification methods can be applied, as outlined in Table 2. Selection of a given approach depends on the ECM's characteristics as noted. However, it can also be influenced by the savings verification approach taken. For example, if Option B is being used to verify savings then a more simple visual inspection may suffice for operational verification. However if Option A is applied, then a more thorough *operational verification* approach should be used to verify that the ECM functionality is confirmed and characterization complete.

Operational verification activities are accomplished through comprehensive commissioning of affected systems supplemented by more data-driven activities (e.g. data trending and review). The M&V Plan should note the *operational verification* approach in addition to the savings verification method. *Operational verification* should be completed prior to implementing M&V savings verification activities. This ensures the savings from ECMs, energy-efficient controls and operation improvements are fully realized.

Table 1 Operational Verification Approaches

Operational Verification Approach	Typical ECM Application	Activities
Visual Inspection	ECM will perform as anticipated when properly installed; direct measurement of ECM performance is not possible. Examples: wall insulation, windows	View and verify the physical installation of the ECM
Sample Spot Measurements	Achieved ECM performance can vary from published data based on installation details or component load. Examples: fixtures/lamps/ballasts, fans, pumps	Measure single or multiple key energy-use parameters for a representative sample of the ECM installations
Short-Term Performance Testing	ECM performance may vary depending on actual load, controls, and/or interoperability of components. Examples: Daylighting sensors and lighting dimming controls, VSD fans, Demand-control ventilation	Test for functionality and proper control. Measure key energy-use parameters. May involve conducting tests designed to capture the component operating over its full range or performance data collection over sufficient period of time to characterize the full range of operation.
Data Trending and Control-Logic Review	ECM performance may vary depending on actual load and controls. Component or system is being monitored and controlled through the BAS or can be monitored through independent meters.	Set up trends and review data and/or control logic. Measurement period may last for a few days to a few weeks, depending on the period needed to capture the full range of performance.

Operational verification activities can also be applied following the *Reporting Period* to support energy savings persistence. While ot formally a part of the M&V process, such a practice is beneficial for an organization which has improved its energy efficiency. It reduces the risk of adverse shifts in performance associated with ECMs that can fail, fade or be bypassed.

4.5 Savings Verification

The following sections add details about how to determine and report *savings*.

4.5.1 Measurement Boundary

Savings may be determined for an entire *facility* or simply for a portion of it, depending upon the purposes of the reporting.

- If the purpose of reporting is to help manage only the equipment affected by the *savings* program, a *measurement boundary* should be drawn around that equipment. Then all significant *energy* requirements of the equipment within the boundary can be determined[7]. This approach is used in the Retrofit Isolation Options of Chapter 4.7.
- If the purpose of reporting is to help manage total *facility energy* performance, the meters measuring the supply of *energy* to the total *facility* can be used to assess performance and *savings*. The *measurement boundary* in this case encompasses the whole *facility*. The Whole Facility Option C, is described in Chapter 4.8.
- If *baseline* or *reporting period* data are unreliable or unavailable, *energy* data from a calibrated simulation program can take the place of the missing data, for either part or all of the *facility*. The *measurement boundary* can be drawn accordingly. The Calibrated Simulation Option D is described in Chapter 4.9.

[7] Determination of *energy* may be by direct measurement of energy flow or by direct measurement of *proxies* of *energy* use that give direct indication of *energy* use.

Some of the energy requirements of the systems or equipment being assessed may arise outside a practical *measurement boundary*. Nevertheless, all *energy* effects of the *ECM*(s) should be considered. Those energy effects that are significant should be determined from measurements, the rest being estimated or ignored.

Any energy effects occurring beyond the notional *measurement boundary* are called '*interactive effects*'[8]. Find a way to estimate the magnitude of these *interactive effects* in order to determine *savings*. Alternatively they may be ignored as long as the *M&V Plan* includes discussion of each effect and its likely magnitude.

4.5.2 Measurement Period Selection

Care should be taken in selecting the period of time to be used as the *baseline period* and the *reporting period*. Strategies for each are discussed below.

Baseline Period

The *baseline period* should be established to:

- Represent all operating modes of the *facility*. This period should span a full operating cycle from maximum energy use to minimum.

> - Whole-building energy use can be significantly affected by weather conditions. Typically, a whole year of baseline data is needed to define a full operating cycle.
>
> - The energy use of a compressed air system may only be governed by plant production levels, which vary on a weekly cycle. So one week's data may be all that is needed to define baseline performance.

- Fairly represent all operating conditions of a normal operating cycle. For example, though a year may be chosen as the baseline period, if data is missing during the selected year for one month, comparable data for the same month in a different year should be used to ensure the baseline record does not under represent operating conditions of the missing month.
- Include only time periods for which all fixed and variable energy-governing facts are known about the facility. Extension of baseline periods backwards in time to include multiple cycles of operation requires equal knowledge of all energy-governing factors throughout the longer baseline period in order to properly derive routine and non-routine adjustments (see Chapter 4.6) after ECM installation.
- Coincide with the period immediately before commitment to undertake the retrofit. Periods further back in time would not reflect the conditions existing before retrofit and may therefore not provide a proper *baseline* for measuring the effect of just the *ECM*.

ECM planning may require study of a longer time period than is chosen for the *baseline period*. Longer study periods assist the planner in understanding *facility* performance and determining what the normal *cycle* length actually is.

[8] These *interactive effects* are sometimes called 'leakages.'

Reporting Period

The user of the *savings* reports should determine the length of the *reporting period*. The *reporting period* should encompass at least one normal operating *cycle* of the equipment or *facility*, in order to fully characterize the *savings* effectiveness in all normal operating modes.

Some projects may cease reporting *savings* after a defined "test" period ranging from an instantaneous reading to a year or two.

The length of any *reporting period* should be determined with due consideration of the life of the *ECM* and the likelihood of degradation of originally achieved *savings* over time.

Regardless of the length of the reporting period, metering may be left in place to provide feedback of operating data for routine management purposes and specifically to detect subsequent adverse changes in performance. Section 4.9 explains this at greater length.

If reducing the frequency of savings measurement after initial proof of performance, other on site monitoring activities could be intensified to ensure savings remain in place.

IPMVP-adherent *savings* can only be reported for the *reporting period* that uses IPMVP-adherent procedures. If IPMVP-adherent savings are used as a basis for assuming future *savings*, future *savings* reports do not adhere to IPMVP.

Adjacent Measurement Periods (On/Off Test)

When an *ECM* can be turned on and off easily, *baseline* and *reporting periods* may be selected that are adjacent to each other in time. A change in control logic is an example of an *ECM* that can often be readily removed and reinstated without affecting the facility.

Such "On/Off tests" involve *energy* measurements with the *ECM* in effect, and then immediately thereafter with the *ECM* turned off so that pre-*ECM* (*baseline*) conditions return. The difference in energy use between the two adjacent measurement periods is the *savings* created by the *ECM*. Equation 1) of Chapter 4.1 can be used for computing *savings*, without an adjustments term if all *energy*-influencing factors are the same in the two adjacent periods.

This technique can be applied under both Retrofit Isolation and Whole-Facility Options. However *measurement boundaries* must be located so that it is possible to readily detect a significant difference in metered *energy* use when equipment or systems are turned on and off.

The adjacent periods used for the On/Off test should be long enough to represent stable operation. The periods should also cover the range of normal facility operations. To cover the normal range, the On/Off test may need to be repeated under different operating modes such as various seasons or production rates.

Take notice that *ECMs* which can be turned Off for such testing also risk being accidentally or maliciously turned Off when intended to be On.

4.5.3 Basis For Adjustments

The adjustments term shown in Equation 1) of Chapter 4.1 should be computed from identifiable physical facts about the energy governing characteristics of equipment within the *measurement boundary*. Two types of adjustments are possible:

- ***Routine Adjustments*** – for any *energy*-governing factors, expected to change routinely during the *reporting period*, such as weather or production volume. A variety of techniques can be used to define the adjustment methodology. Techniques may be as simple as a constant value (no adjustment) or as complex as a several multiple parameter non-linear equations each correlating *energy* with one or more independent variables. Valid mathematical techniques must be used to derive the adjustment method for each *M&V Plan*. See Appendix B for some guidance on assessing the validity of mathematical methods.

and

- ***Non-Routine Adjustments*** – for those energy-governing factors which are not usually expected to change, such as: the facility size, the design and operation of installed equipment, the number of weekly production shifts, or the type of occupants. These static factors must be monitored for change throughout the reporting period. See Chapter 8.2 for discussion of non-routine adjustments.

Static Factors

Examples of *static factors* needing *non-routine adjustments* are changes in the:

- amount of space being heated or air conditioned,
- type of products being produced or number of production shifts per day
- building envelope characteristics (new insulation, windows, doors, air tightness),
- amount, type or use of the *facility's* and the users' equipment,
- indoor environmental standard (e.g. light levels, temperature, ventilation rate), and
- occupancy type or schedule.

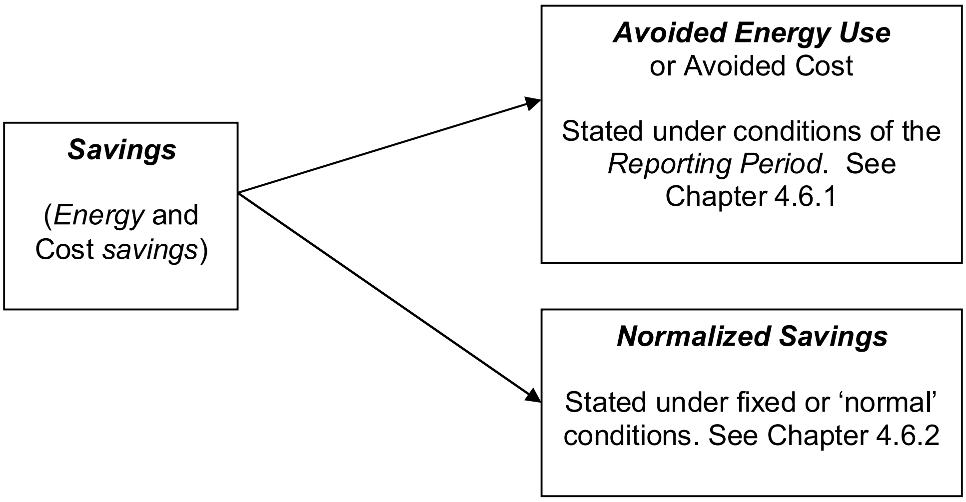
Therefore Equation 1) can be expressed more fully as:

Savings = (*Baseline Energy* – *Reporting-Period Energy*)
± *Routine Adjustments* ± *Non-Routine Adjustments* 1a)

The *adjustments* terms in Equation 1a) are used to express both pieces of measured energy data under the same set of conditions. The mechanism of the adjustments depends upon whether *savings* are to be reported on the basis of the conditions of the *reporting period*, or normalized to some other fixed set of conditions as discussed below[9].

[9] The following general methods can be applied to Options A, B and C described in the rest of the Chapter 4. Option D generally includes the adjustments within the simulation, though the set of conditions for adjustment must still be chosen.

Figure 3 Two Types of Savings



Reporting-Period Basis or Avoided Energy Use

When *savings* are reported under the conditions of the *reporting period*, they can also be called *avoided energy use* of the *reporting period*. *Avoided energy use* quantifies *savings* in the *reporting period* relative to what *energy* use would have been without the *ECM*(s).

When reporting *savings* under *reporting-period* conditions, *baseline-period energy* needs to be adjusted to *reporting-period* conditions.

For this common style of *savings* reporting Equation 1a) can be restated as:

Avoided Energy Use (or *Savings*) =

(*Baseline Energy* ± *Routine Adjustments* to *reporting-period* conditions

± *Non-Routine Adjustments* to *reporting-period* conditions) - *Reporting-Period Energy*

This equation is often simplified to the following:

Avoided Energy Use (or *Savings*) =

Adjusted-Baseline Energy – *Reporting-Period Energy*

± *Non-Routine Adjustments* of *baseline energy* to *reporting-period* conditions 1b)

Where *Adjusted-Baseline Energy* is defined as the *baseline energy* plus any *routine adjustments* needed to adjust it to the conditions of the *reporting period*.

The *adjusted-baseline energy* is normally found by first developing a mathematical model which correlates actual *baseline energy* data with appropriate *independent variable(s)*in the *baseline period*. Each *reporting period's independent variable(s)* are then inserted into this *baseline* mathematical model to produce the *adjusted-baseline energy* use.

Independent Variables

An *independent variable* is a parameter that is expected to change regularly and have a measurable impact on the *energy* use of a system or *facility*. For example, a common *independent variable* governing building energy use is outdoor temperature. Likewise in a manufacturing plant the number of units produced in a period is often an *independent variable* significantly affecting energy use. Another common *independent variable* is the number of seconds, hours or days in each metering period. See also Chapter 4.9.3.

Fixed Conditions Basis or *Normalized Savings*

Conditions other than those of the *reporting period* may be used as the basis for adjustment. The conditions may be those of the *baseline period*, some other arbitrary period, or a typical, average or ‘normal’ set of conditions.

Adjustment to a fixed set of conditions reports a style of *savings* which could be called “*normalized savings*” of the *reporting period*. In this method *energy* of the *reporting period* and possibly of the *baseline* period are adjusted from their actual conditions to the common fixed (or ‘normal’) set of conditions selected.

Equation 1c) restates the more general Equation 1a) for such *normalized savings* reports:

Normalized Savings =

(*Baseline Energy* ± *Routine Adjustments* to fixed conditions

± *Non-Routine Adjustments* to fixed conditions)

- (*Reporting Period Energy* ± *Routine Adjustments* to fixed conditions

± *Non-Routine Adjustments* to fixed conditions) 1c)

The calculation of the *reporting period routine-adjustments* term usually involves the development of a mathematical model correlating *reporting-period energy* with the *independent variables* of the *reporting period*. This model is then used to adjust *reporting-period energy* to the chosen fixed conditions. Further, if the fixed set of conditions is <u>not</u> from the *baseline period*, a mathematical model of *baseline energy* is also used to adjust *baseline energy* to the chosen fixed conditions.

What Basis for Adjustment, or Which Type of '*Savings*?'

Factors to consider when choosing between *avoided energy use* and *normalized savings*:

"*Avoided Energy Use*" style of *savings* (Equation 1b)):

- are dependent upon the *reporting period*'s operating conditions. Even though *savings* can be properly adjusted for phenomena such as weather, the level of reported *savings* depends upon the actual weather.
- cannot be directly compared with *savings* predicted under *baseline* conditions.

"*Normalized savings"* style of *savings* (Equation 1c):

- are unaffected by *reporting-period* conditions since the fixed set of conditions are established once and not changed.
- can be directly compared with *savings* predicted under the same set of fixed conditions.
- can only be reported after a full *cycle* of *reporting-period energy* use, so that the mathematical correlation between *reporting-period energy* and operating conditions can be derived.

4.6 Overview Of IPMVP Options

The *energy* quantities in the several forms of Equation 1) can be measured by one or more of the following techniques:

- Utility or fuel supplier invoices, or reading utility meters and making the same adjustments to the readings that the utility makes.
- Special meters isolating an *ECM* or portion of a *facility* from the rest of the *facility*. Measurements may be periodic for short intervals, or continuous throughout the *baseline* or *reporting periods*.
- Separate measurements of parameters used in computing *energy* use. For example, equipment operating parameters of electrical load and operating hours can be measured separately and multiplied together to compute the equipment's energy use.
- Measurement of proven *proxies* for *energy* use. For example, if the energy use of a motor has been correlated to the output signal from the variable speed drive controlling the motor, the output signal could be a proven *proxy* for motor energy.
- Computer simulation that is calibrated to some actual performance data for the system or *facility* being modeled. One example of computer simulation is DOE-2 analysis for buildings (Option D only).

If the a *energy* value is already known with adequate accuracy or when it is more costly to measure than justified by the circumstances, then measurement of *energy* may not be necessary or appropriate. In these cases, *estimates* may be made of some *ECM* parameters, but others must be measured (Option A only).

IPMVP provides four Options for determining *savings* (A, B, C and D). The choice among the Options involves many considerations including the location of the *measurement boundary* (see Chapter 4.4). If it is decided to determine *savings* at the *facility* level, Option C or D may be favored. However if only the performance of the *ECM* itself is of concern, a retrofit-isolation technique may be more suitable (Option A, B or D).

Table 2 summarizes the four Options that are detailed in Chapters 4.8 through 4.10. Examples of the use of the Options are contained in Appendix A. Section 4.11 offers guidance on selecting the proper Option for any specific project.

Table 2 Overview of IPMVP Options

IPMVP Option	How Savings Are Calculated	Typical Applications
A. Retrofit Isolation: Key Parameter Measurement *Savings* are determined by field measurement of the key performance parameter(s) which define the *energy* use of the *ECM*'s affected system(s) and/or the success of the project. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the *reporting period*. Parameters not selected for field measurement are *estimated. Estimates* can based on historical data, manufacturer's specifications, or engineering judgment. Documentation of the source or justification of the *estimated* parameter is required. The plausible *savings* error arising from *estimation* rather than measurement is evaluated.	Engineering calculation of *baseline* and *reporting period energy* from: ○ short-term or continuous measurements of key operating parameter(s); and ○ *estimated* values. *Routine* and *non-routine adjustments* as required.	A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimate operating hours of the lights based on *facility* schedules and occupant behavior.
B. Retrofit Isolation: All Parameter Measurement *Savings* are determined by field measurement of the *energy* use of the *ECM*-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the *savings* and the length of the *reporting period*.	Short-term or continuous measurements of *baseline* and *reporting-period energy*, and/or engineering computations using measurements of proxies of *energy* use. Routine and non-routine adjustments as required.	Application of a variable-speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power every minute. In the *baseline period* this meter is in place for a week to verify *constant* loading. The meter is in place throughout the *reporting period* to track variations in power use.

Table 2 Overview of IPMVP Options

IPMVP Option	How Savings Are Calculated	Typical Applications
C. Whole Facility *Savings* are determined by measuring energy use at the whole *facility* or sub-*facility* level. Continuous measurements of the entire *facility's energy* use are taken throughout the *reporting period*.	Analysis of whole *facility baseline* and *reporting period* (utility) meter data. *Routine adjustments* as required, using techniques such as simple comparison or regression analysis. *Non-routine adjustments* as required.	Multifaceted energy management program affecting many systems in a *facility*. Measure energy use with the gas and electric utility meters for a twelve month *baseline period* and throughout the *reporting period*.
D. Calibrated Simulation *Savings* are determined through simulation of the *energy* use of the whole *facility,* or of a sub-*facility*. Simulation routines are demonstrated to adequately model actual *energy* performance measured in the *facility*. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)	Multifaceted energy management program affecting many systems in a facility but where no meter existed in the *baseline* period. Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation. *Baseline* energy use, determined using the calibrated simulation, is compared to a simulation of *reporting period* energy use.

4.7 Options A & B: Retrofit Isolation

Chapter 4.4 defines the concept of a *measurement boundary* encompassing the retrofitted equipment. Retrofit isolation allows the narrowing of the *measurement boundary* in order to reduce the effort required to monitor *independent variables* and *static factors,* when retrofits affect only a portion of the *facility*. However boundaries smaller than the total *facility* usually require additional meters at the *measurement boundary.* Narrow *measurement boundaries* also introduce the possibility of 'leakage' through unmeasured *interactive effects*.

Since measurement is of less than the total *facility*, the results of retrofit isolation techniques cannot be correlated to the *facility*'s total *energy* use shown on utility bills. *Facility* changes beyond the *measurement boundary* but unrelated to the *ECM* will not be reported by retrofit-isolation techniques but will be included in the utility's metered consumption or demand.

Two Options are presented for isolating the *energy* use of the equipment affected by an *ECM* from the energy use of the rest of the facility:

- Option A: Retrofit Isolation: Key Parameter Measurement (See Chapter 4.8.1)
- Option B: Retrofit Isolation: All Parameter Measurement (See Chapter 4.8.2)

Isolation metering is placed at the *measurement boundary* between equipment which the *ECM* affects and equipment which it does not affect.

Retrofit Isolation Example

A boiler is replaced with a more efficient one. A *measurement boundary* is drawn around just the boiler so that the assessment of the new boiler is unaffected by variations in the heating load of the whole facility.

Meters for fuel consumption and boiler heat output are all that are needed to assess the efficiencies of the two boilers over their full range of operations. *Savings* are reported for the boiler retrofit by applying the observed efficiency improvement to an estimated annual boiler load. The boiler efficiency test is repeated annually.

When drawing a *measurement boundary*, care should be taken to consider any energy flows affected by the *ECM* but beyond the boundary. A method must be derived for estimating such *interactive effects* (See Chapter 4.4). For example, a lighting load reduction often reduces HVAC system energy use, but the only reasonable *measurement boundary* would encompass just the electricity use of the lights, not their heating and cooling energy impacts. In this case the *ECM*'s effect on HVAC energy requirements is an *interactive effect,* which must be assessed. If the *interactive effect* is expected to be significant, engineering estimates could be made of the *interactive effect* as some fraction of the measured lighting-energy *savings*. Conventional heating and cooling calculations would be used to determine the appropriate fraction(s) for each season. However if the *measurement boundary* can be expanded to encompass *interactive effects*, there is no need to estimate them.

Apart from small estimated *interactive effects,* the *measurement boundary* defines the metering points and the scope of any *adjustments,* which may be used in the various forms of Equation 1). Only changes to *energy* systems and operating variables within the *measurement boundary* must be monitored to prepare the *adjustments* term(s) of Equation 1).

Chapter 4.5 discusses measurement periods, generally. Parameters may be continuously measured or periodically measured for short periods. The expected amount of variation in the parameter will govern the decision of whether to measure continuously or periodically. Where a parameter is not expected to change it may be measured immediately after *ECM* installation and checked occasionally throughout the *reporting period*. The frequency of this checking can be determined by beginning with frequent measurements to verify that the parameter is *constant*. Once proven *constant*, the frequency of measurement may be reduced. To maintain control on *savings* as measurement frequency drops, more frequent inspections or other tests might be undertaken to verify proper operations.

Continuous metering provides greater certainty in reported *savings* and more data about equipment operation. This information can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the *ECM* itself. Results from several studies have shown five to fifteen percent annual energy *savings* can be achieved through careful use of continuous data logging (Claridge et al. 1994, 1996; Haberl et al. 1995).

If measurement is not continuous and meters are removed between readings, the location of the measurement and the specifications of the measurement device should be recorded in the M&V Plan, along with the procedure for calibrating the meter being used. Where a parameter is expected to be constant, measurement intervals can be short and occasional. Electric motors in an industrial plant provide a common example of *constant* power flow, assuming they have a *constant* load. However motor-operating periods may vary with the type of product being produced from day to day. Where a parameter may change periodically, the occasional measurements of the parameter (operating hours in this motor example) should happen at times representative of the normal system behavior.

Where a parameter may vary daily or hourly, as in most building heating or cooling systems, continuous metering may be simplest. For weather dependent loads, measurements may be taken over a long enough period to adequately characterize the load pattern through all parts of its normal annual cycle (i.e. each season, and weekday/weekend) and repeated as necessary through the *reporting period*. Examples of such day-type profiling can be found in Katipamula and Haberl (1991), Akbari et al. (1988), Hadley and Tomich (1986), Bou Saada and Haberl (1995a, 1995b) and Bou Saada et al. (1996).

Where multiple versions of the same *ECM* installation are included within the *measurement boundary*, statistically valid samples may be used as valid measurements of the total parameter. Such situations may arise, for example, where total lighting power draw cannot be read at the electrical panel due to the presence of non-lighting loads on the same panel. Instead a statistically significant sample of fixtures is measured before and after retrofit to assess the change in power draw. These sample data may be used as the 'measurements' of total lighting power draw. Appendix B-3 discusses the statistical issues involved in sampling.

Portable meters may be used if only short-term metering is needed. The costs of portable meters can be shared with other objectives. However, permanently installed meters also provide feedback to operating staff or automated control equipment for optimization of systems. Added meters may also enable billing of individual users or departments in the facility.

Retrofit isolation techniques are best applied where:

- Only the performance of the systems affected by the *ECM* is of concern, either due to the responsibilities assigned to the parties in an *energy performance contract*, or due to the *savings* of the *ECM* being too small to be detected in the time available using Option C.
- *Interactive effects* of the *ECM* on the *energy* use of other *facility* equipment can be reasonably estimated, or assumed to be insignificant.
- Possible changes to the *facility*, beyond the *measurement boundary*, would be difficult to identify or assess.
- The *independent variables*, which affect *energy* use, are not excessively difficult or expensive to monitor.
- Sub-meters already exist to isolate *energy* use of systems.
- Meters added at the *measurement boundary* can be used for other purposes such as operational feedback or tenant billing.
- Measurement of parameters is less costly than Option D simulations or Option C *non-routine adjustments*.
- Long term testing is not warranted.
- There is no need to directly reconcile savings reports with changes in payments to energy suppliers.

The unique characteristics of each of the retrofit-isolation techniques are discussed in Chapters 4.7.1 and 4.7.2, below. Common measurement issues arising when using retrofit-isolation techniques are discussed in Chapter 4.8.3..

4.7.1 Option A: Retrofit Isolation: Key Parameter Measurement

Under Option A, Retrofit Isolation: Key Parameter Measurement, *energy* quantities in Equation 1) can be derived from a computation using a combination of measurements of some parameters and *estimates* of the others. Such *estimates* should only be used where it can be shown that the combined uncertainty from all such *estimates* will not significantly affect the overall reported *savings*. Decide which parameters to measure and which to *estimate* by considering each parameter's contribution to the overall uncertainty of the reported *savings*. The *estimated values* and analysis of their significance should be included in the *M&V Plan* (Chapter 5). *Estimates* may be based on historical data such as recorded operating hours from the *baseline*, equipment manufacturer's published ratings, laboratory tests, or typical weather data.

If a parameter, such as hours of use is known to be *constant* and not expected to be impacted by the *ECM*, then its measurement in the *reporting period* is sufficient. The *reporting period* measurement of such constant parameter can also be considered a measurement of its *baseline* value.

Wherever a parameter, known to vary independently, is not measured in the facility during both the *baseline* and *reporting periods*, the parameter should be treated as an *estimate.*

Engineering calculations or mathematical modeling may be used to assess the significance of the errors in estimating any parameter in the reported *savings*. For example if a piece of equipment's operating hours are to be estimated, but may range from 2,100 to 2,300 hours per year, the calculated *savings* at 2,100 and 2,300 hours should be computed and the difference evaluated for its significance to the expected *savings*. The combined effect of all such possible *estimations* should be assessed before determining whether sufficient measurement is in place. See also Appendix B-5.1.

The selection of which factor(s) to measure may also be considered relative to the objectives of the project or the duties of a contractor undertaking some *ECM*-performance risk. Where a factor is significant to assessing performance, it should be measured. Other factors beyond the contractor's control can be estimated.

If a *savings* computation involves subtracting a measured parameter from an *estimated* parameter, the result is an *estimate*. For example if a parameter is measured in the *reporting period* and subtracted from an unmeasured value for the same parameter in the *baseline period*, the resultant difference is only an *estimate*.

An example application of Option A is an *ECM* involving the installation of high-efficiency light fixtures, without changing lighting periods. *Savings* can be determined using Option A by metering the lighting-circuit power draw before and after retrofit while *estimating* the operating period. Other variations on this type of *ECM*, shown in Table 2 below, show the circumstances where *estimates* adhere to the guidance of Option A.

What to Measure?

Consider the example of a lighting project where *reporting period* power draw is measured, but *baseline* power is not measured. Therefore power draw should be treated as an *estimate* in designing an Option A procedure.

As a result, operating hours must be measured if the procedure is to adhere to IPMVP Option A.

Table 2
Example
Lighting

Situation	Measurement vs. Estimation Strategy		Adherent to Option A?
	Operating Hours	**Power Draw**	
ECM reduces operating hours	Measure	*Estimate*	Yes
	Estimate	Measure	No
ECM reduces power draw	*Estimate*	Measure	Yes
	Measure	*Estimate*	No
ECM reduces both power draw and operating hours:			
Baseline power uncertain, operating hours known	*Estimate*	Measure	Yes
	Measure	*Estimate*	No
Power known but operating hours uncertain	Measure	*Estimate*	Yes
	Estimate	Measure	No
Power and operating hours poorly known	Measure	*Estimate*	No – Use Option B
	Estimate	Measure	

When planning an Option A procedure, consider both the amount of variation in *baseline energy* and the *ECM*'s *energy* impact before establishing which parameter(s) to measure. The following three examples show the range of scenarios that may arise.

- *ECM* reduces a *constant* load without changing its operating hours. Example: industrial-plant lighting fixtures are replaced with more efficient ones, but the operating hours of the lights do not change. To reasonably measure the effect of the project, fixture power levels should be measured in the *baseline* and *reporting periods*, while operating hours are *estimated* in the energy calculations.
- *ECM* reduces operating hours while load is unchanged. Example: automatic controls shut down air compressors during unoccupied periods. To reasonably measure the effect of the project, compressors' operating time should be measured in both the *baseline* and *reporting periods*, while compressors' power can be estimated in the energy calculations.
- *ECM* reduces both equipment load and operating hours. Example: Resetting of temperature on a hot-water radiation system reduces overheating and induces occupants to close windows, thereby reducing boiler load and operating periods. When both load and operating periods are variable and uncertain, Option A cannot be used.

Generally, conditions of variable load or variable operating hours require more rigorous measurement and computations.

Option A: Calculations

General Equation 1) in Chapter 4.1 is used in all IPMVP adherent computations. However under Option A, there may be no need for *adjustments*, *routine* or *non-routine*, depending upon the location of the *measurement boundary*, the nature of any *estimated values*, the length of the *reporting period*, or the amount of time between *baseline* measurements and *reporting-period* measurements.

Similarly *baseline* or *reporting-period energy* measurements involve measurement of only one parameter under Option A, and estimation of the other. Therefore Equation 1) may simplify down to:

Option A *Savings* = *Estimated Value* x (*Baseline-Period,* measured parameter
– *Reporting-period,* measured parameter) 1d)

Option A: Installation Verification

Since some values may be *estimated* under Option A, great care is needed to review the engineering design and installation to ensure that the *estimates* are realistic, achievable, and based on equipment that should truly produce *savings* as intended.

At defined intervals during the *reporting period*, the installation should be re-inspected to verify continued existence of the equipment and its proper operation and maintenance. Such re-inspections will ensure continuation of the potential to generate predicted *savings* and validate *estimated parameters*. The frequency of these re-inspections is determined by the likelihood of performance changes. Such likelihood can be established through initial frequent inspections to establish the stability of equipment existence and performance.

An example of a situation needing routine re-inspection is a lighting retrofit. You can determine *savings* by sampling of the performance of fixtures and counting the number of operating fixtures. In this case, the continued existence of the fixtures and operation of the lamps is critical to the *savings* determination. Similarly, where the settings of controls are assumed, but subject to tampering, regular recordings of control settings or actual equipment functions can limit the uncertainty of the *estimated values*.

Option A: Cost

Savings determinations under Option A can be less costly than under other Options, since the cost of *estimating* a parameter is often significantly less than the cost of measurement. However in some situations where *estimation* is the only possible route, a good *estimate* may be costlier than if direct measurement were possible. Cost planning for Option A should consider all elements: analysis, *estimation*, meter installation, and the ongoing cost to read and record data.

Option A: Best Applications

In addition to the retrofit isolation best applications in Chapter 4.8, above, Option A is best applied where:

- *Estimation* of non-key parameters may avoid possibly difficult *non-routine adjustments* when future changes happen within the *measurement boundary*.
- The uncertainty created by *estimations* is acceptable.
- The continued effectiveness of the *ECM* can be assessed by simple routine re-testing of key parameters.
- *Estimation* of some parameters is less costly than measurement of them in Option B or simulation in Option D.
- The key parameter(s) used in computing *savings* can be readily identified. Key parameters are parameters used to judge a project's or contractor's performance.

4.7.2 Option B: Retrofit Isolation: All Parameter Measurement

Option B, Retrofit Isolation: All Parameter Measurement, requires measurement of all Equation 1) *energy* quantities, or all parameters needed to compute *energy*.

The *savings* created by most types of *ECM*s can be determined with Option B. However, the degree of difficulty and costs increase as metering complexity increases. Option B methods will generally be more difficult and costly than those of Option A. However, Option B will produce more certain results where load and/or *savings* patterns are variable. These additional costs may be justifiable if a contractor is responsible for all factors affecting *energy savings*.

Option B: Calculations

General Equation 1) in Chapter 4.1 is used in all IPMVP adherent computations. However under Option B, there may be no need for *adjustments*, *routine* or *non-routine*, depending upon the location of the *measurement boundary*, the length of the *reporting period*, or the amount of time between *baseline* and *reporting period* measurements. Therefore, for Option B, Equation 1 may simplify down to:

Option B *Savings* = *Baseline Energy* - *Reporting-Period Energy* 1e)

Option B: Best Applications

In addition to the retrofit-isolation methods in Chapter 4.8, above, Option B is best applied where:

- Meters added for isolation purposes will be used for other purposes such as operational feedback or tenant billing.
- Measurement of all parameters is less costly than simulation in Option D.
- *Savings* or operations within the *measurement boundary* are variable.

4.7.3 Retrofit Isolation Measurement Issues

Retrofit isolation usually requires the addition of special meters, on either a short term or permanent basis. These meters may be installed during an *energy* audit to help characterize *energy* use before design of the *ECM*. Or meters may be installed to measures *baseline* performance for an *M&V Plan*.

You can measure temperature, humidity, flow, pressure, equipment runtime, electricity or thermal energy, for example, at the *measurement boundary*. Follow good measurement practices to enable calculation of *energy savings* with reasonable accuracy and repeatability. Measurement practices are continually evolving as metering equipment improves. Therefore, use the latest measurement practices to support your *savings* (see also Chapter 8.11).

The following sections define some key measurement issues to consider when using retrofit-isolation techniques.

Electricity Measurements

To measure electricity accurately we measure the voltage, amperage and power factor, or true rms[10] wattage with a single instrument. However measurement of amperage and voltage alone can adequately define wattage in purely resistive loads, such as incandescent lamps and resistance heaters without blower motors. When measuring power, make sure that a resistive load's electrical wave-form is not distorted by other devices in the *facility*.

Measure electric demand at the same time that the power company determines the peak demand for its billing. This measurement usually requires continuous recording of the demand at the sub-meter. From this record, the sub-meter's demand can be read for the time when the power company reports that the peak demand occurred on its meter. The power company may reveal the time of peak demand either on its invoices or by special report.

Electric-demand measurement methods vary amongst utilities. The method of measuring electric demand on a sub-mter should replicate the method the power company uses for the relevant billing meter. For example, if the power company calculates peak demand using fixed

[10] Rms (root mean squared) values can be reported by solid state digital instruments to properly account for the net power when wave distortions exist in alternating current circuits.

15 minute intervals, then the recording meter should be set to record data for the same 15 minute intervals. However if the power company uses a moving interval to record electric demand data, the data recorder should have similar capabilities. Such moving interval capability can be emulated by recording data on one minute fixed intervals and then recreating the power company's intervals using post-processing software. However, care should be taken to ensure that the facility does not contain unusual combinations of equipment that generate high one minute peak loads which may show up differently in a moving interval than in a fixed interval. After processing the data into power company intervals, convert it to hourly data for archiving and further analysis.

Calibration

Meters should be calibrated as recommended by the equipment manufacturer, and following procedures of recognized measurement authorities. Primary standards and no less than third-order-standard traceable calibration equipment should be utilized wherever possible. Sensors and metering equipment should be selected based in part on the ease of calibration and the ability to hold calibration. An attractive solution is the selection of equipment that is self-calibrating.

Selected calibration references are provided in Chapter 10.3.

4.8 Option C: Whole Facility

Option C: Whole Facility, involves use of utility meters, whole-*facility* meters, or sub-meters to assess the energy performance of a total *facility*. The *measurement boundary* encompasses either the whole *facility* or a major section. This Option determines the collective *savings* of all *ECM*s applied to the part of the *facility* monitored by the *energy* meter. Also, since whole-*facility* meters are used, *savings* reported under Option C include the positive or negative effects of any non-*ECM* changes made in the *facility*.

Option C is intended for projects where expected *savings* are large compared to the random or unexplained energy variations which occur at the whole-*facility* level. If savings are large compared to the unexplained variations in the *baseline*-*energy* data, then identifying *savings* will be easy. Also the longer the period of *savings* analysis after *ECM* installation, the less significant is the impact of short-term unexplained variations[11]. Typically *savings* should exceed 10% of the *baseline energy* if you expect to confidently discriminate the *savings* from the *baseline* data when the *reporting period* is shorter than two years.

Identifying *facility* changes that will require *non-routine adjustments* is the primary challenge associated with Option C, particularly when *savings* are monitored for long periods. (See also Chapter 8.2 on *non-routine baseline adjustments*.) Therefore, you should perform periodic inspections of all equipment and operations in the *facility* during the *reporting period*. These inspections identify changes in the *static factors* from *baseline* conditions. Such inspections may be part of regular monitoring to ensure that the intended operating methods are still being followed.

4.8.1 Option C: Energy Data Issues

Where utility supply is only measured at a central point in a group of *facilities*, sub-meters are needed at each *facility* or group of *facilities* for which individual performance is assessed.

Several meters may be used to measure the flow of one *energy* type into a facility. If a meter supplies *energy* to a system that interacts with other *energy* systems, directly or indirectly, this meter's data should be included in the whole-*facility savings* determination.

---

[11] See Appendix B-5. ASHRAE (2002) provides quantitative methods for assessing the impact of variations in the *baseline* data as the *reporting period* lengthens.

Meters serving non-interacting *energy* flows, for which *savings* are not to be determined, can be ignored. Separately metered outdoor-lighting circuits is one example.

*D*etermine *savings* separately for each meter or sub-meter serving a *facility* so that performance changes can be assessed for separately metered parts of the *facility*. However, where a meter measures only a small fraction of one *energy* type's total use, it may be totaled with the larger meter(s) to reduce data-management tasks. When electrical meters are combined this way, it should be recognized that small consumption meters often do not have demand data associated with them so that the totalized consumption data will no longer provide meaningful load factor information.

If several different meters are read on separate days, then each meter having a unique billing period should be separately analyzed. The resultant *savings* can be combined after analysis of each individual meter, if the dates are reported.

If any of the energy data are missing from the *reporting period*, a *reporting-period* mathematical model can be created to fill in missing data. However the reported *savings* for the missing period should identify these *savings* as "missing data."

4.8.2 Option C: Energy Invoices Issues

Energy data for Option C are often derived from utility meters, either through direct reading of the meter, or from utility invoices. Where utility bills are the source of data, it should be recognized that a utility's need for regular meter reading is not usually as great as the needs of *M&V*. Utility bills sometimes contain estimated data, especially for small accounts. Sometimes it cannot be determined from the bill itself whether the data came from an estimate or an actual meter reading. Unreported estimated meter readings create unknown errors for estimated month(s) and and also for the subsequent month of the actual meter reading. However the first invoice with an actual reading after one or more estimates will correct the previous errors in energy quantities. *Savings* reports should note when estimates are part of the utility data.

When an electrical utility estimates a meter reading, no valid data exist for the electrical demand of that period.

Energy may be supplied indirectly to a facility, through on-site storage facilities, such as for oil, propane or coal. In these situations, the energy supplier's shipment invoices do not represent the facility's actual consumption during the period between shipments. Ideally a meter downstream of the storage facility measures energy use. However where there is no downstream meter, inventory-level adjustments for each invoice period should supplement the invoices.

4.8.3 Option C: *Independent Variables*

Regularly changing parameters affecting a *facility's energy* use, are called *independent variables* (see also box in Chapter 4.6.1). Common *independent variables* are weather, production volume and occupancy. Weather has many dimensions, but for whole-facility analysis, weather is often just outdoor dry-bulb temperature. Production has many dimensions, depending upon the nature of the industrial process. Production is typically expressed in mass units or volumetric units of each product. Occupancy is defined in many ways, such as hotel-room occupancy, office-building occupancy hours, occupied days (weekdays/weekends), or restaurant-meal sales.

Mathematical modeling can assess *independent variables* if they are cyclical. *Regression analysis* and other forms of mathematical modeling can determine the number of *independent variables* to consider in the *baseline* data (See Appendix B-2). Parameters, which have a significant effect on the *baseline energy* use, should be included in the *routine adjustments* when determining *savings*[12] using Equation 1a), b) or c).

Independent variables should be measured and recorded at the same time as the *energy* data. For example, weather data should be recorded daily so they can be totaled to correspond with the exact monthly energy-metering period, which may be different from the calendar month. Use of simple monthly mean temperature data for a non-calendar month energy metering period introduces unnecessary error into the analysis.

4.8.4 Option C: Calculations and Mathematical Models

For Option C, the *routine adjustments* term of Equation 1a) is calculated by developing a valid mathematical model of each meter's *energy*-use pattern. A model may be as simple as an ordered list of twelve measured monthly *energy* quantities without any adjustments. However a model often includes factors derived from *regression analysis*, which correlate *energy* to one or more *independent variables* such as outdoor temperature, *degree days*, metering period length, production, occupancy, and/or operating mode. Models can also include a different set of regression parameters for each range of conditions, such as summer or winter in buildings with seasonal *energy*-use variations. For example, in schools where the building's *energy* use differs between the school year and the vacation period, you may need separate regression models for the different usage periods (Landman and Haberl 1996a; 1996b).

Option C should use complete years (12, 24, or 36 months) of continuous data, during the *baseline period,* and continuous data during the *reporting periods* (Fels 1986). Models, which use other numbers of months, (9, 10, 13, or 18 months, for example) can create statistical bias by under or over-representing normal modes of operation.

Meter data can be hourly, daily or monthly whole-*facility* data. Hourly data should be combined into daily data to limit the number of *independent variables* required to produce a reasonable *baseline* model, without significantly increasing the uncertainty in computed *savings* (Katipamula 1996, Kissock et al. 1992). Variation in the daily data often results from the weekly *cycle* of most facilities.

Many mathematical models are appropriate for Option C. To select the one most suited to the application, consider statistical-evaluation indices, such as R^2 and t (see Appendix B-2.2)[13]. Appendix B-2.2 or published statistical literature can help you demonstrate the statistical validity of your selected model.

4.8.5 Option C: Metering

Whole-*facility energy* measurements can use the utiltity's meters. Utility-meter data is considered 100% accurate for determining *savings* because this data defines the payment for *energy*. Utility-meter data is usually required to meet commercial accuracy regulations for sale of *energy* commodities.

The *energy* supplier's meter(s) may be equipped or modified to provide an electical pulse output that can be recorded by the *facility's* monitoring equipment. The *energy*-per-pulse constant of the pulse transmitter should be calibrated against a known reference such as similar data recorded by the utility meter.

---

[12] All other parameters affecting *energy* use (i.e. "*static factors*" see box in Chapter 4.6) should be measured and recorded in the *baseline* and *reporting periods* so that *non-routine adjustments* can be made if needed (see Chapter 8.8)

[13] Additional information concerning these selection procedures can be found in Reynolds and Fels (1988), Kissock et al. (1992, 1994) and in the ASHRAE Handbook of Fundamentals (2005) Chapter 32. ASHRAE (2002) also provides several statistical tests to validate the usefulness of derived regression models.

Separate meters installed by the *facility* owner can measure whole-*facility energy*. The accuracy of these meters should be considered in the *M&V Plan*, together with a way of comparing its readings with the utility meter readings.

4.8.6 Option C: Cost

Option C's cost depends on the source of the *energy* data, and the difficulty of tracking *static factors* within the *measurement boundary* to enable *non-routine adjustments* during the *reporting period.* The utility meter or an existing sub-meter works well if the meter's data is properly recorded. This choice requires no extra metering cost.

The cost of tracking changes in *static factors* depends on the *facility's* size, the likelihood of *static-factor* change, the difficulty of detecting changes, and the surveillance procedures already in place.

4.8.7 Option C: Best Applications

Option C is best applied where:

- The *energy* performance of the whole *facility* will be assessed, not just the *ECM*s.
- There are many types of *ECM*s in one *facility*.
- The *ECM*s involve activities whose individual *energy* use is difficult to separately measure (operator training, wall or window upgrades, for example).
- The *savings* are large compared to the variance in the *baseline* data, during the *reporting period* (See Appendix B-1.2).
- When Retrofit-Isolation techniques (Option A or B) are excessively complex. For example, when *interactive effects* or interactions between *ECM*s are substantial.
- Major future changes to the facility are not expected during the *reporting period*.
- A system of tracking *static factors* can be established to enable possible future *non-routine adjustments*.
- Reasonable correlations can be found between *energy* use and other *independent variables*.

4.9 Option D: Calibrated Simulation

Option D, Calibrated Simulation, involves the use of computer simulation software to predict *facility energy* for one or both of the terms in Equation 1). A simulation model must be "calibrated" so that it predicts an *energy* pattern that approximately matches actual metered data.

Option D may be used to assess the performance of all *ECM*s in a *facility*, akin to Option C. However, the Option D simulation tool allows you to also estimate the *savings* attributable to each *ECM* within a multiple-*ECM* project.

Option D may also be used to assess just the performance of individual systems within a *facility*, akin to Options A and B. In this case, the system's *energy* use must be isolated from that of the rest of the facility by appropriate meters, as discussed in Chapters 4.5.1 and 4.7.

Option D is useful where:

- *Baseline energy* data do not exist or are unavailable. Such situation may arise for:
    - A new construction project
    - A facility expansion needing to be assessed separately from the rest of the facility, or

- A centrally metered campus of *facilities* where no individual *facility* meter exists in the *baseline period*, but where individual meters will be available after *ECM* installation.

- *Reporting-period energy* data are unavailable or obscured by factors that are difficult to quantify. Sometimes it is too difficult to predict how future *facility* changes might affect *energy* use. Industrial-process changes or new equipment often make the computation of *non-routine adjustments* so inaccurate that Options A, B or C would create excessive error in the *savings* determination.
- It is desired to determine the *savings* associated with individual *ECM*s, but measurements with Options A or B are too difficult or costly.

If the *reporting-period energy* is predicted by the simulation software, the determined *savings* persist only if the simulated operating methods continue. Periodic inspections will identify changes from *baseline* conditions and modeled equipment performance (see also Chapter 4.7.1. Option A Installation Verification). Simulation runs should be adjusted accordingly.

Option D is the primary *M&V* approach for assessing *energy* efficiency inclusions in new *facility* designs. The IPMVP Volume III Part I, titled “Concepts and Options for Determining *Savings* In New Construction”, provides guidance on a variety of *M&V* techniques applicable to new buildings.

Accurate computer modeling and calibration to measured *energy* data are the major challenges associated with Option D. To control the costs of this method while maintaining reasonable accuracy, the following points should be considered when using Option D:

- Simulation analysis should be conducted by trained personnel who are experienced with both the software and the calibration techniques.
- Input data should represent the best available information including as much as possible of available actual performance data from key components in the facility
- The simulation inputs need to be adjusted so its results match both the demand and consumption data from monthly utility bills, within acceptable tolerances (i.e. "calibrated"). Close agreement between predicted and actual annual <u>total</u> *energy* is usually insufficient demonstration that the simulation adequately predicts the *energy* behavior of the facility (See Chapter 4.9.2).
- Option D requires careful documentation. Simulation printouts, survey data and the metering or monitoring data used to define input values and calibrate the simulation model should be kept in paper and electronic files. The version number should be declared of publicly available software, so that another person can review the computations.
- For new construction projects, modeling efforts can be streamlined by retaining the buildng energy modeler that created the “as-designed” model to create the calibrated, “as-built” and adjusted baseline models.

Building types which are not easily simulated include those with:

- large atriums,
- a significant fraction of the space underground or ground coupled,
- unusual exterior shapes,
- complex shading configurations, or
- a large number of distinct zones of temperature control.

Some building *ECM*s cannot be simulated without great difficulty, such as:

- addition of radiant barriers in attics, and

- some complex HVAC system changes.

4.9.1 Option D: Types of Simulation Programs

Information on building simulation programs in common use in different parts of the world can be found in Appendix C herein

Whole-building-simulation programs usually use hourly calculation techniques. However simplified HVAC system models may also be used if the building's heat losses, heat gains, internal loads, and HVAC systems are simple. Other types of special-purpose programs may be used to simulate *energy* use and operation of devices or industrial processes.

Any software used must be well documented and well understood by the user. Due to the wide variety of available methods, it is prudent to receive acceptance by the owner or project authority of the proposed modeling program before commencing analysis.

4.9.2 Option D: Calibration

Savings determined with Option D are based on one or more complex estimates of *energy* use. The accuracy of the *savings* depends on how well the simulation models actual equipment performance, and how well calibrated it is to metered *energy* performance.

Calibration is achieved by verifying that the simulation model reasonably predicts the *energy* patterns of the *facility* by comparing model results to a set of calibration data. These calibration data include measured *energy* data, *independent variables* and *static factor*.

Calibration of building simulations is usually done with 12 monthly utility bills. These bills should be from a period of stable operation. In a new building, it may take a number of months before full occupancy and before the staff learns the best ways to operate the facility. The calibration data should be documented in the *M&V Plan* along with a description of its sources.

Detailed operating data from the *facility* help to develop the calibration data. These data might include operating characteristics, occupancy, weather, loads and equipment efficiency. Some variables may be measured for short intervals (day, week or month) or extracted from existing operating logs. The accuracy of meters should be verified for critical measurements. If resources permit, building ventilation and infiltration should be measured because these quantities often vary widely from expectations. One-time measurements will improve simulation accuracy without much additional cost. On/off tests can measure lighting, receptacle loads and motor control centers. These tests can be performed over a weekend using a data logger or building automation system to record whole-*facility energy* use, usually at one-minute intervals, Sometimes, inexpensive portable loggers, which are synchronized to a common time, are also effective for short-term measurement (Benton et al. 1996, Houcek et al. 1993, Soebarto 1996).

Following collection of as much calibration data as possible, the steps in calibrating the simulation are as listed below.

1. Assume other necessary input parameters, and document them.
2. Whenever possible, gather actual weather data from the calibration period, especially if weather conditions varied significantly from standard-year weather data used in the basic simulations. However, obtaining and preparing actual weather data for use with a simulation may be time-consuming and expensive. If developing an actual weather data file is too difficult, then adjust an average weather file to resemble actual weather data using valid statistical methods.
3. Run the simulation and verify that it predicts operating parameters such as temperature and humidity.
4. Compare the simulated *energy* results with the metered *energy* data from the calibration period, on an hourly or monthly basis.

5. Evaluate patterns in the differences between simulation results and calibration data. Bar charts, monthly percent difference time-series graphs, and monthly x-y scatter plots help to identify the error patterns. The calibration accuracy should be established in the *M&V Plan* to accommodate the *M&V* budget.
6. Revise input data in step 1 and repeat steps 3 and 4 to bring predicted results within the calibration specifications in 5, above. Collect more actual operating data from the facility to meet the calibration specification if necessary.

The creation and calibration of a simulation is time consuming. Using monthly rather than hourly *energy* data helps to limit the effort needed for calibration. However if Option D will be used to determine savings at the ECM level, calibration of major end-uses, systems, and/or equipment impacted by the ECMs is recommended.

4.9.3 Option D: Calculations

Savings can be determined using calibrated simulation results representing the baseline energy and/or the *reporting-period* energy. For projects with a physical baseline, the two calibrated models include one with the *ECM*s and one without them. For projects with a hypothetical baseline, calibrated models may include the hypothetical baseline and the as-built *(reporting period)* conditions, but measured data will only be available for calibration under as-built conditions. In either case, both models and measured energy data must be under the same set of operating conditions.

Savings with Option D can be estimated using two forms of Equation 1), Equations 1f) and 1g)[14]. Both forms presume that the calibration 'error' equally affects both *baseline* and *reporting period* models. The same savings will be determined from the two equations for any given set of data and simulations.

Savings = *Baseline energy* from the calibrated model [hypothetical or without *ECM*s]
– *Reporting-period energy* from the calibrated model [with *ECM*s] 1f)

One of the model-derived energy terms in Equation 1f) may be replaced by the actual measured *energy*. However, you must adjust your calculations for the calibration error for each month in the calibration period, using. Equation 1g):

Savings = *Baseline energy* from the calibrated model [hypothetical or without *ECM*s]
- Actual calibration-period *energy*
+/- Calibration error in the corresponding calibration reading 1g)

Equation 1may be most easily understood by non-technical persons, since the final savings computation uses actual metered data rather than only the results of simulation models.

4.9.4 Option D: Ongoing *Savings* Reporting

If multi-year performance evaluation is required, Option D may be used for the first year after the *ECMs* are installed. In later years, Option C may be less costly than Option D if you use as the *baseline* the meter data from the first year of steady operation after installation. Then Option C is used to determine whether *energy* use changes from the first year of operation after the *ECM* was installed. In this situation, the first year of steady operation's *energy* use would be

[14] Equations 1f) and 1g) are the same as Methods 1 and 2, respectively, found in IPMVP Vol III Part 1.

used: a) to calibrate an Option D simulation model, and b) to establish an Option C *baseline* for measuring additional *savings* (or losses) in the second year and beyond.

4.9.5 Option D: Best Applications

Option D is usually used where no other Option is feasible.

Option D is best applied where:

- Either *baseline energy* data or *reporting-period energy* data, but not both, are unavailable or unreliable.
- There are too many *ECM*s to assess using Options A or B.
- The *ECM*s involve diffuse activities, which cannot easily be isolated from the rest of the *facility*, such as operator training or wall and window upgrades.
- The performance of each *ECM* will be estimated individually within a multiple-*ECM* project, but the costs of Options A or B are excessive.
- Interactions between *ECM*s or *ECM interactive effects* are complex, making the isolation techniques of Options A and B impractical.
- Major future changes to the facility are expected during the *reporting period,* and there is no way to track the changes and/or account for their impact on *energy* use.
- An experienced *energy*-simulation professional is able to gather appropriate input data to calibrate the simulation model.
- The *facility* and the *ECM*s can be modeled by well documented simulation software.
- Simulation software predicts metered calibration data with acceptable accuracy.
- Only one year's performance is measured, immediately following installation and commissioning of the *energy*-management program.

4.10 Option Selection Guide

The selection of an IMPVP Option is a decision that is made by the designer of the *M&V* program for each project, based on the full set of project conditions, analysis, budgets and professional judgment. Figure 4 outlines common logic used in Option selection.

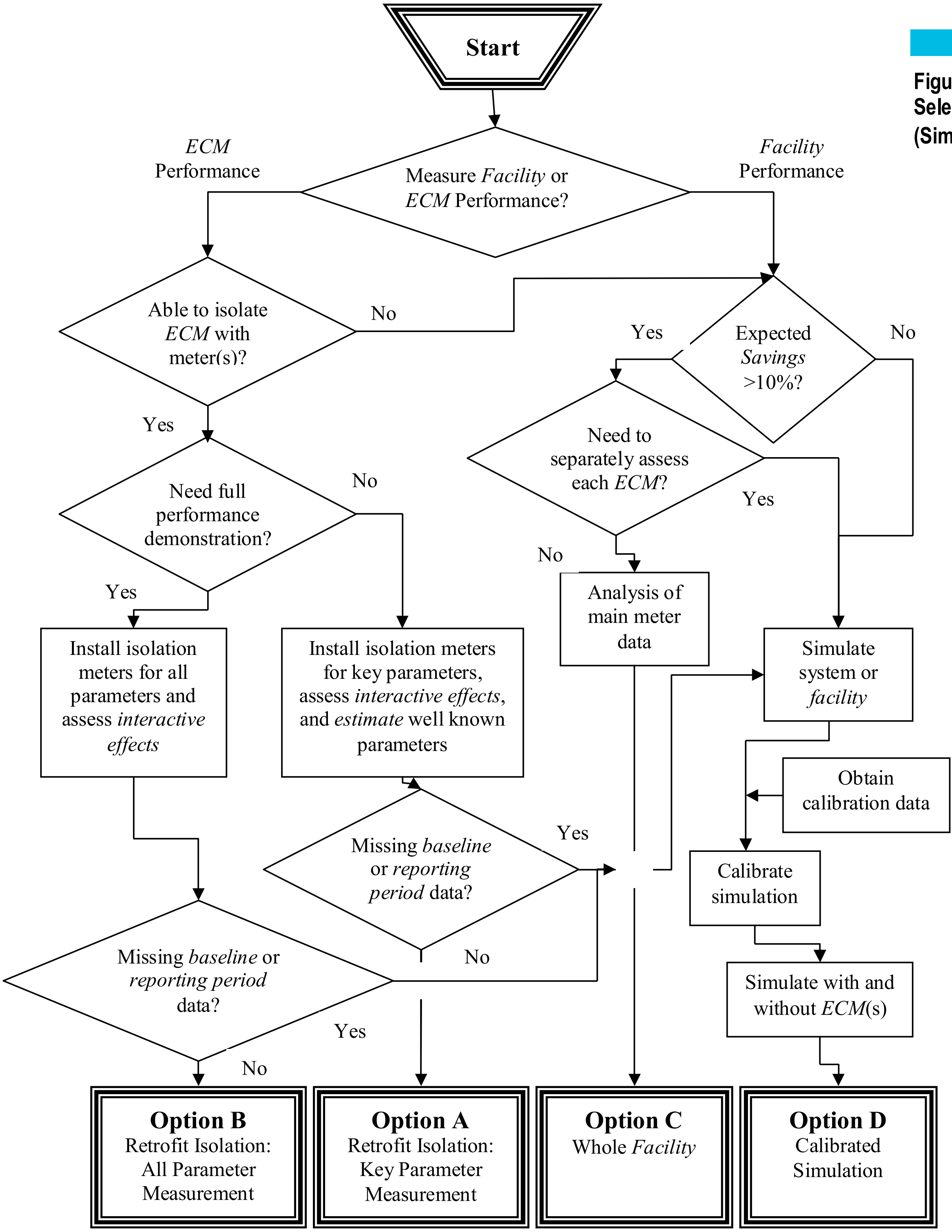


Figure 4 Option Selection Process (Simplified)

It is impossible to generalize on the best IPMVP Option for any type of situation. However some key project characteristics suggest commonly favored Options as shown in Table 3 below.

Table 3 Suggested (not the only) Options - Marked by X

ECM Project Characteristic	Suggested Option			
	A	**B**	**C**	**D**
Need to assess *ECMs* individually	X	X		X
Need to assess only total facility performance			X	X
Expected *savings* less than 10% of utility meter	X	X		X
Significance of some *energy* driving variables is unclear		X	X	X
Interactive effects of ECM are signficant or unmeasurable			X	X
Many future changes expected within *measurement boundary*	X			X
Long term performance assessment needed	X		X	
Baseline data not available				X
Non-technical persons must understand reports	X	X	X	
Metering skill available	X	X		
Computer simulation skill available				X
Experience reading utility bills and performing regression analysis available			X	

4.11 Persistence of Savings

An organisation which has improved its energy efficiency is more at risk from adverse shifts in performance, not only because its ECMs may be of a kind that can fail, fade or be bypassed, but also because the additional headroom in its energy budgets may allow unrelated incidents of avoidable energy waste to pass unchallenged.

Persistence of energy savings can be achieved beyond the M&V reporting period by completing follow on efforts that build on M&V. One approach is "Monitoring and Targeting" (M&T), which can seamlessly follow the M&V process. If Options B and C (see sections 4.6 above) have been used for verifying savings, the project will have metering in place for the routine measurement of consumption. More importantly, models will also have been developed that correlate energy use with driving factors such as weather. These same models can be 're-tuned' to estimate energy consumption that accounts for ECM installation. This enables a periodic comparison of actual and expected consumption, which will readily reveal and quantify any loss of ECM effect (or unrelated waste) enabling prompt remedial action to be taken in cases where the unexpected avoidable cost is deemed significant.

CHAPTER 5 *M&V PLAN* CONTENTS

The preparation of an *M&V Plan* is a recommended part of *savings* determination. Advance planning ensures that all data needed for *savings* determination will be available after implementation of the *ECM(s)*, within an acceptable budget.

Data from the *baseline* and details of the *ECM*s may be lost over time. Therefore record them for future reference in case conditions change or *ECM*s fail. Documentation should be easy to find and easy to understand by verifiers and others, because years may pass before these data are needed.

A complete *M&V Plan* should include discussion of the following 13 topics:

1. ***ECM* Intent** Describe the *ECM*, its intended result, and the *operational verification* procedures that will be used to verify successful implementation of each *ECM*. Identify any planned changes to conditions of the *baseline*, such as unoccupied building temperature settings.
2. **Selected IPMVP Option and *Measurement Boundary*** Specify which IPMVP Option, defined in Chapters 4.8 – 4.10, will be used to determine *savings*. This identification should include the date of publication or the version number and Volume number of the IPMVP edition being followed (IPMVP Volume I EVO 10000-1:2012), for example). Identify the *measurement boundary* of the *savings* determination. The boundary may be as narrow as the flow of *energy* through a pipe or wire, or as broad as the total energy use of one or many *facilities*. Describe the nature of any *interactive effects* beyond the *measurement boundary* together with their possible effects (see Chapter 4.4).
3. ***Baseline:* Period, Energy and Conditions** Document the facility's *baseline* conditions and *energy* data, within the *measurement boundary*. (In *energy performance contracts*, *baseline energy* and *baseline* conditions may be defined by either the owner or the *ESCO*, providing the other party is given adequate opportunity to verify them.)

   An energy audit used for establishing the objectives of a *savings* program or terms of an *energy performance contract* usually provides most if not all of the *baseline* documentation needed in the *M&V Plan.* This *baseline* documentation should include:

   a) Identification of the *baseline period* (Chapter 4.5.1)

   b) All *baseline energy* consumption and demand data

   c) All *independent variable* data coinciding with the *energy* data (e.g. production rate, ambient temperature)

   d) All *static factors* coinciding with the *energy* data:

   - Occupancy type, density and periods

   - Operating conditions for each *baseline* operating period and season, other than the *independent variables*. (For example, in an industrial process, *baseline* operating conditions might include product type(s), raw material type, and number of production shifts per day. In a building *baseline* operating conditions might include light level, space temperature humidity and ventilation levels. An assessment of thermal comfort and/or indoor air quality (IAQ) may also prove useful in cases where the new system performs differently than the old inefficient system. See IPMVP Volume II.)

   - Description of any *baseline* conditions that fall short of required conditions. For example, the space is under-heated during the *baseline*, but the *ECM* will restore the desired temperature. Details of all adjustments that are necessary to the *baseline* *energy* data to reflect the energy-management program's expected improvement from *baseline* conditions.

- Size, type, and insulation of any relevant building envelope elements such as walls, roofs, doors, windows.

- Equipment inventory: nameplate data, location, condition. Photographs or videotapes are effective ways to record equipment condition.

- Equipment operating practices (schedules and setpoints, actual temperatures and pressures)

- Significant equipment problems or outages during the *baseline period*.

The *baseline* documentation typically requires well-documented audits, surveys, inspections and/or short-term metering activities. The extent of this information is determined by the *measurement boundary* chosen or the scope of the *savings* determination.

Where whole-*facility M&V* methods are employed (Chapter 4.9 or 4.10), all *facility* equipment and conditions should be documented.

4. ***Reporting Period*** Identify the *reporting period*. This period may be as short as an instantaneous measurement during commissioning of an *ECM*, or as long as the time required to recover the investment cost of the *ECM* program (See Chapter 4.5.2).
5. **Basis for Adjustment** Declare the set of conditions to which all *energy* measurements will be adjusted. The conditions may be those of the *reporting period* or some other set of fixed conditions. As discussed in Chapter 4.6, this choice determines whether *savings* are reported as *avoided energy* (4.6.1) or as *normalized savings* (4.6.2).
6. **Analysis Procedure** Specify the exact data analysis procedures, algorithms and assumptions to be used in each *savings* report. For each mathematical model used, report all of its terms and the range of *independent variables* over which it is valid.
7. ***Energy* Prices** Specify the energy prices that will be used to value the *savings*, and whether and how savings will be adjusted if prices change in future (See Chapter 8.1).
8. **Meter Specifications** Specify the metering points, and period(s) if metering is not continuous. For non-utility meters, specify: meter characteristics, meter reading and witnessing protocol, meter commissioning procedure, routine calibration process, and method of dealing with lost data (see Chapter 8.11.1).
9. **Monitoring Responsibilities** Assign responsibilities for reporting and recording the *energy* data, *independent variables* and *static factors* within the *measurement boundary* during the *reporting period*.
10. **Expected Accuracy** Evaluate the expected accuracy associated with the measurement, data capture, sampling and data analysis. This assessment should include qualitative and any feasible quantitative measures of the level of uncertainty in the measurements and adjustments to be used in the planned *savings* report (See Chapter 8.3 and Appendix B).
11. **Budget** Define the budget and the resources required for the *savings* determination, both initial setup costs and ongoing costs throughout the *reporting period*.
12. **Report Format** Specify how results will be reported and documented (see Chapter 6). A sample of each report should be included.
13. **Quality Assurance** Specify quality-assurance procedures that will be used for *savings* reports and any interim steps in preparing the reports.

Depending upon the circumstances of each project, some additional specific topics should also be discussed in a complete *M&V Plan*:

For Option A:

- **Justification of Estimates** Report the values to be used for all *estimated values.* Explain the source of these *estimated values*. Show the overall significance of these *estimates* to the total expected *savings* by reporting the range of the possible *savings* associated with the range of plausible values of the *estimated* parameters.
- **Periodic Inspections** Define the periodic inspections that will be performed in the *reporting period* to verify that equipment is still in place and operating as assumed when determining the *estimated* values.

For Option D:

- **Software Name** Report the name and version number of the simulation software to be used.
- **Input/Output Data** Provide a paper and electronic copy of the input files, output files, and weather files used for the simulation.
- **Measured Data** Note which input parameters were measured and which were estimated. Describe the process of obtaining any measured data.
- **Calibration** Report the *energy* and operating data used for calibration. Report the accuracy with which the simulation results match the calibration *energy* data.

Where the nature of future changes can be anticipated, define methods for making the relevant *non-routine adjustments*.

Time and budget requirements (item 11, above) are often underestimated, which leads to incomplete data collection. A less accurate and less expensive *savings* determination is better than an incomplete or poorly done determination, which is theoretically more accurate but under-funded. Chapter 8.5 addresses cost/benefit tradeoffs.

Issues arising in developing *M&V Plans* are discussed in the examples shown in Appendix A. The website of Efficiency Valuation Organization (www.evo-world.org) contains a growing selection of sample *M&V Plan*s.

CHAPTER 6 *M&V* REPORTING

M&V Reports should be prepared and presented as defined in the *M&V Plan* (Chapter 5)

Complete *M&V* reports should include at least:

- Observed data of the *reporting period*: the *measurement period* start and end points in time, the *energy* data, and the values of the *independent variables*
- Description and justification for any corrections made to observed data
- For Option A the agreed *estimated values*
- *Energy* price schedule used
- All details of any *baseline non-routine adjustment* performed. Details should include an explanation of the change in conditions since the *baseline period*, all observed facts and assumptions, and the engineering calculations leading to the adjustment.
- Computed *savings* in *energy* and monetary units.

M&V reports should be written to their readers' levels of understanding.

Energy managers should review the *M&V* reports with the *facility's* operating staff. Such reviews may uncover useful information about how the facility uses *energy*, or where operating staff could benefit from more knowledge of the *energy*-consumption characteristics of their *facility*.

CHAPTER 7 ADHERENCE WITH IPMVP

IPMVP is a framework of definitions and methods for properly assessing *savings* in energy or water use or demand. The IPMVP guides users in developing *M&V Plans* for specific projects. IPMVP is written to allow maximum flexibility in creating *M&V Plans*, while adhering to the principles of accuracy, completeness, conservativeness, consistency, relevance and transparency (Chapter 3).

Users claiming adherence with IPMVP must:

1. Identify the person responsible for approving the site-specific *M&V Plan*, and for making sure that the *M&V Plan* is followed for the duration of the *reporting period*.
2. Develop a complete *M&V Plan* which:
   - clearly states the date of publication or the version number of the IPMVP edition and Volume being followed,
   - uses terminology consistent with the definitions in the version of IPMVP cited,
   - includes all information mentioned in the *M&V Plan* chapter (Chapter 5 of the present edition),
   - is approved by all parties interested in adherence with IPMVP, and
   - is consistent with the Principles of *M&V* shown in Chapter 3.
3. Follow the approved IPMVP adherent *M&V Plan*.
4. Prepare *M&V* reports containing the information mentioned in the *M&V* Reporting chapter (Chapter 6).

Users wishing to specify the use of IPMVP in an energy performance contract or emission trade may use phrases such as, “The determination of actual energy and monetary savings will follow current best practice, as defined in IPMVP Volume I, EVO 10000 -1:2012.”

Specification may go further to include “The M&V Plan shall adhere to IPMVP Volume I, EVO 10000 - 1:2012 and be approved by……” and may also, if known at the time of contract approval, add, “following IPMVP Option ….”

CHAPTER 8 OTHER COMMON *M&V* ISSUES

Beyond the basic framework described in Chapter 4, there are a number of issues which commonly arise regardless of the IPMVP Option chosen. Each of these issues is discussed in this Chapter.

8.1 Applying Energy Prices

Cost *savings*[15] are determined by applying the appropriate price schedule in the following equation:

$$\text{Cost } \textit{Savings} = C_b - C_r \qquad 2)$$

Where:

C_b = Cost of the *baseline energy* plus any *adjustments*[16]

C_r = Cost of the *reporting period energy* plus any *adjustments*

Costs should be determined by applying the same price schedule in computing both C_b and C_r.

When the conditions of the *reporting period* are used as the basis for reporting energy *savings* (i.e. *avoided energy* use Chapter 4.6.1), the price schedule of the *reporting period* is normally used to compute "avoided cost."

Examples of the application of energy prices are contained in the examples of Appendix A.

8.1.1 Price Schedules

The price schedule should be obtained from the energy supplier. This price schedule should include all elements that are affected by metered amounts, such as consumption charges, demand charges, transformer credits, power factor, *demand ratchets*, fuel price adjustments, early payment discounts and taxes.

Price schedules may change at points in time different from meter reading dates. Therefore, C_b and C_r in Equation 2) should be computed for periods exactly aligned with price change dates. This alignment may require an estimated allocation of quantities to periods before and after the price change date. The allocation methodology should be the same as that used by the *energy* supplier.

The selected price schedule may be fixed at the date of *ECM* installation, or changed as prices change. (Increasing prices will shorten the *ECM* payback period. Decreasing prices will lengthen the payback period though total *energy* costs will drop when prices drop.) Where a third party has invested in an owner's *facility*, the price schedule for *savings* reporting is not normally allowed to drop below that which prevailed at the time of commitment to the investment.

---

[15] See Chapter 9 for the definition of "*savings*." See also Chapter 4.6 for discussion of the difference between energy *savings* and avoided energy or normalized savings. The same discussion applies to the difference between cost *savings* and cost avoidance or normalized cost savings.

[16] *Adjustments* are the appropriate ones described in Chapter 4.

8.1.2 Marginal Price

An alternative procedure for valuing *savings* involves multiplying *energy* units *saved* by the *marginal price* of *energy*. Be careful to ensure that the *marginal price* is valid for the level of consumption and demand of both the *baseline* and *reporting periods*.

Average, or blended prices, determined by dividing billed cost by billed consumption, are often different from *marginal prices.* In this situation average prices create inaccurate statements of cost *savings* and should not be used.

8.1.3 Fuel Switching and Price Schedule Changes

The Chapter 8.1 general strategy of applying the same price schedule to *baseline* and *reporting period energy* introduces some special considerations when the *ECM* creates a change in fuel type or a change in price schedule between the *baseline* and *reporting periods*. Such situations arise, for example, when an *ECM* includes a change to a lower cost fuel, or shifts the *energy* use pattern such that the facility qualifies for a different price schedule.

In such situations, use the price schedule of the *baseline* commodity to determine C_b in Equation 2). The price schedule of the *reporting-period* commodity should be used in determining C_r. However, both commodity-price schedules would be for the same time period, usually the *reporting period*.

For example, the heating source is changed from electricity to gas, and you intend to use *reporting period* prices. Then C_b would use the *reporting period*'s electricity-price schedule for all electricity. C_r would use the *reporting period*'s gas-price schedule, for the new gas load, and the *reporting period*'s electricity-price schedule for any remaining electricity use.

However, this treatment of an intentional change of price schedule does not apply if the change was not part of the *ECM*(s) being assessed. For example, if the utility changed its price structures for no reason related to the *ECM*(s) being assessed, the Chapter 8.1 general principle of using the same price schedule for C_b and C_r still applies.

8.2 Baseline Adjustments (*Non-Routine*)

Conditions, which vary in a predictable fashion and are significant to *energy* use within the *measurement boundary,* are normally included within the mathematical model used for *routine adjustments*, described in Chapter 4.6. Where unexpected or one-time changes occur in conditions within the *measurement boundary*, which are otherwise static (*static factors*), *non-routine adjustments*, also called *baseline adjustments,* must be made (see also Chapter 4.6).

Non-routine adjustments are needed where a change occurs to equipment or operations within the *measurement boundary* after the *baseline period*. Such change occurs to a *static factor* not to *independent variables*. For example, an *ECM* improved the efficeincy of a large number of light fixtures. When more light fixtures were installed, after *ECM* installation, a *non-routine adjustment* was made. The estimated *energy* of the extra fixtures was added to the *baseline energy* so that the *ECM*'s true *savings* were still reported.

Values *estimated* for use in IPMVP Option A are usually chosen to eliminate the need for adjustments when changes happen within the *measurement boundary* (see Chapter 4.8.1). Therefore *non-routine adjustments* can be avoided using Option A. For example, a chiller plant's cooling load was *estimated* rather than measured in order to determine Option A *savings* created by a chiller efficiency *ECM*. After retrofit, a *facility* addition increased the actual cooling load within the *measurement boundary*. However since Option A was chosen using a fixed cooling load, reported *savings* are unchanged. The use of Option A avoided the need for a *non-routine adjustment*.

Baseline conditions need to be fully documented in the *M&V Plan* so that changes in *static factors* can be identified and proper *non-routine adjustments* made. It is important to have a method of tracking and reporting changes in these same *static factors*. This tracking of conditions may be performed by one or more of: the *facility* owner, the agent creating *savings*, or a third party verifier. It should be established in the *M&V Plan* who will track and report each *static factor*.

Where the nature of future changes can be anticipated, methods for making the relevant *non-routine adjustments* should be included in the *M&V Plan*.

Non-routine adjustments are determined from actual or assumed physical changes in equipment or operations (*static factors*). Sometimes it may be difficult to quantify the impact of changes, for example, if they are numerous or not well documented. If the *facility's energy* consumption record is used to quantify the impact of such changes, the impact of the *ECM*s on the *facilitiy's energy* consumption must first be removed by Option B techniques. Option C cannot be used to determine *savings* when the *facilitiy's energy* meter is also used to quantify the impact of changes to *static factors*.

8.3 The Role Of Uncertainty (Accuracy)

The measurement of any physical quantity includes errors because no measurement instrument is 100% accurate. Errors are the differences between observed and true *energy* use. In a *savings*-determination process, errors prevent the exact determination of *savings*. Equation 1) usually involves at least two such measurement errors (*baseline* and *reporting period energy*), and whatever error exists in the computed adjustments. To ensure that the resultant error (uncertainty) is acceptable to the users of a *savings* report, be certain to manage the errors inherent in measurement and analysis when developing and implementing the *M&V Plan*.

Characteristics of a *savings* determination process which should be carefully reviewed to manage accuracy or uncertainty are:

- Instrumentation – measurement equipment errors are due to calibration, inexact measurement, or improper meter selection installation or operation.
- Modeling – the inability to find mathematical forms that fully account for all variations in *energy* use. Modeling errors can be due to inappropriate functional form, inclusion of irrelevant variables, or exclusion of relevant variables.
- Sampling – use of a sample of the full population of items or events to represent the entire population introduces error as a result of: the variation in values within the population, or biased sampling. Sampling[17] may be done in either a physical sense (i.e., only 2% of the lighting fixtures are measured) or a temporal sense (instantaneous measurement only once per hour).
- *Interactive effects* (beyond the *measurement boundary*) that are not fully included in the *savings* computation methodology.
- *Estimation* of parameters using Option A, rather than measurement. You can minimize the variation between the parameter's *estimated value* and its true value through careful review of the *ECM* design, careful estimating of the parameter, and careful *ECM* inspection after installation.

Methods of quantifying, evaluating and reducing some of these uncertainties are discussed in this document's Appendix B. Appendix C lists some references from different regions about applying standard-error-analysis methods to the typical *savings* determination. These quantification tools should only be used to develop the *M&V Plan*, in order to test the inherent uncertainty associated with optional *M&V* program characteristics.

[17] As used in this Protocol, sampling does not refer to rigorous statistical procedures, but to the best practices as addressed in Appendix B-3.

Establish the users' acceptable *savings* accuracy during the *M&V Plan*ning process. Chapter 8.5 discusses some issues in establishing the correct level of uncertainty for any *ECM* or project. Appendix B-1.2 defines how large *savings* must be, relative to statistical variations in baseline data, for *M&V* reports to be valid.

The accuracy of any measured value is properly expressed as the range within which we expect the true value to fall, with some level of *confidence*. For example, a meter may measure consumption as 5,000 units with a *precision* of ±100 units, and a *confidence* of 95%. Such statement means that 95% of the readings of the same true value are expected to be between 4,900 and 5,100 units.

In a *savings* determination, it is feasible to quantify many uncertainty factors but usually not all of them. Therefore when planning an *M&V* process, you report both quantifiable uncertainty factors and also qualitative elements of uncertainty. The objective is to recognize and report all uncertainty factors, either qualitatively or quantitatively.

When you describe *precision* within any *savings* report, report the *savings* with no more *significant digits* than the least number of *significant digits* in metered quantities, estimates or constants used in the quantification process. See Chapter 8.12.

8.4 Cost

The cost of determining *savings* depends on many factors such as:

- IPMVP Option selected,
- the number of *ECMs* and the complexity and amount of interaction among them,
- number of energy flows across the *measurement boundary* in Options A, B, or D when applied to a system only,
- level of detail and effort associated with establishing *baseline* conditions needed for the Option selected,
- amount and complexity of the measurement equipment (design, installation, maintenance, calibration, reading, removal),
- sample sizes used for metering representative equipment,
- amount of engineering required to make and support the *estimations* used in Options A or D,
- number and complexity of *independent variables* which are accounted for in mathematical models,
- duration of the *reporting period*,
- accuracy requirements,
- *savings* report requirements,
- process of reviewing or verifying reported *savings*, and
- experience and professional qualifications of the people conducting the *savings* determination.

M&V costs should be appropriate for the size of expected *savings*, the length of the *ECM* payback period, and the report users' interests in accuracy, frequency, and the duration of the reporting process. Often these costs can be shared with other objectives such as real time control, operational feedback, or tenant or departmental sub-billing. Prototype or research projects may bear a larger than normal *M&V* cost, for the sake of accurately establishing the *savings* generated by *ECM*s which will be repeated. However IPMVP is written to provide many possible ways to document the results of an *ECM* so that users can develop low-cost *M&V* procedures that provide adequate information.

It is difficult to generalize about costs for the different IPMVP Options, since each project will have its own budget. However, *M&V* should incur no more cost than needed to provide adequate certainty and verifiability in the reported *savings*, consistent with the overall budget for the *ECM*s.

Table 4 Unique Elements of *M&V* Costs

Option A	Number of measurement points; complexity of estimation; frequency of *reporting period* inspections.
Option B	Number of measurement points; length of the *reporting period.*
Option C	Number of static factors to be tracked during the *reporting period*; number of *independent variables* to be used for *routine adjustments*.
Option D	Number and complexity of systems simulated; number of field measurements needed to provide input data for the calibrated simulation; skill of professional simulator in achieving calibration.

Table 4 highlights key cost-governing factors unique to each Option, or not listed above.

Commonly, since Option A involves *estimates*, it will involve fewer measurement points and lower cost, providing *estimation* and inspection costs are not unusually high. Option A methods usually have lower cost and higher uncertainty than Option B methods.

Since new measurement equipment is often involved in Options A or B, the cost of maintaining this equipment may make Option C less costly for long *reporting periods*. However, the costs of extra meters for Options A or B may be shared with other objectives of monitoring or cost allocation.

When multiple *ECM*s are installed at one site, it may be less costly to use Options C or D than to isolate and measure multiple *ECM*s with Options A or B.

An Option D simulation model is often time-consuming and costly. However, the model may have other uses such as for designing the *ECM*s themselves or designing a new *facility*.

Expect M&V costs to be highest at the beginning of the *reporting period*. At this stage in a project, measurement processes are being refined, and accurate performance monitoring helps to optimize *ECM* operation. The cost for each *savings* determination should be in proportion to the expected *savings* and the variation in *savings* (see Chapter 8.5).

A contractor is often responsible for only certain performance indicators. Other indicators may not have to be measured for contractual purposes, though the *facility* owner may still wish to measure all indicators. In this situation, the owner and contractor share the costs of measurement.

8.5 Balancing Uncertainty And Cost

The acceptable level of uncertainty in a *savings* report is related to the cost of decreasing uncertainty to an appropriate level for the expected amount of *savings*. Typically average annual *M&V* costs are less than 10% of the average annual *savings* being assessed. The quantity of *savings* at stake therefore places a limit on the *M&V* budget, which in turn determines how much uncertainty is acceptable.

For example, consider a project with an expected *savings* of $100,000 per year and $5,000/year cost for a basic *M&V* approach with a *precision* no better than ±$25,000 per year with 90% confidence. To improve the *precision* to ±$7,000 it may be seen as reasonable to increase *M&V* expenditures up to $10,000/year (10% of the *savings*), but not $20,000/year (20%).

The acceptable level of uncertainty in a *savings*-reporting process is often a personal matter, which depends on the report reader's desire for rigor. However reducing uncertainty requires more or better operational data. Enhanced operational data enables fine tuning of *savings* and enhancement of other operational variables. More operational information may also help to size equipment for plant expansions or for the replacement of old equipment.

Enhanced feedback created by *M&V* may also allow higher payments to be made under an *energy performance contract* based on measured data rather than deemed values of *savings,* which must be conservative.

Additional investments for lower uncertainty should not exceed the expected increase in value. This issue is discussed in more detail by Goldberg (1996b).

Of course, not all uncertainties can be quantified (see Chapter 8.3). Therefore both quantitative and qualitative uncertainty statements should be considered when considering *M&V* cost options for each project.

For each project, site and *facility* owner, there is an optimal *M&V Plan*. That optimal *M&V Plan* should include iterative consideration of the sensitivity of the *savings* uncertainty and *M&V* cost to each *M&V* design parameter. Appendix B presents methods of quantifying uncertainty. Appendices B-5.1 and B-5.2 present methods of combining several components of uncertainty and setting uncertainty criteria or objectives.

Not all *ECM*s should expect to achieve the same level of *M&V* uncertainty since uncertainty is proportional to the complexity of the *ECM* and the variations in operations during both the *baseline period* and *reporting period*. For example, Option A methods may allow the *savings* from a simple industrial-plant lighting retrofit to be determined with less uncertainty than the *savings* from a chiller retrofit, since *estimated* lighting parameters may have less uncertainty than *estimated* chiller-plant parameters.

In determining the measurement level and associated costs, the *M&V Plan* should consider the amount of variation in the *energy* use within the *measurement boundary.* For example, indoor lighting may use electricity fairly consistently all year, making it relatively easy to determine *savings*, while heating and cooling loads change seasonally making *savings* identification more difficult. Consider the following general guidelines for balancing cost and uncertainty in an *M&V* process.[18]

1. **Low *Energy* Variation & Low-Value *ECM.*** Low-value *ECM*s cannot typically afford much *M&V*, based on the 10%-of-*savings* guideline, especially if there is little variation in the measured *energy* data. Such combined situations would tend to favour use of Option A, and short *reporting periods*, for example, in the case of a constant-speed exhaust-fan motor that operates under a constant load according to a well-defined schedule.
2. **High *Energy* Variation & Low-Value *ECM.*** Low-value *ECM*s cannot generally afford much *M&V*, as in 1, above. However with a high amount of variation in the *energy* data, the all-parameter measurement techniques of Option B may be needed to achieve the required uncertainty. Sampling techniques may be able to reduce Option B costs. Option C may not be suitable based on the general guidance in Chapter 4.9 that *savings* should exceed 10% of a *facility's* metered use in order to be measurable.

[18] Also see FEMP (2002).

3. **Low *Energy* Variation & High-Value *ECM.*** With low variation in *energy* use, the level of uncertainty is often low, so Option A techniques may be most suitable. However, since you expect high *savings*, small improvements in *precision* may have monetary rewards large enough to merit more precise metering and data analysis, if you can keep *M&V* costs appropriate relative to the *savings*. For example, if the *savings* from an *ECM* are $1,000,000 annually, you may decide to increase the $5,000 annual *M&V* cost to $20,000, if it increases *precision* and provides more operational data. Alternatively, a high-value *ECM* may be clearly measurable with Option C. Option C can keep *M&V* costs low, if simple means are used to monitor *static factors* to detect the need for *non-routine adjustments*.
4. **High *Energy* Variation & High-Value *ECM.*** This situation allows appropriate uncertainty reduction through extensive data collection and analysis using Options A, B or D. However *savings* are also likely to show in the utility records, so that Option C techniques may be used with careful monitoring of *static factors* to detect the need for *non-routine adjustments*. The *reporting period* may have to span multiple normal *cycles* of *facility* operation.

8.6 Verification by an Independent Verifier

Where a contractor is hired by a *facility* owner to make and report *energy savings*, the owner may need an independent verifier to review the *savings* reports. This independent verifier should begin by reviewing the *M&V Plan* during its preparation, to ensure that the *savings* reports will satisfy the owner's expectations for uncertainty.

The independent review could also examine *non-routine adjustments*. However full review of *non-routine adjustments* requires good understanding of the *facility,* its operations and *energy* engineering calculation techniques. The *facility* owner should provide summaries of changes in *static factors* so that the verifier can focus on the engineerign calculations in the *non-routine adjustments*.

An *energy performance contract* requires that both parties believe that the performance payments are based on valid information. An independent verifier may be helpful to ensure measurement validity and to prevent conflicts. If conflicts arise during the *reporting period*, this independent verifier can help to resolve the conflicts.

Independent verifiers are typically engineering consultants with experience and knowledge in *ECMs*, *M&V* and *energy performance contracting*. Many are members of industry professional societies, or are Certified Measurement and Verification Professionals (CMVP®s).[19]

8.7 Data for Emission Trading

Adherence to IPMVP can provide increased confidence in energy-*savings* reports, which also increases confidence in associated reports of emission-reduction commodities.

Combined with the specific *M&V Plan* of each project, IPMVP enhances consistency of reporting and enables validation and verification of energy-saving projects. However to verify an emission-reduction commodity, IPMVP and the project's *M&V Plan* must be used in conjunction with the emission-trading program's specific guidance on converting energy *savings* into equivalent emissions reductions.

Emission trading will be facilitated if the following energy-reporting methods are considered when designing the process for determining the units of energy *saved*.

- Electrical *savings* should be split into peak period and off peak periods, and ozone season and non-ozone season when NOx or VOC trading is involved. These periods are defined by the relevant emission-trading program.

---

[19] The CMVP® program is a joint activity of Efficiency Valuation Organization and the Association of Energy Engineers (AEE). It is accessible through EVO's website www.evo-world.org.

- Reductions in purchases from the electrical grid should be divided into those due to load reduction and those due to increased self-generation at the facility.
- The *adjusted baseline* used for computing energy *savings* may need to change to suit the requirements of the particular emission-trading program. For emission-trading purposes, *adjusted baselines* need to consider whether the *ECMs* were 'surplus' or 'additional' to normal behavior. *ECMs* may not be allowed for emisison trading if they are 'business as usual' or simply compliance with existing regulations. Baseline rules are defined by the relevant emission-trading program. For example, where equipment minimum–efficiency standards govern the equipment market, these standards set the baseline for determining tradable amounts.
- Segregate energy *savings* by site, if a project spans a power pool's boundary line, or if emission quantities may be outside an air shed of concern.
- Segregate fuel *savings* by fuel or boiler type, if different emission rates apply to each combustion device.

Each emission-trading system usually has its own rules surrounding emission factors to be applied to energy *savings*. For fuel *savings*, default emission rates may be given when no emission-measuring equipment is in place. For electricity *savings*, default values may also be given for the power grid emission rate. Alternatively users may establish their own emisison rate for electricity savings, following recognized principles such as those published as part of the Guidelines for Grid-Connected Electricity Projects (WRI 2007).

8.8 Minimum Operating Conditions

An energy-efficiency program should not affect the use of the *facility* to which it is applied, without the agreement of building occupants or industrial process managers. Key user paramaters may be: light level, temperature, ventilation rate, compresssed air pressure, steam pressure and temperature, water flow rate, production rate, etc.

The *M&V Plan* should record the agreed minimum operating conditions that will be maintained (see Chapter 5).

IPMVP Volume II, Concepts and Practices for Improved Indoor Environmental Quality, suggests methods of monitoring indoor space conditions throughout an energy-efficiency program.

8.9 Weather Data

Where monthly energy measurements are used, weather data should be recorded daily so it can be matched to the actual energy-metering reading dates.

For monthly or daily analysis, government published weather data is usually the most accurate and verifiable. However weather data from government sources may not be available as promptly as site-monitored weather data. If you use on-site weather-monitoring equipment, be sure it is regularly and properly calibrated.

When analyzing the response of energy use to weather in mathematical modeling, daily mean temperature data or *degree days* may be used.

8.10 Minimum Energy Standards

When a certain level of efficiency is required either by law or the facility owner's standard practice, *savings* may be based on the difference between *reporting-period energy* and that minimum standard. In these situations, *baseline-period energy* may be set equal to or less than the applicable minimum *energy* standards.

8.11 Measurement Issues

The proper application of meters for specific applications is a science in itself. Numerous references are available for this purpose (see Chapter 10.2). The EVO web site contains relevant current references on measurement techniques.

Table 5, below, summarizes some key types of meters, and provides comment on *M&V* matters for some of them. This Table should neither be taken as complete nor definitive.

8.11.1 Data Collection Errors and Lost Data

No data collection process is without error. Methodologies for *reporting period* data collection differ in degree of difficulty, and consequently in the amount of erroneous or missing data that may arise. The *M&V Plan* should establish a maximum acceptable rate of data loss and how it will be measured. This level should be part of the overall accuracy consideration. The level of data loss may dramatically affect cost. The *M&V Plan* should also establish a methodology by which missing or erroneous *reporting-period* data will be re-created by interpolation for final analysis. In such cases, *reporting-period* models are needed to interpolate between measured data points so that *savings* can be calculated for each period.

Note that *baseline* data consist of real facts about *energy* and *independent variables* as they existed during the *baseline period*. Therefore *baseline* data problems should not be replaced by modelled data, except when using Option D. Where *baseline* data is missing or inadequate, seek other real data to substitute, or change the *baseline period* so that it contains only real data. The *M&V Plan* should document the source of all *baseline* data.

Table 5 Key Meter Types – Part 1

Application	Meter Category	Meter Types	Typical Accuracy	Relative Cost	Best Uses	Special *M&V* Issues
AC Current (amps)	Current transformer (CT)	Solid torroid or split core transformer	<1%			Not for use where power factor is less than 100% or there is sinewave distortion
AC Voltage (volts)	Voltage leads or 'potential transformer' (PT)	Solid torroid or split core transformer				
AC Electric Power (watts) or AC Energy (watthours)	True rms watt meter or watthour meter	Measure watts (or amps volts and power factor), and watthours. Use digital sampling (IEEE 519-1992) to properly measure distorted waveforms				Necessary for inductive loads (eg motors, ballasts) or circuits with harmonics from components such as a variable speed drive
Runtime (hours)	Measure and record equipment operating periods	Battery operated		Lower cost than watthour recording	Logging of lighting periods	For equipment having a constant power usage rate when on
Tempera-ture (degrees)	Resistance Temperature Detector (RTD)		Reasonable	Low cost	Air and water	Widely used. Take care to compensate for different lead lengths
	Thermo-couple		High	High		Narrow range. Suited to thermal energy metering. Need signal amplifiers

Table 5 Key Meter Types – Part 2

Application	Meter Category	Meter Types	Typical Accuracy	Relative Cost	Best Uses	Special *M&V* Issues
Humidity (%)						Regular re-calibration required
Liquid Flow (units/sec)	Intrusive	Differential Pressure	1-5% of max			
		Positive Displacement	<1%			
		Turbine, or hot tap insertion turbine	<1%		Clean fluid, straight pipe	
		Vortex Shedding	High			
	Non-intrusive	Ultrasonic	<1%		Straight pipe	Spot flow measure-ment
		Magnetic		High		
		Bucket & Stop watch		Low	Steam condensate, plumbing outlet fixture	Spot flow measure-ment
Pressure						
Thermal Energy	Packaged flow and tempera-ture logging and comput-ation	Uses accurate flow and temperature sensors. For steam may need pressure and temperature sensors	<1%	High		Use matched temperature sensors for measuring a temperature difference. Carefully manage all possible sources of error

8.11.2 Use of Control Systems for Data Collection

A computerized control system can provide much of the monitoring necessary for data collection. However, the system's hardware and software must be capable of performing control and data gathering simultaneously, without slowing computer processing, consuming excess communication bandwidth, or overfilling storage.

Some measured parameters may not be useful for control: electric power metering, for example. Trending of small power, lighting and main-feed power consumption may be very useful for high-quality *savings* determination and operational feedback, but useless for real-time control.

Control system software can often perform other functions to assist the tracking of changes to *static factors* during the *reporting period*, such as automatically recording changes in set-points.

Facility staff should be properly trained in this use of the system so they can develop their own trending information for diagnosing system problems, providing the system has the capacity for extra trending. However where a contractor is responsible for some operations controlled by the system, security arrangements should ensure that persons can only access functions for which they are competent and authorized.

The control-system design and monitoring team may have a direct read-only connection into the system via a modem link so that it can easily inspect trend data in the team's office. However possible concerns for virus attacks and computer security should be addressed in this situation.

Control systems can record energy use with their trending capability. However, some systems record "change of value" (COV) events that are not directly used for calculating energy *savings* without tracking time intervals between individual COV events (Claridge et al. 1993, Heinemeier and Akbari 1993). It is possible to tighten COV limits in order to force the trending towards more regular intervals, but this can overload systems that are not designed for such data densities.

Great care should be exercised to:

- Control access and/or changes to the sysem trend log from which the *energy* data are extracted.
- Develop post-processing routines for changing any control-system COV data into time-series data for performing an analysis.
- Get from the control system supplier:
  - standard traceable calibrations of all sensors it supplies,
  - evidence that proprietary algorithms for counting and/or totaling pulses and units are accurate. (Currently, there are no industry standards for performing this analysis (Sparks et al. 1992)), and
  - commitment that there is adequate processing and storage capacity to handle trending data while supporting the system's control functions.

8.12 Significant Digits

When performing any arithmetic calculation, one must consider the inherent accuracy of the data so the result does not presume greater accuracy than is defendable. For this reason, engineers have adopted a standard of rounding rules that limits the resolution of a result to that which is supported by the data. Therefore, the IPMVP has adopted the following rules to insure all calculations performed under this standard adhere to strict accuracy standards.

Rules for significant digits are derived from the "total derivative" concept from calculus.

Expressed as a function of two variables, the total derivative is, $df(x,y) = \frac{\partial f}{\partial x} \cdot dx + \frac{\partial f}{\partial y} \cdot dy$ 3.1)

If the incremental change, *dx* & *dy, where* exchanged for absolute error, Δx & Δy, the following equation results,

$$df(x,y) = \frac{\partial f}{\partial x} \cdot \Delta x + \frac{\partial f}{\partial y} \cdot \Delta y \qquad 3.2)$$

From equation 3.2, we can calculate the limits of absolute error. The rules for significant digits agree with equation 3.2 when the absolute error is greater than or equal to ±1 unit of the smallest significant digit.

To calculate the significant digits of a number, simply count the number of digits ignoring any leading zeros or trailing zeros terminating at the "ones" column (without a decimal point). Any trailing zeros to the right or left of a decimal point are considered significant.

Arithmetic Operation[20]	**RULE**
Addition / Subtraction[21] **X + Y**	Round (up or down as appropriate) the result at the right-most decimal place (lowest unit) where all numbers have a common digit. The number of significant digits will be the total of the digits of the result.
Multiplication / Division[21] **X × Y**	The number of significant digits in the result equals the smallest number of significant digits of any one of the input numbers.
Powers $\mathbf{X}^a$	The number of significant digits equals the number of significant digits in the input.

8.12.1 EXAMPLES

Numbers:

- 00123 → 3 significant digits.
- 12300 → 3 significant digits (because it is represented as 1.23×10^4).
- 12300. → 5 significant digits (because it can be represented as 1.2300×10^4).
- 12300.000 → 8 significant digits.
- 12300.012 → 8 significant digits.

[20] Additional rules exist for logarithmic and exponential functions that are not included here.
[21] Mark's Standard Handbook for Mechanical Engineers, 8th Ed., pp. 2.2-2.3

Addition:

$$\begin{array}{r} 0.2056 \\ 2.572 \\ 144.25 \\ +\ 876.1 \\ \hline 1{,}023.1 \end{array}$$

The number of significant digits is 5.

Multiplication:

- 12.345 × 0.0369 = 0.456
- 56.000 × 0.00785212 = 0.43972

Powers:

- $3.00^{\pi} = 31.5$ (3 significant digits in the input generates 3 in the output)

In order to insure consistency and repeatability, all calculations should be carried out by arithmetic operation before applying these rules. For instance, if a motor, running at a constant 32.1 kW ran for 4,564 hrs annually and the utility rate was $0.0712 per kWh, the cost of the electrical energy is ***NOT ...***

$$32.1kW \times 4564hrs = 146{,}504 \cdot kWh \rightarrow 147{,}000 \cdot kWh$$

$$147{,}000 \cdot kWh \times \frac{\$0.0712}{kWh} = \$10{,}466 \rightarrow \$10{,}500$$

It is instead correctly calculated by carrying out all the multiplication and division together.

$$32.1kW \times 4564hrs \times \frac{\$0.0712}{kWh} = \$10{,}431 \rightarrow \$10{,}400$$

Please also note that the significant digit rules do not mix well together. Carry out all calculations by "arithmetic operation" before proceeding to the next operation type.

8.12.2 SPECIAL CASES

Some numbers are represented with finite significant digits even though they can be treated as exact. Exact numbers have infinite significant digits. An example of an exact number could be a utility rate. If a local power company's rate was $0.06 per kWh and Company X used 725,691.0 kWhs one month, the utility bill would be $43,541.46, not $40,000 per the multiplication rule above. This is because the utility rate is exact … it can be represented as $\$0.0600\bar{0}$ per kWh. There is no measurement error associated with utility rates.

Another example includes time variables. If Company X was guaranteed energy savings of $1.15M per year for 3 years, the total savings would be $3.45M, not $3M. Unless expressed as a decimal number, a time variable should be considered as exact.

Care must be taken to recognize these numbers in M&V calculations else the precision of the result may be compromised.

CHAPTER 9 DEFINITIONS

Terms are *italicized* in the text to signify that they have the following meanings:

Adjusted-baseline energy: The *energy* use of the *baseline period*, adjusted to a different set of operating conditions.

Avoided energy use: The reduction in *energy* use that occurred in the *reporting period*, relative to what would have occurred if the *facility* had been equipped and operated as it was in the *baseline period* but under *reporting period* operating conditions. (see Chapter 4.6.1). "Cost avoidance" is the monetary equivalent of "avoided energy use." Both are commonly called *savings*. *Normalized savings* is another type of *savings*.

Baseline Adjustments: The *non-routine adjustments* (Chapters 4.6 and 8.2) arising during the *reporting period* from changes in any *energy* governing characteristic of the *facility* within the *measurement boundary*, except the named *independent variables* used for *routine adjustments*.

Baseline Energy: The *energy* use occurring during the *baseline period* without adjustments.

Baseline Period: The period of time chosen to represent operation of the *facility* or system before implementation of an *ECM*. This period may be as short as the time required for an instantaneous measurement of a *constant* quantity, or long enough to reflect one full operating *cycle* of a system or *facility* with variable operations.

Baseline: Pertaining to the *baseline period*.

Confidence Level: The probability that any measured value will fall within a stated range of *precision*. See Appendix B-1.1.

Constant: A term used to describe a physical parameter which does not change during a period of interest. Minor variations may be observed in the parameter while still describing it as constant. The magnitude of variations that are deemed to be 'minor' must be reported in the *M&V Plan*.

Commissioning: A process for achieving, verifying and documenting the performance of equipment to meet the operational needs of the *facility* within the capabilities of the design, and to meet the design documentation and the owner's functional criteria, including preparation of operating personnel.

CV(RMSE): See Appendix B-2.2.2

Coefficient of Variance (cv): See Appendix B-3.1

Cycle: The period of time between the start of successive similar operating modes of a *facility* or piece of equipment whose *energy* use varies in response to operating procedures or *independent variables*. For example the cycle of most buildings is 12 months, since their energy use responds to outdoor weather which varies on an annual basis. Another example is the weekly cycle of an industrial process which operates differently on Sundays than during the rest of the week.

Degree Day: A degree day is measure of the heating or cooling load on a *facility* created by outdoor temperature. When the mean daily outdoor temperature is one degree below a stated reference temperature such as 18^{o}C, for one day, it is defined that there is one heating degree day. If this temperature difference prevailed for ten days there would be ten heating degree days counted for the total period. If the temperature difference were to be 12 degrees for 10 days, 120 heating degree days would be counted. When the ambient temperature is below the reference temperature it is defined that heating degree days are counted. When ambient temperatures are above the reference, cooling degree days are counted. Any reference temperature may be used for recording degree days, though it is usually chosen to reflect the temperature at which a particular building no longer needs heating or cooling.

Demand: The rate of energy use. Many utilities base a portion of their bills on the highest (or peak) demand they measure during each billing period. Peak demand value are sometimes referred to as simply "demand." Electrical demand is normally expressed in kilowatts (kW). The sum of monthly billed kW quantities can be expressed in unit of kW-months. See also Demand Ratchet.

Demand Ratchet: A method utilities use to establish the demand for which they invoice when it is different from the demand they meter. Utilities may consider seasonal maximums or minimums, power factor, or contract amounts to set the demand on invoices (called "billing demand").

Energy: Energy or water use, or demand.

Energy Conservation Measure (ECM): An activity or set of activities designed to increase the *energy* efficiency of a *facility*, system or piece of equipment. ECMs may also conserve *energy* without changing efficiency. Several ECM's may be carried out in a *facility* at one time, each with a different thrust. An ECM may involve one or more of: physical changes to *facility* equipment, revisions to operating and maintenance procedures, software changes, or new means of training or managing users of the space or operations and maintenance staff. An ECM may be applied as a retrofit to an existing system or *facility*, or as a modification to a design before construction of a new system or *facility*.

Energy Performance Contract: A contract between two or more parties where payment is based on achieving specified results, such as reductions in *energy* costs or payback of investment within a stated period.

Energy Services Company (ESCO): A firm which provides services of design and construction of *ECMs* under an *energy performance contract*.

Estimate: A process of determining a parameter used in a *savings* calculation through methods other than measuring it in the *baseline* and *reporting periods*. These methods may range from arbitrary assumptions to engineering estimates derived from manufacturer's rating of equipment performance. Equipment performance tests that are not made in the place where they are used during the *reporting period* are estimates, for purposes of adherence with IPMVP.

Facility: A building or industrial site containing several *energy* using systems. A wing or section of a larger *facility* can be treated as a *facility* of its own if it has meters which separately measure all of its *energy*.

Independent Variable: A parameter that is expected to change regularly and have a measurable impact on the *energy* use of a system or *facility*.

Interactive Effects: *Energy* effects created by an *ECM* but not measured within the *measurement boundary*.

Marginal Price: The cost of one additional unit of a commodity billed under a complex rate schedule.

Mean: See Appendix B-1.3.

Mean Bias Error (MBE): See Appendix B-2.2.2.

Measurement and Verification (M&V): The process of using measurements to reliably determine actual *savings* created within an individual facility by an *energy* management program. *Savings* cannot be directly measured, since they represent the absence of *energy* use. Instead *savings* are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions. See also Chapter 2.

Measurement Boundary: A notional boundary drawn around equipment and/or systems to segregate those which are relevant to *savings* determination from those which are not. All *energy* uses of equipment or systems within the measurement boundary must be measured or estimated, whether the *energy* uses are within the boundary or not. See Chapter 4.4.

Metering: Collection of *energy* data over time at a *facility* through the use of measurement devices.

M&V Plan: The document defined in Chapter 5.

Non-Routine Adjustments: The individually engineered calculations in Equation 1a) of Chapter 4 to account for changes in *static factors* within the *measurement boundary* since the *baseline period*. When non-routine adjustments are applied to the *baseline energy* they are sometimes called just “baseline adjustments.” (See also Chapter 8.2.)

Normalized *Savings:* The reduction in *energy* use or cost that occurred in the *reporting period*, relative to what would have occurred if the *facility* had been equipped and operated as it was in the *baseline period* but under a normal set of conditions. These normal conditions may be a long term average, or those of any other chosen period of time, other than the *reporting period*. Normal conditions may also be set as those prevailing during the *baseline period*, especially if they were used as the basis for predicting *savings*. (See Chapter 4.6.2) If conditions are those of the *reporting period*, the term *avoided energy use* (see Chapter 4.6.1), or just *savings*, is used instead of normalized savings.

Operational Verification: Verification that the ECMs are installed and operating properly and have the potential to generate savings. *Operational verification* may involve inspections, functional performance testing, and/or data trending with analysis.

Precision: The amount by which a measured value is expected to deviate from the true value. Precision is expressed as a “±” tolerance. Any precision statement about a measured value should include a *confidence* statement. For example a meter’s precision may be rated by the meter manufacturer as ±10% with a 95% confidence level. See Appendices B-1.1 and B-1.2 for definitions of *Absolute Precision* and *Relative Precision*.

Probable Error: See Appendix B-5.

Proxy: A measured parameter substituted in place of direct measurement of an *energy* parameter, where a relationship between the two has been proven on site. For example, if a relationship has been proven between the output signal from a variable speed drive controller and the power requirements of the controlled fan, this output signal is a proxy for fan power.

R Squared (R^2): See Appendix B-2.2.1.

Regression Analysis: A mathematical technique that extracts parameters from a set of data to describe the correlation of measured *independent variables* and dependent variables (usually *energy* data). See Appendix B-2.

Reporting Period: The period of time following implementation of an *ECM* when *savings* reports adhere to IPMVP. This period may be as short as the time for an instantaneous measurement of a constant quantity; long enough to reflect all normal operating modes of a system or *facility* with variable operations; the length of the financial payback period for an investment; the duration of a performance measurement period under an *energy performance contract*; or indefinite.

Routine Adjustments: The calculations in Equation 1a) of Chapter 4 made by a formula shown in the *M&V Plan* to account for changes in selected *independent variables* within the *measurement boundary* since the *baseline period*.

Savings: The reduction in *energy* use or cost. Physical savings may be expressed as *avoided energy use* or *normalized savings* (see Chapter 4.6.1 and 4.6.2, respectively). Monetary savings may be expressed analogously as “cost avoidance” or “normalized cost savings” (see Chapter

8.1). Savings, as used in IPMVP, are **not** the simple difference between baseline and reporting period utility bills or metered quantities. See Chapter 4.1 for elaboration on this point.

Significant Digits: Non-zero digits, and zeroes having non-zero digits to their left. Note that whole numbers (numbers displaying no decimal point) have an unlimited number of significant digits. Whole numbers ending in zero have an unclear number of significant digits. (See also Chapter 8.12.) Note also that when adding numbers, the significant digits rule is replaced by a rule on the number of digits after the decimal place. The number of such digits in any sum should match that of the number with the fewest such digits.

Simulation Model: An assembly of algorithms that calculates *energy* use for a facility based on engineering equations and user-defined parameters.

Standard Deviation: See Appendix B-1.3.

Standard Error: See Appendix B-1.3.

Standard Error of the Coefficient: See Appendix B-2.2.3.

Standard Error of the Estimate: See Appendix B-2.2.2.

Static Factors: Those characteristics of a *facility* which affect *energy* use, within the chosen *measurement boundary*, but which are not used as the basis for any *routine adjustments*. These characteristics include fixed, environmental, operational and maintenance characteristics. They may be constant or varying. (See particularly Chapters 4.6 and 8.2.)

t-statistic: See Appendix B-2.2.3.

Variance: See Appendix B-1.3.

Verification: The process of examining a report prepared by others to comment on its suitability for the intended purpose.

CHAPTER 10 REFERENCES

NOTE: The following references are meant to provide the reader with sources of additional information. These sources consist of publications, textbooks and reports from government agencies, universities, professional organizations and other recognized authorities. For the most part, care has been taken to cite the publication, publisher or source where the document can be obtained.

1. Akbari, H., Heinemeier, K.E., LeConiac, P. and Flora, D.L. 1988. "An Algorithm to Disaggregate Commercial Whole-Facility Hourly Electrical Load Into End Uses", Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, Vol. 10, pp. 10.14-10.26.
2. ASHRAE Guideline 1-1996. The HVAC Commissioning Process. American Society of Heating, Ventilating, and Air Conditioning Engineers, Atlanta, Georgia.
3. ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings. American Society of Heating, Ventilating, and Air Conditioning Engineers, Atlanta, Georgia.
4. ASHRAE. 1989. An Annotated Guide to Models and Algorithms for Energy Calculations Relating to HVAC Equipment, American Society of Heating, Ventilating, and Air Conditioning Engineers, Atlanta, Georgia.
5. ASHRAE 2005. Handbook: Fundamentals, Chapter 32 - "Energy Estimating and Modeling Methods", Atlanta, Georgia.
6. ASTM 1992. Standard Test Method for Determining Air Leakage Rate by Fan Pressurization, American Society for Testing Materials, Philadelphia, Pennsylvania.
7. Baker, D. and Hurley, W. 1984. "On-Site Calibration of Flow Metering Systems Installed in Buildings", NBS Building Science Series Report No. 159, January.
8. Benedict, R. 1984. Fundamentals of Temperature, Pressure and Flow Measurement. John Wiley and Sons, New York, New York.
9. Benton, C., Chace, J., Huizenga, C., Hyderman, M. and Marcial, R. 1996. "Taking A Building's Vital Signs: A Lending Library of Handheld Instruments", Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings, Vol. 4, pp. 4.11-4.21.
10. Bourdouxhe, J.P., Grodent, M., LeBrun, J. 1995. "HVAC01 Toolkit: A Toolkit for 20 Primary HVAC System Energy System Energy Calculations", Final report submitted to ASHRAE.
11. Bourdouxhe, J.P., Grodent, M., LeBrun, J. 1994a. "Toolkit for Primary HVAC System Energy Calculation - Part 1: Boiler Model", ASHRAE Transactions, Vol. 100, Pt. 2.
12. Bourdouxhe, J.P., Grodent, M., LeBrun, J. 1994b. "Toolkit for Primary HVAC System Energy Calculation - Part 2: Reciprocating Chiller Models", ASHRAE Transactions, Vol. 100, Pt. 2.
13. Bou Saada, T.E. and Haberl, J.S. 1995a. "A Weather-Daytyping Procedure for Disaggregating Hourly End-Use Loads in an Electrically Heated and Cooled Building from Whole-facility Hourly Data", 30th Intersociety Energy Conversion Energy Conference, July 30-August 4.
14. Bou Saada, T.E. and Haberl, J.S. 1995b. "An Improved Procedure for Developing Calibrated Hourly Simulated Models", Proceedings of Building Simulation, 1995: pp. 475-484.
15. Bou Saada, T.E., Haberl, J., Vajda, J. and Harris, L. 1996. "Total Utility Savings From the 37,000 Fixture Lighting Retrofit to the USDOE Forrestal Building", Proceedings of the 1996 ACEEE Summery Study, August.

16. Brandemuehl, M. 1993. HVAC02: Toolkit: Algorithms and Subroutines for Secondary HVAC Systems Energy Calculations, American Society of Heating, Ventilating, and Air Conditioning Engineers, Atlanta, Georgia.
17. Bryant, J. and O'Neal, D. 1992. "Calibration of Relative Humidity Transducers for use in the Texas LoanSTAR Program", Proceedings of the 1992 Hot and Humid Conference, Texas A&M University, Energy Systems Laboratory Report No. ESL-PA-92/02-15.
18. Claridge, D., Haberl, J., Bryant, J., Poyner, B. and McBride, J. 1993. "Use of Energy Management and Control Systems for Performance Monitoring of Retrofit Projects", Final Summary Report, USDOE Grant #DE-FG01- 90CE21003, Submitted to the USDOE Office of Conservation and Energy, Energy Systems Laboratory Report ESL-TR-91/09/02, Texas A&M University, March.
19. Claridge, D., Haberl, J., Liu, M., Houcek, J. and Aather, A. 1994. "Can You Achieve 150% of Predicted Retrofit Savings? Is it Time for Recommissioning?", Proceedings of the 1994 ACEEE Summer Study, pp. 5.73- 5.88, August.
20. Claridge, D., Haberl, J., Liu, M. and Athar, A. 1996. "Implementation of Continuous Commissioning in the Texas LoanSTAR Program: Can you Achieve 150% of Estimated Retrofit Savings: Revisited", Proceedings of the 1996 ACEEE Summery Study, August.
21. Cortina, V. (ed.) 1988. "Precision Humidity Analysis", EG&G Environmental Equipment, 151 Bear Hill Road, Waltham, Massachusetts, (IR sensors).
22. Doebelin, E. 1990. Measurement Systems. McGraw-Hill, New York, New York, ISBN 0-07-017338-9.
23. EEI 1981. Handbook for Electricity Metering, Edison Electric Institute, Washington, D.C., ISBN-0-931032-11-3.
24. EPRI 1993. "Fundamental Equations for Residential and Commercial End- Uses" (Rep. #EPRI TR-100984 V2). Palo Alto, California: Electric Power Research Institute.
25. Fels, M. (ed.)1986. "Special Issue Devoted to Measuring Energy Savings, The Princeton Scorekeeping Method (PRISM)", Energy and Buildings, Vol. 9, Nos. 1 and 2.
26. Fels, M., Kissock, K., Marean, M.A. and Reynolds, C. 1995. "Advanced PRISM User's Guide", Center for Energy and Environmental Studies Report, Princeton University, Princeton,New Jersey, January.
27. FEMP – Federal Energy Management Program of the U.S. Department of Energy, 2000. "M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 2.2"
28. FEMP – Federal Energy Management Program of the U.S. Department of Energy, 2002. "Detailed Guidelines for FEMP M&V Option A"
29. Goldberg, M.L. 1996a. "The Value of Improved Measurements: Facing the Monsters That Won't Annihilate Each Other", Energy Services Journal, 2(1):43- 56.
30. Goldberg, M.L. 1996b. "Reasonable Doubts: Monitoring and Verification for Performance Contracting", Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings, 4.133-4.143 Washington, D.C.: American Council for an Energy-Efficient Economy.
31. Haberl, J., Bronson, D. and O'Neal, D. 1995. "Impact of Using Measured Weather Data vs. TMY Weather Data in a DOE-2 Simulation", ASHRAE Transactions, V. 105, Pt. 2, June.
32. Haberl, J., Reddy, A., Claridge, D., Turner, D., O'Neal, D. and Heffington, W. 1996. "Measuring Energy-Savings Retrofits: Experiences from the Texas LoanSTAR Program", Oak Ridge National Laboratory Report No. ORNL/Sub/93-SP090/1, February.

33. Haberl, J., Turner, W.D., Finstad, C., Scott, F. and Bryant, J. 1992. "Calibration of Flowmeters for use in HVAC Systems Monitoring", Proceedings of the 1992 ASME/JSES/KSES International Solar Energy Conference.
34. Hadley, D.L. and Tomich, S.D. 1986. "Multivariate Statistical Assessment or Meteorological Influences in Residence Space Heating", Proceedings of the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Vol. 9, pp. 9.132-9.145.
35. Harding, J. (ed). 1982. "Recent Advances in Chilled Mirror Hygrometry", General Eastern Corporation Technical Bulletin, 50 Hunt Street, Watertown, Massachusetts.
36. Heinemeier, K. and Akbari, H. 1993. "Energy Management and Control Systems and Their Use for Performance Monitoring in the LoanSTAR Program", Lawrence Berkeley National Laboratory Report No. LBL-33114- UC-350, June, (prepared for the Texas State Energy Conservation Office).
37. Houcek, J., Liu, M., Claridge, D., Haberl, J., Katipamula, S. and Abbas, M. 1993. "Potential Operation and Maintenance (O&M) Savings at the State Capitol Complex", Energy Systems Lab Technical Report No. ESL-TR-93/01- 07, Texas A&M University, College Station, Texas.
38. Huang, P. 1991. "Humidity Measurements and Calibration Standards", ASHRAE Transactions, Vol. 97, p.3521.
39. Hurley, C.W. and Schooley, J.F. 1984. "Calibration of Temperature Measurement Systems Installed in Buildings", N.B.S. Building Science Series Report No. 153, January.
40. Hurley, W. 1985. "Measurement of Temperature, Humidity, and Fluid Flow", Field Data Acquisition for Building and Equipment Energy Use Monitoring, ORNL Publication No. CONF-8510218, March.
41. Hyland, R.W. and Hurley, C.W. 1983. "General Guidelines for the On-Site Calibration of Humidity and Moisture Control Systems in Buildings", N.B.S. Building Science Series 157, September.
42. IPCC 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland. pp 64.
43. Katipamula, S. 1996. "The Great Energy Predictor Shootout II: Modeling Energy Use in Large Commercial Buildings", ASHRAE Transactions, Vol. 102, Pt 2.
44. Katipamula, S. and Haberl, J. 1991. "A Methodology to Identify Diurnal Load Shapes for Non-Weather-Dependent Electric End-Uses", Proceedings of the 1991 ASME-JSES International Solar Energy Conference, ASME, New York, New York, pp. 457-467, March.
45. Kats, G., Kumar, S., and Rosenfeld, A. 1999. "The Role for an International Measurement & Verification Standard in Reducing Pollution", Proceedings of the ECEEE 1999 Summer Study, Vol. 1, Panel 1.
46. Kats, G., Rosenfeld, A., and McGaraghan, S. 1997. "Energy Efficiency as A Commodity: The Emergence of an Efficiency Secondary Market for Savings in Commercial Buildings", Proceedings of the ECEEE 1997 Summer Study, Vol. I, Panel 2.
47. Kissock, K., Claridge, D., Haberl, J. and Reddy, A. 1992. "Measuring Retrofit Savings For the Texas LoanSTAR Program: Preliminary Methodology and Results", Solar Engineering, 1992: Proceedings of the ASME-JSES-SSME International Solar Energy Conference, Maui, Hawaii, April.
48. Kissock, K., Wu, X., Sparks, R., Claridge, D., Mahoney, J. and Haberl, J. 1994. "EModel Version, 1.4d", Energy Systems Laboratory ESL-SW-94/12-01, Texas Engineering Experiment Station, Texas A&M University System, December.

49. Knebel, D.E. 1983. "Simplified Energy Analysis Using the Modified Bin Method", ASHRAE, Atlanta, Georgia, ISBN 0-910110-39-5.

50. Kulwicki, B. 1991. "Humidity Sensors", Journal of the American Ceramic Society, Vol. 74, pp. 697-707.

51. Landman, D. and Haberl, J. 1996a. "Monthly Variable-Based Degree Day Template: A Spreadsheet Procedure for Calculating 3-parameter Change-point Model for Residential or Commercial Buildings", Energy Systems Laboratory Report No. ESL-TR-96/09-02.

52. Landman, D. and Haberl, J. 1996b. "A Study of Diagnostic Pre-Screening Methods for Analyzing Energy Use of K-12 Public Schools", Energy Systems Laboratory Report No. ESL-TR-96/11-01, November.

53. Leider, M. 1990. A Solid State Amperometric Humidity Sensor, Journal of Applied Electrochemistry, Chapman and Hill: Vol. 20, pp. 964-8.

54. Liptak, B. 1995. Instrument Engineers' Handbook, 3rd Edition: Process Measurement and Analysis. Chilton Book Company, Radnor, Pennsylvania, ISBN 0-8019-8197-2.

55. Miller, R. 1989. Flow Measurement Handbook, McGraw Hill Publishing Company, New York, New York, ISBN 0-07-042046-7.

56. Morrissey, C.J. 1990. "Acoustic Humidity Sensor", NASA Tech Brief. Vol. 14, No. 19, April, (acoustic).

56a. ORNL (1999) “A Practical Guide for Commissioning Existing Buildings” Prepared by Portland Energy Coservation Inc., for Oak Ridge National Laboratory (ORNL/TM-1999/34) Available through http://eber.ed.ornl.gov/commercialproducts/retrocx.htm

57. Rabl, A. 1988. "Parameter Estimation in Buildings: Methods for Dynamic Analysis of Measured Energy Use", Journal of Solar Energy Engineering, Vol. 110, pp. 52-66.

58. Rabl, A. and Riahle, A. 1992. "Energy Signature Model for Commercial Buildings: Test With Measured Data and Interpretation", Energy and Buildings, Vol. 19, pp.143-154.

59. Ramboz, J.D. and McAuliff, R.C. 1983. "A Calibration Service for Wattmeters and Watt-Hour Meters", N.B.S. Technical Note 1179.

60. Reddy, T. and Claridge, D. 2000. "Uncertainty of "Measured" Energy Savings From Statistical Baseline Models," ASHRAE HVAC&R Research, Vol 6, No 1, January 2000.

61. Reynolds, C. and Fels, M. 1988. "Reliability Criteria for Weather Adjustment of Energy Billing Data", Proceedings of ACEEE 1988 Summer Study on Energy Efficiency in Buildings, Vol. 10, pp.10.237-10.241.

62. Robinson, J., Bryant, J., Haberl, J. and Turner, D. 1992. "Calibration of Tangential Paddlewheel Insertion Flowmeters", Proceedings of the 1992 Hot and Humid Conference, Texas A&M University, Energy Systems Laboratory Report No. ESL-PA-92/02-09.

63. Ross, I.J. and White, G.M. 1990. "Humidity", Instrumentation and Measurement for Environmental Sciences: Transactions of the ASAE, 2nd ed., p. 8-01.

64. Ruch, D. and Claridge, D. 1991. "A Four Parameter Change-Point Model for Predicting Energy Consumption in Commercial Buildings", Proceedings of the ASME-JSES-JSME.

65. SEL 1996. TRNSYS Version 14.2, and Engineering Equation Solver (EES). Solar Energy Laboratory, Mechanical Engineering Department, University of Wisconsin, Madison, Wisconsin.

66. Soebarto, V. 1996. "Development of a Calibration Methodology for Hourly Building Energy Simulation Models Using Disaggregated Energy Use Data From Existing Buildings", Ph.D. Dissertation, Department of Architecture, Texas A&M University, August.

67. Sparks, R., Haberl, J., Bhattacharyya, S., Rayaprolu, M., Wang, J. and Vadlamani, S. 1992. "Testing of Data Acquisition Systems for Use in Monitoring Building Energy Conservation Systems", Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, Texas, pp.197-204, May.

68. Vine, E. and Sathaye, J. 1999. "Guidelines for the Monitoring, Evaluation, Reporting, Verification, and Certification of Energy-Efficiency Projects for Climate-Change Mitigation", LBNL Report # 41543.

69. Violette, D., Brakken, R., Schon, A. and Greef, J. 1993. "Statistically-Adjusted Engineering Estimate: What Can The Evaluation Analyst Do About The Engineering Side Of The Analysis?" Proceedings of the 1993 Energy Program Evaluation Conference, Chicago, Illinois.

70. Wiesman, S. (ed.) 1989. Measuring Humidity in Test Chambers, General Eastern Corporation, 50 Hunt Street, Watertown, Massachusetts.

71. Wise, J.A. 1976. "Liquid-In-Glass Thermometry", N.B.S. Monograph 150, January.

72. Wise, J.A. and Soulen, R.J. 1986. "Thermometer Calibration: A Model for State Calibration Laboratories", N.B.S. Monograph 174, January.

73. WRI (2007) Guidelines for Grid-Connected Electricity Projects of the GHG Protocol for Project Accounting, planned for 2007 publication by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), available at www.ghgprotocol.org.

10.1 Resource Organizations

The following US organizations provide useful and relevant information. EVO attempts to maintain on its website (www.evo-world.org) an up to date list of the following, and all other web links in this document:

1. Air Conditioning and Refrigeration Center, Mechanical Engineering, University of Illinois. TEL: 217-333-3115, http://acrc.me.uiuc.edu.
2. American Council for an Energy Efficient Economy (ACEEE), Washington, D.C. TEL: 202-429-8873, http://www.aceee.org.
3. American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Atlanta, Georgia. TEL: 404-636-8400, http://www.ashrae.org.
4. American Society of Mechanical Engineers (ASME), New Jersey. TEL: 800-843-2763. http://www.asme.org.
5. Association of Energy Engineers (AEE), Lilburn, GA. TEL: 404-925-9558, http://www.aeecenter.org.
6. Boiler Efficiency Institute, Department of Mechanical Engineering, Auburn University, Alabama. TEL: 334/821-3095, http://www.boilerinstitute.com.
7. Center for Energy and Environmental Studies (CEES), Princeton University, New Jersey. TEL: 609-452-5445, http://www.princeton.edu/~cees.
8. Edison Electric Institute (EEI). Washington, DC. TEL: 202-508-5000, http://www.eei.org/resources/pubcat.
9. Energy Systems Laboratory, College Station, Texas. TEL: 979-845-9213, http://www-esl.tamu.edu.
10. Florida Solar Energy Center, Cape Canaveral, Florida. TEL: (407) 638- 1000, http://www.fsec.ucf.edu.

11. IESNA Publications, New York, New York. TEL: 212-248-5000, http://www.iesna.org.
12. Lawrence Berkeley National Laboratory (LBNL), Berkeley CA. TEL: 510- 486-6156, Email: EETDinfo@lbl.gov, http://eetd.lbl.gov.
13. National Association of Energy Service Companies (NAESCO), Washington, D.C. TEL: 202-822-0950, http://www.naesco.org.
14. Energy Information Administration (EIA), Department of Energy, Washington, D.C., TEL: 202-586-8800, http://www.eia.doe.gov.
15. National Renewable Energy Laboratory (NREL), Boulder, Colorado, TEL: (303) 275-3000, http://www.nrel.gov.
16. National Technical Information Service (NTIS), U.S. Department of Commerce (This is repository for all publications by the Federal labs and contractors), Springfield Virginia. TEL: 703-605-6000, http://www.ntis.gov.
17. Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, Tel: (865) 574-5206, http://www.ornl.gov/ORNL/BTC.
18. Pacific Northwest National Laboratory (PNNL), Richland, Washington, Tel: (509) 372-4217, http://www.pnl.gov/buildings/.

.

10.2 Measurement References

ASHRAE (2002) Annex A contains useful information on sensors, calibration techniques, lab standards for measurement, and test methods for chillers, fans, pumps, motors, boilers, furnaces, thermal storage and air handling systems. It also contains useful error and cost considerations, though the cost information is dated because the research that produced the data was done in 1994.

Standards under European Directive 2004/22/EC relative to measurement instruments are:

EN 1359:1998 Gas meters - Diaphragm gas meters
EN 1359:1998/A1:2006
EN 1434-1:2007 Heat meters - Part 1: General requirements
EN 1434-2:2007 Heat meters - Part 2: Constructional requirements
EN 1434-4:2007 Heat meters - Part 4: Pattern approval tests
EN 1434-5:2007 Heat meters - Part 5: Initial verification tests
EN 12261:2002 Gas meters - Turbine gas meters
EN 12261:2002/A1:2006
EN 12405-1:2005 Gas meters - Conversion devices - Part 1: Volume conversion
EN 12405-1:2005/A1:2006
EN 12480:2002 Gas meters - Rotary displacement gas meters
EN 12480:2002/A1:2006
EN 14154-1:2005+A1:2007 Water meters - Part 1: General requirements

EN 14154-2:2005+A1:2007 Water meters - Part 2: Installation and conditions of use
EN 14154-3:2005+A1:2007 Water meters - Part 3: Test methods and equipment
EN 14236:2007 Ultrasonic domestic gas meters
EN 50470-1:2006 Electricity metering equipment (a.c.) - Part 1: General requirements, tests and test conditions - Metering equipment (class indexes A, B and C)
EN 50470-2:2006 Electricity metering equipment (a.c.) - Part 2: Particular requirements - Electromechanical meters for active energy (class indexes A and B)
EN 50470-3:2006 Electricity metering equipment (a.c.) - Part 3: Particular requirements - Static meters for active energy (class indexes A, B and C)

Other European and Interantional standards for measurements and interpretation of data are:

EN ISO 4259 Petroleum products - Determination and application of precision data in relation to methods of test
EN 24185 Measurement of liquid flow in closed conduits - Weighing method (ISO 4185:1980)
EN 29104 Measurement of fluid flow in closed conduits -- Methods of evaluating the performance of electromagnetic flow-meters for liquids
EN ISO 5167 Measurement of fluid flow by means of pressure differential devices - Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full
EN ISO 6817 Measurement of conductive liquid flow in closed conduits - Methods using electromagnetic flow-meters (ISO 6817:1992)
EN ISO 9300 Measurement of gas flow by means of critical flow Venturi nozzles
EURACHEM Quantifying Uncertainty in Analytical Measurement
EUROLAB Technical Report “Measurement Uncertainty – a collection for beginners”
ISO 11453 Statistical interpretation of data - Tests and confidence intervals relating to proportions (1996)
ISO 16269-7 Statistical interpretation of data - Part 7: Median - Estimation and confidence interval (2001)
ISO 3534 Statistics - Vocabulary and symbols
ISO 5479 Statistical interpretation of data - Tests for departure from the normal distribution (1997)
ISO 5725 Accuracy (trueness and precision) of measurement method and results
ISO/TR 5168 Measurement of fluid flow - Evaluation of uncertainties
ISO/TR 7066-1 Assessment of uncertainty in calibration and use of flow measurement devices - Part 1: Linear calibration relationships

See also Annex C for specific measuement standards in various regions of the world.

10.3 Calibration References

Calibration references in Chapter 10's list of US publications above include: ASTM (1992), Baker and Hurley (1984), Benedict (1984), Bryant and O'Neal (1992), Cortina (1988), Doebelin (1990), EEI (1981), Haberl et al. (1992), Harding (1982), Huang (1991), Hurley and Schooley (1984), Hurley (1985), Hyland and Hurley (1983), Kulwicki (1991), Leider (1990), Liptak (1995), Miller (1989), Morrissey (1990), Ramboz and McAuliff (1983), Robinson et al. (1992), Ross and White (1990), Sparks (1992), Wiesman (1989), Wise (1976), Wise and Soulen (1986).

10.4 European and International Standards Supporting Energy Efficiency In Buildings

Assessment of energy performance of buildings on the basis of measured energy use:

- EN15603
- EN 15251
- CEN CR 1752
- ISO/DIS 16814
- ISO 7730

Definitions and requirements related to energy services:

- EN 15900

Economic performance:

- ISO 15686-5, Part 5
- EN 15459

Overall building:

- PrEN15203 (Assessment of delivered energy used in buildings)
- PrEN15603 (Overall energy use primary energy and CO_2 emission)
- PrEN15232 (Calculation methods for energy efficiency improvements by the application of integrated building automation systems)
- EN15316 series (Method for calculation of system energy requirements and system efficiency for heating and domestic hot water)
- ISO 13790 (Thermal performance of buildings – calculation of energy use for space heating)

Heating and cooling calculation and inspection methods:

- EPBD WI 014
- EN14335 series
- EN14243
- ISO 13790
- ISO 16814
- EN13465

- EN13779
- EN15240
- EN15242

Indoor and outdoor condition calculation and presentation of climatic data:

- ISO 15927-1
- ISO 15927-2
- ISO 15927-4
- ISO 15927-5
- ISO 15927-6

APPENDIX A EXAMPLES

A-1 Introduction

This Appendix presents a variety of project types and discusses the key *M&V* design issues arising from the described situations. Each example shows just one IPMVP adherent *M&V* design, though there are numerous possible designs for any project.

The examples cover 12 different scenarios:

- Pump/motor efficiency improvement (A-2)
- Pump/motor demand shifting (A-2-1)
- Lighting efficiency (A-3)
- Lighting operational control (A-3-1)
- Street lighting efficiency and dimming (A-3-2)
- Compressed air leakage management (A-4)
- Turbine-generator set improvement (A-5)
- Boiler efficiency improvement (A-6)
- Multiple *ECM* with metered *baseline* data (A-7)
- Whole facility energy accounting relative to budget (A-7-1)
- Multiple *ECMs* in a building without energy meters in the *baseline period* (A-8)
- New building designed better than code (A-9)

These examples go into varying levels of depth, in order to highlight different features of common *M&V* approaches. None of them is comprehensive. Readers are referred to the EVO website for more complete *M&V Plans* and sample *savings* reports (www.evo-world.org) accessible to EVO Subscribers. Also IPMVP Volume III contains example *M&V* applications for new buildings and renewable-energy projects.

These examples from around the world use the variety of technical units and currencies in local common use. The following table provides an appreciation of the magnitude of the technical quantities expressed in approximate alternate units.

Multiply:		By:	to get:
Natural gas	m^3	35	ft^3
	mcf	1000	ft^3
Steam	pound	0.45	kg of steam
Oil	liter	0.26	gallon (US)

EVO subscribers are encouraged to submit their own examples for possible inclusion in the website's library (email to: ipmvprev@evo-world.org).

A-2 Pump/Motor Efficiency Improvement – Option A

Situation Ten irrigation pump-sets are distributed around a South African agricultural property to pump water from underground wells. Pump operation is usually continuous during the normal six-month annual dry season, though pumps are turned on and off manually as needed. The local utility offered a partial subsidy to replace the pumps with new high-efficiency pumps and motors. To make the final payment of the subsidy, the utility required short-term demonstration of avoided energy use in a form that adheres to IPMVP. The owner is interested in replacing his old pumps and reducing energy costs, so he paid for the balance of the installation costs and agreed to provide data to the utility after retrofit.

Factors Affecting the *M&V* Design Pump electricity metering is by 5 utility owned consumption meters. These meters serve only the 10 pumps. Before implementation of the project it was considered possible that the new pumps might enhance pumping rates at some wells, so that pumping hours could be reduced. The owner and the utility recognize that operating hours and therefore *savings* depend upon the growing conditions and rainfall each year. Neither party has control over these energy-governing variables.

The owner sought the lowest possible cost for gathering and reporting information to the utility. The owner hired a contractor to select and install pumps that met his and the utility's specifications.

Pump flow is constant when operating because there are no restricting valves and well depth is largely unaffected by the pumping.

M&V Plan The *M&V Plan* was jointly developed by the owner and utility, following a model provided by the utility. IPMVP Volume I, EVO 10000 – 1:2012, Option A was selected to minimize *M&V* costs. The agreed Option A method is to negotiate an *estimate* of the annual pump operating hours for a normal year, and multiply that number by measured power reductions.

It was agreed that the installation contractor's measurement equipment would be adequately accurate to measure motor wattage requirements. Before removal, the contractor measured the power draw of each old motor after it had been running for at least 3 hours. The utility company maintained the right to witness these measurements. Since the pumps are constant-flow, average annual operating hours were derived from the billed electricity kWh consumption of the past year divided by the measured kW power draw of the old pump motors. This computation showed that on average the pumps operated for 4,321 hours in the dry year before retrofit. The utility found data revealing that total rainfall during that dry season was 9.0% less than normal. The owner and utility therefore agreed that pump operation during that year was 9.0% longer than normal. They agreed that normal hours would be 91.0% of 4,321, or 3,932[22] hours per year.

Results The energy *savings* were determined using IPMVP Option A, Equation 1d) as follows:

Total load of all pumps before retrofit:	132 kW
Total load of all pumps after retrofit:	98.2 kW
Net load reduction:	33.8 kW[23]

Energy *savings*: = 34 kW x 3,932 hours/year = 130,000 kWh/year[24]

The utility company's final payment of its subsidy was based on 130,000 kWh energy *savings*.

[22] Note this 3,932 number should be expressed with only 3 significant digits, since 91.0% has only 3 significant digits. It should more correctly be expressed as 3.93×10^3. However common form is used.

[23] The actual calculated number of 33.8 should be treated as having 2 significant digits. This statement is made because the subtraction that led to the 33.8 should show no more digits to the right of the decimal than the number with the fewest to its right (132 has none, so 34 has none).

[24] The products of 34 and 3,932 have only 2 significant digits. Though the result is133,688, the proper expression of their product is 1.3×10^5, or 130,000.

Using the same *estimated* operating periods, the owner's *estimated savings* under normal rainfall conditions and at current utility prices were determined to be 34 kW × 3,932 hr[25] x R0.2566/kWh = R34,000/year.26 Utility service and network charges were unchanged.

A-2.1 Pump/Motor Demand Shifting – Option B

Situation The irrigation system described in Appendix A-2 above was also eligible for a substantial utility incentive if the pumps are kept off during the peak periods of 0700-1000 and 1800-2000 on all weekdays that are not public holidays. The owner installed a radio-signal-based control system to remotely and automatically control the pumps to implement this load shifting strategy. The pump control will be reset by the owner annually according to the upcoming year's schedule of public holidays.

Factors Affecting the *M&V* Design The owner believed that curtailing pumping for a maximum of 25 hours per week (15%) would not be critical to his operation in dry seasons. (He expected fewer breakdowns of the new pumps, so there would be no net impact on his dry-season growth.)

The utility recognizes that the owner decides whether to shut down the pumps based on his own needs. Therefore the utility required adherence to IPMVP Volume I, EVO 10000 – 1:2012, Option B to substantiate each year's performance, before making the incentive payment.

The owner felt that his financial payback period for the control and monitoring equipment was already long. Therefore he does not want to spend a significant part of the incentive on providing the evidence required by the utility.

M&V Plan The utility and owner agreed that continuous recording of a *proxy* variable would give the ongoing evidence that the pumps were off during every peak period all year long. The *proxy* variable is the presence of electricity flow (in excess of the 500mA needed by the control equipment) through any of the 5 electrical feeds to the 10 pumps. Small un-calibrated current sensors and data loggers were clamped on each power line near the 5 meters. The sensors and loggers have a re-chargeable battery-backup power system.

The owner has hired the supplier of the control and monitoring devices to annually read the data, check the clock settings, and give a report to the utility of the dates and times of any operation within any weekday peak periods.

Results For the first year after implementation of the control and monitoring system, the monitoring agent reported to the utility that power was used between 1800 hrs and 2000 hrs on 5 specific weekdays. The utility verified that these days were all public holidays, so there were no operations during the defined peak periods. The demand shift was determined to be 98.2 kW, from the measurement of the new pumps (see Appendix A-2). The annual utility incentive was computed and paid based on this Option B recorded 98.2 kW demand shift.

A-3 Lighting Efficiency – Option A

Situation More efficient light fixtures are installed in place of existing fixtures in a Canadian school, while maintaining light levels. This project was part of a broader program of the school board to hire a contractor, who would design, install and finance many changes in a number of schools. Payments under the contract are based on measured *savings* at the utility prices prevailing at the time of signing the contract. *Savings* are to be demonstrated, according to an IPMVP adherent *M&V Plan,* immediately after commissioning of the retrofit. Since the owner controls operation of the lights, the contract specified that the *M&V Plan* follow IPMVP Volume I,

[25] 133,688 is the actual calculated value before significant digit rounding.
[26] This amount can be expressed in no more than 2 significant digits, as from the above observations about the minimum number of significant digits. The actual calculated value is R34,103 and should better be expressed as R3.4 x 10^4, though 34,000 is customary currency format.

EVO 10000 – 1:2012, Option A, using *estimated* operating hours. The *M&V Plan* was to be detailed after contract signing.

Factors Affecting the *M&V* Design In developing the *M&V Plan* the following were considered:

- All light fixtures are powered by a common 347-volt supply system dedicated to lighting. This situation makes power measurement simple.
- Operation of lights significantly affects heating energy requirements, so the interactive effect needed to be estimated.
- Operation of lights significantly affects mechanical-cooling requirements. However, since very little of the school is mechanically cooled and that space is usually vacant during the warmer weather, cooling *interactive effects* were ignored.
- School-board officials had difficulty accepting an arbitrary assumption of lighting operating periods. They agreed to pay for a carefully instrumented two-month period of logging lighting patterns in one school. This test would substantiate the *estimate*d operating hours that would be agreed for all schools.

M&V Plan The *measurement boundary* of this *ECM* was drawn to include the lighting fixtures connected to the 347-volt supply system.

- The heating *interactive effect* was determined by engineering calculations to be a 6.0% increase in boiler-output energy requirements, for the period from November through March. Boiler efficiency in winter was estimated to be 79% under typical winter conditions.
- The *static factors* recorded for the *baseline* included a lighting survey giving a description, location, light level, and count of the number of operating and burned out lamps ballasts and fixtures.
- 30 lighting loggers were placed in randomly chosen classrooms, corridors, locker rooms, and offices and also in the gym and auditorium, for two months. This period included the one-week spring holiday and two legal holidays. Table A-3-1 summarizes the data obtained.

Location	Fraction of Lighting Load	*Mean* weekly hours	
		School Time	Holiday Time
Locker rooms	5%	106.	22.
Offices	5%	83.	21.
Classrooms	61%	48.	5.
Auditorium	10%	31.	11.
Gymnasium	10%	82.	25.
Corridors	9%	168.	168.

Table A-3-1 Operating Period Survey

Since classrooms are the largest load, the *relative precision* of the classroom operating period measurements was evaluated before school board officials could agree to *estimated* values. For the 19 classroom loggers, the *standard deviation* among the readings for 6 recorded school weeks was found to be 15 hours per week. With 19 x 6 = 114 readings, the *standard error* in the *mean* values was computed to be 1.4 hours per week (Equation B-4). At 95% *confidence*, the value of t for a large number of observations is 1.96 (Table B-1). Therefore, using Equation B-9, it was established with 95% *confidence* that the *relative precision* in the measured classroom operating hours is:

$$= \frac{1.96 \times 1.4}{48} = 5.7\%$$

School board officials deemed this measurement *precision* adequate.

Before estimating values for all schools, it was decided to add 6 hours per week to classroom hours because of plans to increase night school classes. Considering that there are 39 school weeks and 13.2 holiday weeks in an average year (with leap years), the *estimated* annual operating hours were agreed to be as follows:

Table A-3-2 Estimated Operating Hours

Location	Fraction of Lighting Load	*Estimated* Weekly Hours		*Estimated* Annual Hours
		39.0 school weeks	13.2 holiday weeks	
Locker rooms	5.00%	106	22	4,420
Offices	5.00%	83	21	3,480
Classrooms	61.00%	54	5	2,170
Auditorium	10.00%	31	11	1,350
Gymnasium	10.00%	82	25	3,530
Corridors	9.00%	168	168	8,770

Since the lighting retrofit was applied uniformly to all fixtures, the load-weighted average *estimated* annual operating hours for this school were determined to be 2,996, or 3,000 rounded to 3 significant digits (a better representation of the result would be 3.00×10^3).

- *Baseline* power measurements were made with a recently calibrated true rms watt meter of the three-phase power draw on the 347-volt lighting circuits. From a thirty-second measurement on the input side of two lighting transformers, it was found that with all fixtures switched on, the total power draw was 288 kW. Seventy lamps (= 3 kW or 1%) were burned out at the time of the test. It was determined that the fraction burned out at the time of this measurement was normal.
- Since lighting loads establish the building electrical peak at a time when all lights are on, electrical demand *savings* will be estimated to be the same as the measured load reduction on the lighting circuits. The utility bills showed a lower demand during the summer holidays, and there was minimal use of the facility during these months. Also considering which other equipment was used during the summer, it was assumed that the July and August lighting-circuit demand is only 50% of the peak measured circuit load.
- The marginal utility prices at the time of contract signing was CDN\$0.063/kWh, CDN\$10.85/kW-month, and CDN\$0.255/m^3 of gas.

Results After installation of the *ECM*, the lighting circuit power was re-measured as in the *baseline* test. The power draw was 162 kW with all lights on and none burned out. With the same 1% burnout rate as in the base year, the post-retrofit period maximum power would be 160. kW (=162 x 0.990). Therefore the power reduction is 288. – 160. = 128 kW.

Energy *savings* (using Equation 1d) with no adjustments) are 128 kW x 3.00×10^3 hrs/year = 384,000 kWh/year.

Demand *savings* are 128 kW for 10.0 months and 64 kW for 2.0 months, for a total of 1,410 kW-months.

The value of the electrical *savings estimated* under IPMVP Option A is:

(384,000 kWh x \$0.0630) + (1,410 x \$10.85) = CDN\$39,500

Assuming the lighting *savings* are achieved uniformly over a 10 month period, the typical winter month electrical *savings* are 384,000/10 = 38,400 kWh/month. The associated boiler load increase is 6.0% of these electrical *savings* for November through March, namely:

= 6.0% x 38,400 kWh/mo x 5.0 months = 12,000 kWh

Extra boiler input energy is:

= 12,000 kWh / 79% = 6.0% x 38,400 kWh/mo x 5.0 months / 79% = 15,000 kWh equivalent units of fuel input.

The gas being used in the boiler has an energy content of 10.499 kWh/m^3, so the amount of extra gas is = 15,000 / 10.499 = 1,400 m^3 gas

The value of the extra gas used in winter is 1,400 x $0.255 = CDN$360. Therefore total net *savings* are $39,500 – $360 = CDN$39,100.

A-3-1 Lighting Operational Control – Option A

Situation A knitting mill in southern India typically operates 2 shifts per day. There was a standing order for the supervisors to turn off all lights in each zone at the end of the second shift. There are 70 light switches. Supervisors regularly changed between working on the first and second shifts. They habitually forgot their duty to turn off lights.

The plant manager undertook a project to modify the lighting so that occupancy sensors turned lights on and off. He wanted to document the results to show the supervisors how poorly they had been using the light switches.

Factors Affecting *M&V* Design None of the production area had windows or skylights. It is neither heated nor cooled. Lighting circuits are integrated with other electrical loads so that lighting use could not be easily isolated from other uses of electricity.

The plant manager did not wish to spend a lot to determine *savings*, but needed a credible statement of the *savings*.

The electricity price for medium sized commercial users is 450 p/kWh.

M&V Plan To minimize *M&V* costs it was decided to perform *savings* measurements for only a short representative period and use IPMVP Volume I, EVO 10000 – 1:2012, Option A. Since the primary purpose of the retrofit was to control production area lighting hours, a sampling based method was developed to measure the change in operating hours. The lighting power (for use in Equation 1d)) was *estimated* from manufacturers' ratings to be 223 kW.

Lighting loggers were placed randomly around the production area to record the operating hours of randomly chosen lighting zones. The number of loggers was chosen as follows, to obtain an overall *precision* in operating period estimates of ±10%, at 90% *confidence*. It was expected that the *mean* operating hours before installation of the occupancy sensors would be 125 hours per week, and that the *standard deviation* in readings would be 25. Therefore the initially estimated *cv* is 0.20 and the necessary number of samples (with z of 1.96) is 15 (Equation B-16). Since there are only 70 zones, the finite population adjustment lowers the estimated required number of loggers to 12 (Equation B-17). It was assumed that after installation of occupancy sensors the *cv* will be much lower so the 12 loggers will be adequate.

There are no *interactive effects* of this retrofit on other building loads because the plant is neither heated nor air-conditioned. The reduction in night-time lighting is expected to make the building more thermally comfortable at the beginning of the morning shift.

Results After a one month period, data was gathered from the loggers and the average weekly operating hours computed for the 12 zones. The *mean* value was 115 and the *standard deviation* was 29. Therefore the *cv* was 0.24 (= 29 / 115), higher than the expected value and worse than necessary to meet the *precision* requirement. Therefore another month of recording was undertaken. Then the *mean* of the eight weeks of average weekly values was 118, and the *standard deviation* was 24 (*cv* = 0.20). This was deemed an adequate measurement of operating hours in the *baseline period*, with no occupancy sensors.

The occupancy sensor controls were installed after the above *baseline* test. Operating hours were again logged in the same locations for a month. The *mean* was found to be 82 hours per week, and the *standard deviation* was 3 hours. In this situation the *cv* is 0.04 and well within the required 0.2, so the one-month readings were accepted. No changes had happened to the way the plant was used or occupied, so there is no need to make any *non-routine adjustment* to the *baseline* data.

The reduction in operating hours was 118 – 82 = 36 hours per week. *Savings* were computed using Equation 1d) as:

223 kW x 36 hours/week = 8,000 or 8.0×10^3 kWh/week

With 48 weeks of operation every year, the annual value of the consumption *savings* is:

= (8.0×10^3) x 48 x 450 / 100 = Rs 1.7 million

There are no demand *savings* since the retrofits only affect off peak power use.

Therefore, following IPMVP Option A, it can be stated with 90% *confidence* that the *savings,* in the month after occupancy sensor installation, were Rs17 lakh ±10%, given the estimate of installed lighting load.

A-3-2 Street Light Efficiency and Dimming – Option B

Situation A Croatian city's public lighting system was in need of substantial repair and updating. A new lighting system was installed on the same wiring, including high-efficiency fixtures and a dimming system which curtails lighting power by up to 50% in the quietest hours. The lighting is distributed across the city, with 23 metering points. The retrofit included the addition of centralized dimming control. The city retained the current lighting-maintenance contractor to design, install and maintain the system. The city obtained a *savings* performance guarantee from the contractor. The city required the contractor to continuously demonstrate achievement of the guaranteed *savings*.

Factors Affecting The *M&V* Design The *baseline* light levels were inconsistent because 20% of the fixtures were burned out. The city wished to maintain a more uniform light level. Therefore it upgraded its public lighting maintenance contract to specify that burnouts be no more than 3.0% at any time.

Since dimming is critical to the *savings*, continuous recording of energy use is required. The 23 utility meters measure energy use continually. However these meters cannot provide the rapid operational feedback necessary to avoid significant energy wastage if a dimmer fails or is accidentally changed. Consequently an energy recording capability was added to the central dimming control system, to remotely record energy use in the city's central control station. Beyond simple energy reporting, the system compares actual hourly energy use on each circuit to an expected hourly profile. Variances from this target are used to spot burnouts and failures of the dimming system.

M&V Plan *Baseline* electricity on all 23 utility meters for the past year totaled 1,753,000 kWh, from utility bills. The number and location of all fixtures in the *baseline period* was recorded as part of the *M&V Plan*, along with the operating setpoints of the lighting control system.

Annual energy, recorded on the bills for same accounts will be totaled for determining *savings* using IPMVP Volume I, EVO 10000 – 1:2012, Option B, Equation 1c). The only adjustments that will be made to *baseline* or *reporting period* energy use will be for additions or deletions to the system and for burnouts found to be more than 3% at any time.

A *non-routine adjustment* was made immediately to account for reducing the burnout rate from the *baseline period's* 20% to the target *reporting-period* value of 3.0%. The *baseline-energy* was therefore adjusted to 2,130,000 kWh (= 1,753,000 x 0.970 / 0.800).

The city staff will monitor burnout rates monthly. If the burnout rate is greater than 3.0%, a *non-routine adjustment* will be made to bring *reporting-period* metered data up to the contracted 3.0% burnout rate.

Savings will be reported for the length of the 10-year guarantee period using a single price of 0.600 kuna/kWh.

Results *Savings* were reported without adjustment for the first three years after retrofit because burnout rates remained above 3.0%.

For the fourth year the burnout rate was 5.0% for 7 months. Fourth year *savings* were computed as follows:

Baseline Energy 2,130,000 kWh

Fourth year measured energy = 1,243,000 kWh

The burnout adjustment is =

$$\left(\frac{0.970}{0.950} - 1.000\right) \times \frac{7.0}{12} \times 1{,}243{,}000 = \quad 15{,}000\,kWh$$

Adjusted fourth year energy	= 1,243,000 + 15,000 =	1,258,000 kWh
Savings (avoided energy)	= 2,130,000 – 1,258,000 =	870,000 kWh
Avoided Cost	= 870,000 kWh x 0.600 =	kn 520,000

A-4 Compressed-Air Leakage Management – Option B

Situation A Brazilian auto manufacturer's plant engineering department estimated that R$200,000 per year was being lost through compressed-air leakage arising from poor maintenance. The plant engineer persuaded the plant manager that the maintenance department should dedicate one person for two months to repair all leaks. The engineering department agreed to conduct ongoing monitoring of leakage rates and savings, in order to motivate the maintenance staff to regularly check for leakage.

Factors Affecting *M&V* Design There are very few funds available for any *M&V* activity. Also the engineering department wished any *savings* measurement methodology to have a maximum quantifiable error of ±5% in any reported *savings*, with a *confidence* level of 95%.

The plant operates with 2 shifts per day, 10 per week and 442 per year. When it is operating, it's use of compressed air is steady. Heat from compressors is rejected directly outside compressor rooms without impacting any other plant energy-using systems.

The local electric consumption rate (known as the "green rate") for low-load-factor commercial accounts over 0.5 MW is shown in Table A-4-1.

	Dry Months (May – September)	Wet Months (October – April)
Peak Periods (17:30-20:30 hrs Monday to Friday)	R$0.957/kWh	R$0.934/kWh
Off Peak Periods	R$0.143/kWh	R$0.129/kWh

Table A-4-1 Electric Consumption Prices

Taxes totaling 42.9% are added to these rates.

It was assumed that the impact on plant electrical demand would be minimal since it is likely that there will be no change in the maximum number of compressors that will function during plant operations.

M&V Plan A full *M&V Plan* is shown on EVO's subscriber website (www.evo-world.org). It uses IPMVP Volume I, EVO 10000 – 1:2012, Option B, for ongoing measurement of *savings* to indicate changes in compressed-air leakage rates. IPMVP Equation 1b) was used to adjust *baseline energy* to *reporting period* conditions. The *M&V Plan* aimed to minimize extra measurement costs so a simple three-phase true-rms wattmeter was added to the electrical supply of the motor-control center feeding all equipment in the compressor room. This *measurement boundary* encompassed 6 compressors, 3 compressed-air driers, and all other minor auxiliary systems in the compressor room. Heat generated within the compressor room is not an *interactive effect* since it does not affect any other energy uses. Plant staff were instructed to read the meter at the end of each shift (i.e. three times a day) whether the plant was operating or not. The meter was installed three months before leak-management activities began.

The *static factors* related to plant design and operations were listed, as a reference for any future possible *non-routine adjustments*. They included the number, capacity and usage patterns of all compressed-air-driven equipment, plant production-line speed, and vehicle models being produced.

The *baseline period* electricity use, for operating and non-operating shifts, were quite different. Also within either kind of shift there were slight variations in energy use. No specific *independent variable* could be identified to account for the variations. It was decided to use the *mean* energy use of each kind of shift in the *baseline period* for determining the *savings*. A criterion was established for determining when sufficient readings had been made of *baseline energy* per shift to meet the target 95/5 uncertainty target for any *savings* report.

Results A full set of *savings* results are shown on the EVO subscriber website. It was found that to meet the 95/5 uncertainty criterion, the variation in shift energy during the *baseline* required readings for a seven-week period before retrofit. The *baseline* values were therefore established as the seven-week average electricity use of operating and non-operating shifts.

It was noted that after the leakage repair activity was completed there was much less variation in the *reporting-period* energy use per shift. Therefore the uncertainty target could be met by monthly *savings* reports.

Energy *savings* were computed as the difference between actual energy use every month and the *adjusted-baseline* energy determined by multiplying the number of actual shifts in the month by the *baseline mean* energy use for each type of shift.

The appropriate price of electricity was applied to the consumption *savings*, assuming that the utility's "peak period" rates only applied to three hours within the second shift. No demand *savings* were calculated.

These measurements continued as part of normal plant operations. The plant-engineering department adjusted the *baseline energy* periodically as *static factors* changed. Operating staff provided shift energy readings and the engineering department reported *savings* every month. Variations from past *savings* patterns became a focus for assessing the maintenance practices related to the compressed-air system.

A-5 Turbine/Generator Set Improvement – Option B

Situation A pulp mill used a steam turbine to generate much of its own electricity. Recent process changes had reduced the available steam for the turbine-generator (TG) unit from its original design level. As a result electricity output and thermal efficiency of the TG unit was reduced. The mill installed a new more efficient rotor designed for the new smaller steam flow. A measurement process was put in place for assessing the increased electrical output in order to qualify for an electric-utility incentive payment.

Factors Affecting The *M&V* Design The purpose of the *M&V* was to report electrical improvements. The mill recognized that extraction of more energy by the turbine left less steam energy for the process, or required more boiler energy to deliver the same steam to the process. These *interactive effects* were not part of this analysis for the electrical utility. The utility incentive was based purely on increased electricity production.

M&V Plan The mill and the utility agreed to use IPMVP Volume I, EVO 10000 – 1:2012, Option B to determine the increase in electricity output for a one year period. Existing plant instrumentation was used to determine the efficiency of the old rotor as shown in Figure A-5.1.

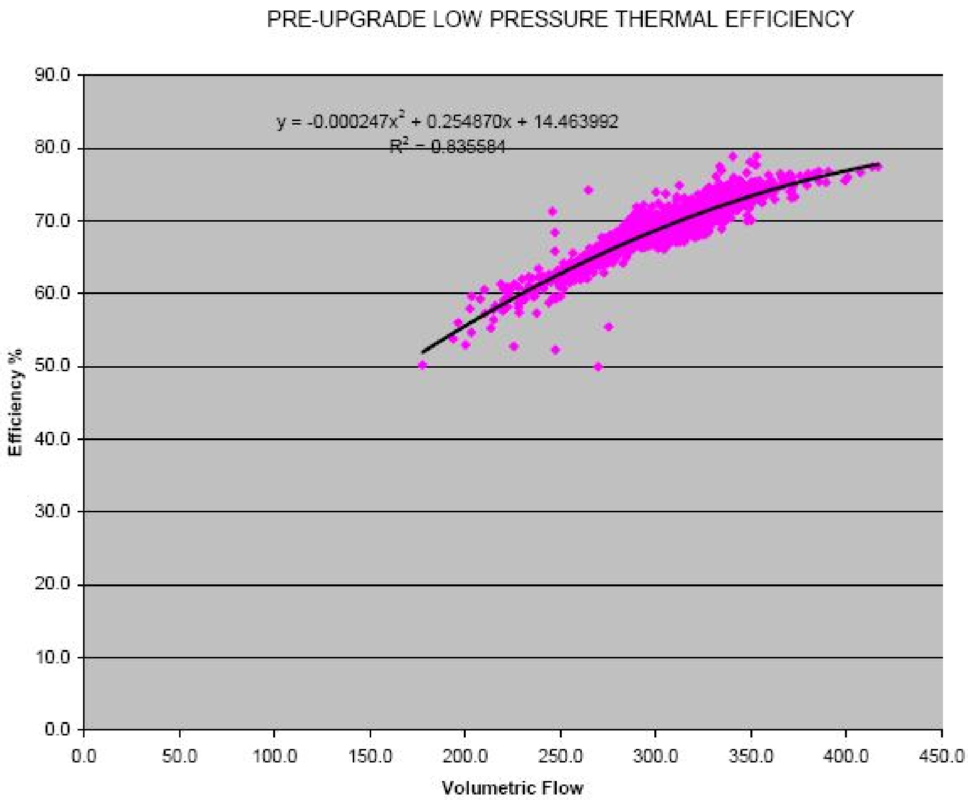


Figure A-5.1 Old Rotor Performance

The mathematical model describing the *baseline* unit efficiency was found by regression analysis to be:

$$\text{Efficiency (\%)} = (-0.000247 \times \text{flow}^2) + (0.255 \times \text{flow}) + 14.5$$

This efficiency model will be used with the steam conditions of the one-year *reporting period* to determine what the electricity production would have been with the old rotor. Increased electricity production will be reported under *reporting-period* conditions, using IPMVP Equation 1b).

Existing plant meters are regularly calibrated as part of plant maintenance. They were deemed to be suitable for the utility's purpose.

Results For a year after retrofit, the steam conditions every minute were applied to the mathematical model of old rotor efficiency to compute the *adjusted-baseline energy* term used in IPMVP Equation 1b). This value was compared to actually measured generation for the same period to determine the increase in electrical output.

No changes happened to the TG unit during this year, so *non-routine adjustments* were unnecessary.

A-6 Boiler Efficiency Improvement – Option A

Situation A boiler contractor replaced a German office building's existing boiler with a more efficient boiler. The contractor guaranteed annual oil *savings* of at least €25,000, assuming the loads on the boiler were the same as he measured during the *baseline period*. The owner's purchase order specified that holdback amounts would be paid only after the contractor presented a *savings* report adhering to IPMVP Volume I, EVO 10000 – 1:2012. It was also specified that the owner and contractor would agree to the *M&V Plan* as part of the final design plans for the retrofit.

Factors Affecting *M&V* Design Numerous building changes were going on at the time of the boiler plant revision, so boiler plant loads were expected to change. The contractor is only responsible for boiler efficiency improvements, not changes in boiler load. The boiler is the only equipment in the building using oil. The price of oil to be used for proof of achieving the performance guarantee was €0.70/liter.

M&V Plan IPMVP Volume I, EVO 10000 – 1:2012, Option A was chosen to isolate the boiler from the changes going on in the rest of the building. The *measurement boundary* was drawn to include only the boiler, measuring fuel use and net thermal energy delivered to the building. This boundary excludes the electricity use of the boiler's burner and blower. Changes to these electrical *interactive effects* were regarded as negligible, and not worth inclusion within the *measurement boundary* or even separate estimation.

The contractor's guarantee was stated relative to the usage of the year before submission of its proposal. During that period, the facility purchased 241,300 liters of heating oil for the boiler. There was a 2,100 liter increase in oil inventory between the beginning and end of that year. Therefore actual consumption was 239,200 liters. The energy load on the boiler will be determined from this oil-use data, once the efficiency of the old boiler is established. IPMVP Equation 1d) will be used with 239,200 liters as the *estimate*. This *estimate* has no error, since most of it[27] comes from oil shipment data, which is the reference source with no error.

Boiler efficiency will be the measured parameter in Equation 1d). Efficiency tests were planned for a period of typical winter conditions before removing the old boiler. Winter conditions were chosen so that there was sufficient load to assess efficiency under the full range of boiler loads. A recently calibrated thermal energy meter was installed by the contractor on the boiler supply and return water lines and a calibrated oil meter installed on the fuel supply to the boiler. Both the oil meter and the thermal-energy meter and data logger have manufacturers' rated *precisions* of ±2% for the ranges involved in this project.

Baseline efficiency tests were conducted over three separate one-week periods when daily *mean* ambient temperatures ranged from -5^{o}C to +5^{o}C. Identical tests were planned for the first period after commissioning of the new boiler when ambient temperatures are once again in the -5^{o}C to +5^{o}C range, using the same oil and thermal energy meters left in place since the *baseline* efficiency tests. Since the three individual one-week tests are expected to include periods

[27] Oil inventory levels are read from an un-calibrated tank gauge of unknown accuracy. Since the magnitude of inventory adjustments are small relative to metered shipments for the year, any error in this inventory term were considered negligible.

representing a range of boiler loads, from low to high, it was agreed that the test results will adequately represent the annual improvement that the owner could expect.

Oil and thermal energy meter readings will be made daily by building maintenance staff through winter months until three valid weeks of testing have been obtained for the old boiler. The same process will be followed for the new boiler. The readings will be logged in the boiler room and open for inspection at any time. The building-automation system measures and records ambient temperature for the valid weeks.

A contract extra of €5,100 was accepted by the owner for the supply, installation and commissioning of the oil and thermal-energy meters and for computing and reporting the *savings*. Consideration was given to requiring demonstration of performance for a whole year. However the contractor pointed out that the extra costs of meter calibration and data analysis would add €3,000 to the fee. The owner decided that a short test period of 3 representative weeks would be adequate. The owner also decided to maintain and calibrate the oil and thermal energy meters himself after the contract, and to annually make his own boiler-efficiency calculations.

Results *Baseline* oil and thermal energy data was collected continuously over a five-week period, until three were found where daily mean ambient temperatures stayed within the specified range -5°C to +5°C. Dividing net thermal energy delivered by oil consumed, the average efficiency readings for the old boiler during the three one-week periods were found to be 65.2%.

After installation and commissioning of the boiler, the three-week *reporting period* was again found with an average ambient temperature between -5°C to +5°C. Boiler efficiency test results averaged 80.6%.

There were no other changes to the boiler plant between the time of the *baseline-period* tests and *reporting-period* tests. Therefore *non-routine adjustments* were not needed.

Using IPMVP Equation 1d), annual *savings* using 239,200 liters as the estimated annual oil use from the baseline period are:

Oil *savings* = 239,200 liters x (1.000 – 0.652 / 0.806)

= 45,700 liters

The value of the *savings* is €0.70 x 45,700 = €31,900.[28]

These estimated annual *savings* from a short-term test validated that the contractor had met its guaranteed performance.

A-7 Multiple *ECM* With Metered *Baseline* Data – Option C

Situation An energy efficiency project was implemented in a high school in northern United States. It involved ten *ECM*s spanning lighting, HVAC, pool heating, operator training and occupant-awareness campaigns. The objectives of the project were to reduce energy costs.

Factors Affecting *M&V* Design The owner wished to record annual cost avoidance relative to the conditions and energy usage rate of 2005 as the *baseline*. The school contained a pool and cafeteria. The school is in use year round, though it closes for a total of 5 weeks a year between sessions. The community uses the building most evenings.

The building's energy requirement is significantly affected by ambient temperature. Temperature data can be easily obtained from a nearby government weather office. No other significant energy-governing variable could be quantified.

[28] The annual oil and money *savings* are expressed conservatively with three *significant digits*, the lowest number of digits used in the computations as found in the efficiency tests.

Only administration offices have mechanical air-conditioning equipment, which operates for 3 months of the year.

Expected annual *savings* on the gas meter are 2,800 mcf, and 380,000 kWh on the main electricity meter.

M&V Plan An *M&V Plan* was developed showing that IPMVP Volume I, EVO 10000 – 1:2012, Option C was to be used for *savings* determination because total facility energy cost was the focus. Option C was also chosen because many *ECM*s were involved, some of which could not be directly measured.

Since *savings* are to be reported as "cost avoidance," i.e. under *reporting period* conditions, Equation 1b) will be used.

An outline of key elements in the *M&V Plan* is shown below. Details, data and analysis are shown on the EVO subscribers' website (www.evo-world.org).

- The *measurement boundary* of this *savings* determination was defined as:
  - An electricity account, including demand, serving the main building,
  - An auxiliary electrical account, without demand, serving lighting in the field house,
  - A natural gas account for the main building.
- The 2005 *baseline* conditions were recorded, including a strategy for the engineering department to easily capture information about future changes.
- The *baseline period*'s energy data and weather data were recorded and analyzed by simple linear regression of monthly energy use and energy demand against *degree days*. *Degree-day* data was with the base temperature, which yielded the best R^2 from a number of regression analyses performed over a range of plausible base temperatures.
- Preliminary analysis found clear correlations with weather for winter gas use and winter electricity consumption on the main meter. Analysis also showed that there is no significant weather correlation with electric demand, summer gas or electricity use. It was decided that regression would only be performed on billing periods with more than 50 *heating degree days* (HDD). It was also decided that for *reporting period*s with 50 or fewer HDDs, *adjusted-baseline* values would be derived directly from the corresponding *baseline* month, adjusted solely for the number of days in the period.

The *energy*/HDD relationships were derived for the heating season on all three accounts as shown in Table A-7-1, along with key regression statistics and coefficients where significant relationships were found.

Table A-7-1 Regression Analysis

	Gas	Electricity		
		Main Building		Field House
		Consumption	Demand	Consumption
Units	mcf	kWh	kW	kWh
Number of months with more than 50 HDD	8	8	8	9
HDD Base	60°F	62°F	62°F	68°F
Regression Statistics:				
R^2	0.93	0.81	0.51	0.29
Standard Error of the estimate	91	15,933		
t statistic of the HDD coefficient	8.7	5.0	2.5	1.7

Assessment of Regression Analysis	Good	Good	Good	Marginal
Regression Coefficients (where accepted):				
Intercept	446.73	102,425		
HDD coefficient	1.9788	179.3916		

The regression statistics for the gas consumption and main electricity consumption show acceptable correlation with HDD as indicated by the high R^2, and the HDD t-statistics being well above the critical IPMVP Table B-1 value of 1.89 for 8 data points and 90% confidence. These observations are logical since the primary use of gas is for building heating. There is also a significant amount of electric heat in the main building.

The field house account showed a poor t-statistic and R^2. The building has no installed heating but must be lit longer in months of less daylight, which are also colder months. Monthly electricity use could be expected to follow a reasonably regular annual pattern related to daylight hours and occupancy, not driven by ambient temperature. Therefore the minimal correlation of this meter with HDD is ignored, and there will be no weather adjustments made to it. Instead, each month's savings report will take its *baseline energy* from the corresponding *baseline* month's consumption, adjusting for the number of days in the *reporting period*.

The main electrical-demand meter showed a poor correlation with the coldest day's weather. Therefore each month's savings report will take its *baseline* demand from the corresponding *baseline* month's actual demand, without adjustment.

- The long term impact on *savings* reports of these regression statistics was analyzed. The relative precision in winter *savings* reports will be less than ±10% for gas and less than ±20% for the main electricity account. The expected *savings* will be statistically significant for winter months since they will be more than twice the *standard error* of the *baseline* formulae (see criterion in Appendix B-1.2). The school officials felt comfortable with this expected quantified *precision*, and with possible unquantifiable errors related to simply adjusting for metering period lengths in months with 50 or fewer HDD.
- The utility rates to be used in valuing *savings* will be the then current full-price schedule appropriate for each account.

Results The *reporting-period* data for the first year was taken directly from utility bills without adjustment, and from government weather reports. This data and the calculations for the *savings* in energy and demand units, using Equation 1b), are shown on EVO's website.

Each month's current utility rate schedule was applied to each account's *adjusted-baseline energy* and *reporting-period energy* to compute *savings*. Since the gas rate changed in month 9 and the electric rate changed in month 7, two different price schedules were used for each commodity during the 12-month *savings* report. These computations are also detailed on the EVO website.

A-7.1 Whole-Facility Energy Accounting Relative To Budget

Situation The energy manager of a chain of hotels was required to annually prepare an energy budget, and routinely account for variances from budget.

Factors Affecting *M&V* Design Hotel guest-room occupancy, convention-area usage and weather significantly affect energy use. In order to account for energy use, the energy manager realized she needed to use *M&V* style techniques to adjust for these significant factors.

M&V Plan The energy manager followed IPMVP Volume I, EVO 10000 – 1:2012, Option C, since she needed to explain budget variances in management accounting reports. She always stated her energy budgets under long-term average weather conditions and the previous year's occupancy.

Results In order to account for budget variances, as soon as a year was complete, the energy manager prepared a regression model of the usage on each utility account, using actual weather and occupancy factors for that year. She then took three steps to separately determine the primary effects of weather, occupancy and utility rates:

- Weather She inserted normal weather statistics into the most recent year's models. Using actual utility rates for the year, she determined how much the energy (and cost) would have been if the weather had been normal. (She also noted how much the actual heating and cooling *degree days* varied from normal, and from the previous year, at each location.)
- Occupancy She inserted the occupancy factors of the previous year into the most recent year's models. Using actual utility rates for the recent year, she determined how much the energy (and cost) would have been if the occupancy had been the same as the previous year. (She also noted how much the occupancy had changed from year to year at each location.)
- Utility Rates She applied the previous year's utility rate to the most recent year's consumption (and demand) to determine how much of the budget variance was related to rate changes for each utility at each location.

With the impact of these three known variables defined, the energy manager still needed to account for the remaining variances. So she inserted the recent year's weather and occupancy factors into the mathematical models of the previous year, and using current utility rates reported cost avoidance from the previous year's pattern. This cost avoidance was then analyzed in relation to changes in *static factors* recorded for each site relative to the previous year's record. All remaining variance was reported as truly random, or unknown phenomena.

This analysis process not only allowed the energy manager to account for budget variances, it also informed her of where to focus efforts to manage unaccounted variances. In addition it allowed her to make more informed budgets for subsequent years.

A-8 Multiple *ECM*s In A Building Without Energy Meters In The *Baseline Period* – Option D

Situation An energy efficiency project was implemented in an American university library building, involving seven *ECM*s spanning lighting, HVAC, operator training and occupant awareness campaigns. The building is part of a multiple-building campus without individual building meters. The objectives of the project were to reduce energy costs in the library.

Factors Affecting The *M&V* Design Since the project at the library was very small relative to the entire campus, its effect could not be measured using the main campus utility meters.

The university wished to achieve *savings* as quickly as possible, despite the lack of a *baseline* energy record.

Savings are to be reported continuously, as soon as possible after retrofit, using the then current energy contract prices.

***M&V* Plan** It was decided not to wait to obtain a year's worth of energy data from new meters before implementing the measures. Instead IPMVP Volume I, EVO 10000 – 1:2012, Option D, Equation 1f) would be used, simulating pre-retrofit performance. Therefore, as part of the energy-management program steam, electricity and electric demand meters were installed on the main supply lines to the library.

The *measurement boundary* of this project was defined as all energy-using systems in the library. However the important *energy* effect was at the main campus utility meters. To transform *energy* measured at the library to its actual impact on the campus utility bills, the following assumptions were made:

- A pound of steam at the library requires 1.5 ft^3 of natural gas at the campus heating plant's gas meter. There is a fixed component in the gas use of the central plant, arising from the standing losses of the steam system. The 1.5 ft^3 factor, an annual average of gas use per pound of steam produced, allocates a load-based share of this fixed component to the library.
- Electricity use at the library requires 3% more electricity at the campus electricity meter because of estimated campus transformer and distribution losses.
- Peak electric demand at the library is assumed to be coincident with the time of peak demand at the campus meter.

The expected *savings* of the *ECM*s were predicted by computer simulation with the publicly available DOE 2.1 software. A full survey of the building's systems and occupancy was needed to gather all the input data. The power requirements of five variable-air-volume air-handling systems were logged for one week to define some of the input data for this planning simulation. The simulation used long-term normal weather conditions and the occupancy and other building characteristics that prevailed at the time of the prediction. It was decided to report actual *savings* under the same conditions.

The university's gas supply contract has a marginal unit price of US$6.25/mcf. It also has a minimum consumption level, which is only 5,300 mcf below the actual gas usage during the *baseline period*. If consumption drops by more than 5,300 mcf, the university will pay for the contract minimum amount. The contract will be renegotiated based on the results determined from this library project. The marginal electricity price at the campus meter is $0.18/kWh in peak periods, $0.05/kWh in off peak periods and demand is priced at $10.25/kW-month.

Following the first year, the first year's meter data will be used as a *baseline* for a new Option C approach for this building.

Results The following steps were used to compute *savings*.

1. The new meters were calibrated and installed. Operating staff recorded monthly energy and demand for 12 months throughout the first year after *ECM* commissioning.
2. Then the original planning *simulation model* was refined to match: the *ECM*s as installed, the weather, the occupancy, and the operating profiles of the *reporting period*. The resultant simulation of space temperatures and humidities were examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days. Initially the simulation result did not match actual energy use very well, so the M&V team investigated the site further. During these additional investigations the team found that unoccupied night periods experienced very little indoor temperature change. Therefore they changed the thermal-mass characteristics of the computer model. After this correction the modeled monthly results were compared to the monthly calibration data. The highest *CV(RMSE)* of the differences was 12%, on the electric demand meter. The university felt that because these *CV(RMSE)* values met ASHRAE (2002) specifications, it could have reasonable *confidence* in the relative results of two runs of the model. Therefore this "calibrated as-built model" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.
3. The calibrated as-built model was then rerun with a weather-data file corresponding to the normal year. Occupancy statistics and *static factors* were also reset to what had been observed during the *baseline period*. The resultant "**post-retrofit normal-conditions model**" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

4. The post-retrofit normal-conditions model was then adjusted to remove the *ECMs*. This "***baseline* normal-conditions model**" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.
5. The energy consumption of the two normal models were then compared using Equation 1f) to yield energy *savings* as shown in Table A-8-1.

A-8-1 Simulated Library *Savings* under Normal Conditions

	Baseline Normal Conditions Model	Post-Retrofit Normal Conditions Model	*Savings*
Peak period electricity consumption (kWh)	1,003,000	656,000	347,000
Off-Peak period electricity consumption (kWh)	2,250,000	1,610,000	640,000
Electric Demand (kW-months)	7,241	6,224	1,017
Steam (thousand pounds)	12,222	5,942	6,280

6. The value of the *savings* at the campus meter were computed as shown in Table A-8-2, allowing for transformation and line losses, and contract minimum gas quantities.

A-8-2 Campus Savings

	Library Energy *Savings*	Campus Energy *Savings*	Billed Energy *Savings*	Cost *Savings* US$
Peak period electricity consumption (kWh)	347,000	357,400	357,400	64,330
Off Peak period electricity consumption (kWh)	640,000	659,200	659,200	33,000
Electric Demand (kW-months)	1,017	1,048	1,048	10,740
Steam or gas	6,280,000 pounds steam	9,420 mcf gas	5,300 mcf gas	33,000
			Total	$141,000[29]

The total *savings* are shown for the year before revision to the gas contract minimum.

A-9 New Building Designed Better Than Code – Option D

Situation A new building was designed to use less energy than required by the local building code. In order to qualify for a government incentive payment, the owner was required to show that the building's energy use during the first year of operation after commissioning and full occupancy was less than 60% of what it would have been if it had been built to code.

[29] The final savings number is expressed using three significant digits due to the significant figure rules in section 8.12..

Factors Affecting *M&V* Design Computer simulation was used extensively throughout the building design process to help meet a target energy use equal to 50% of code.

The building was built as the new corporate headquarters for a large firm. It was expected that the building would become fully occupied immediately after opening.

The owner wished to use the same energy-*savings* calculations that he presents to the government to show how much money was being saved as a result of his extra investment in an efficient building. He also wished to annually review variances from his initially achieved energy performance.

M&V Plan IMPVP Volume I, EVO 10000 – 1:2012, Option D will be used to demonstrate the new building's *savings* compared to an identical building built to building-code standards. It is possible to use either Equation 1f) comparing two simulations, or Equation 1g) comparing the simulated *baseline energy* and measured actual *energy* after correcting for calibration error. The incentive program did not specify which method should be used. The person performing the modeling felt that Equation 1f) would be more accurate. However the owner wished to use actual utility data in his final *savings* statement, so he required the use of Equation 1g).[30]

Following the first year of full operation ("year one"), year one's energy and operational data will become the *baseline* for an IPMVP Volume I, EVO 10000 – 1:2012, Option C approach to reporting ongoing performance.

Results A year after commissioning and full occupancy, the original design simulation's input data was updated to reflect the as-built equipment and the current occupancy. A weather-data file was chosen from available weather files for the building's location based on the file's similarity of total heating and cooling *degree days* with year one's measured *degree days*. This similar file was appropriately adjusted to year one's actual monthly heating and cooling *degree days*. The revised input data was used to rerun the simulation.

The utility consumption data from year one was compared to this *simulation model*. After some further revisions to the simulation's input data, it was deemed that the simulation reasonably modeled the current building. This calibrated simulation was called the "as-built model."

The calibration error in the as-built model relative to actual utility data is shown in Table A-9-1.

Table A-9-1 Monthly Calibration Errors

	Gas	Electric Consumption (kWh)		Electric Demand (kW)
		Peak	Off Peak	
January	+1%	- 2%	+1%	+6%
February	- 3%	+1%	0%	- 2%
March	0%	- 2%	- 1%	- 5%
April	+2%	+3%	+1%	- 3%
May	- 2%	+5%	+2%	+6%
June	+7%	- 6%	- 2%	- 9%
July	- 6%	+2%	0%	+8%
August	+1%	- 8%	- 1%	+5%
September	- 3%	+7%	+1%	- 6%
October	- 1%	- 2%	- 1%	+5%
November	+3%	- 2%	- 1%	- 9%
December	+1%	+4%	+1%	+4%

[30] This method is the same as IPMVP Volume III Part 1 New Construction (2006), Option D, Method 2.

The input data for the as-built model was then changed to describe a building with the same occupancy and location but which simply meets the building-code standard. This was called the "standard model."

The standard model's monthly predicted energy use was adjusted by the monthly calibration errors in Table A-9-1 to yield the "**corrected-standard model**." Actual metered data for year one was then subtracted from the corrected-standard model to yield the monthly *savings*. Percentage *savings* were computed to prove eligibility for the government incentive.

Monetary *savings* were determined for the owner by applying the then current full utility rate structure to the corrected standard model's predicted monthly amounts. This total value was compared to the total utility payments for year one.

The year one energy data became the basis for an Option C approach for subsequent years.

B-1 Introduction

The objective of *M&V* is to reliably determine *energy savings*. In order for *savings* reports to be reliable, they need to have a reasonable level of uncertainty. The uncertainty of a *savings* report can be managed by controlling random errors and data bias. Random errors are affected by the quality of the measurement equipment, the measurement techniques, and the design of the sampling procedure. Data bias is affected by the quality of measurement data, assumptions and analysis. Reducing errors usually increases *M&V* cost so the need for improved uncertainty should be justified by the value of the improved information (see Chapter 8.5).

Energy savings computations involve a comparison of measured *energy* data, and a calculation of “adjustments” to convert *both measurements to the* same set of operating conditions (see Chapter 4.1, Equation 1). Both the measurements and the adjustments introduce error. Errors may arise for example due to meter inaccuracy, sampling procedures or adjustment procedures. These processes produce statistical “estimates” with reported or expected values, and some level of variation. In other words, true values are not known, only estimates with some level of uncertainty. All physical measurement and statistical analysis is based on estimation of central tendencies, such as *mean* values, and quantification of variations such as range, *standard deviation*, *standard error*, and *variance*.

Statistics is the body of mathematical methods that can be applied to data to help make decisions in the face of uncertainty. For example, statistics provide ways of checking results to see if the reported *savings* are “significant,” i.e. likely to be a real effect of the ECM rather than random behavior.

Errors occur in three ways: modeling, sampling, and measurement:

- Modeling. Errors in mathematical modeling due to inappropriate functional form, inclusion of irrelevant variables, exclusion of relevant variables, etc. See Appendix B-2.
- Sampling. Sampling error arises when only a portion of the population of actual values is measured, or a biased sampling approach is used. Representation of only a portion of the population may occur in either a physical sense (i.e., only 20 of 1,000 light fixtures are metered), or in the time sense (metering occurring for only ten minutes out of every hour). See Appendix B-3.
- Measurement. Measurement errors arise from the accuracy of sensors, data tracking errors, drift since calibration, imprecise measurements, etc. The magnitude of such errors is largely given by manufacturer's specifications and managed by periodic re-calibration. See Appendix B-4, and Chapters 4.8.3 and 8.11.

This Appendix gives guidance on quantifying the uncertainties created by these three forms of error. Appendix B-5 discusses methods of combining quantified elements of uncertainty.

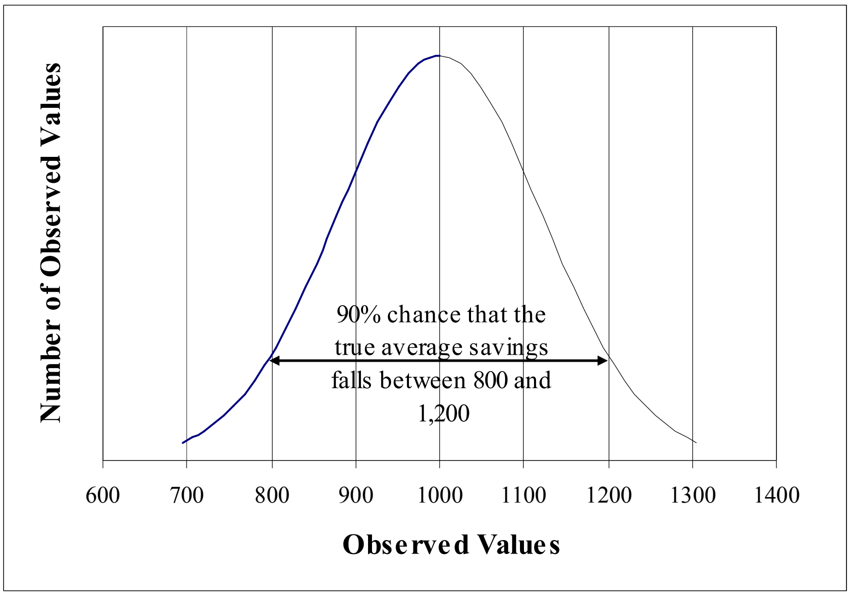
Some sources of error are unknown and unquantifiable. Examples of such sources are poor meter selection or placement, inaccurate *estimates* in Option A, or mis-estimation of *interactive effects* in Options A or B. Unknown or unquantifiable uncertainties can only be managed by following industry best practices.

An example of the use of uncertainty analysis is given in Appendix B-6. Also some of the examples in Appendix A present uncertainty calculations: A-3, A-3-2, A-4 and A-7. EVO’s subscriber website (www.evo-world.org) contains details of the uncertainty calculations in A-4 and A-7.

B-1.1 Expressing Uncertainty

In order to communicate *savings* in a statistically valid manner, *savings* need to be expressed along with their associated *confidence* and *precision* levels. *Confidence* refers to the likelihood or probability that the estimated *savings* will fall within the *precision* range.[31] For example, the *savings* estimation process may lead to a statement such as: "the best estimate of *savings* is 1,000 kWh annually (point estimate) with a 90% probability (*confidence*) that the true-average savings value falls within ±20% of 1,000." A graphical presentation of this relationship is shown in Figure B-1.

Figure B-1 Normally Distributed Population



A statistical *precision* statement (the ±20% portion) without a *confidence* level (the 90% portion) is meaningless. The *M&V* process may yield extremely high *precision* with low *confidence*. For example, the *savings* may be stated with a *precision* of ±1%, but the associated *confidence* level may drop from 95% to 35%.

B-1.2 Acceptable Uncertainty

Savings are deemed to be statistically valid if they are large relative to the statistical variations. Specifically, the *savings* need to be larger than twice the *standard error* (see definition in Appendix B-1.3) of the *baseline* value. If the *variance* of the *baseline* data is excessive, the unexplained random behavior in *energy* use of the *facility* or system is high, and any single *savings* determination is unreliable.

Where you cannot meet this criterion, consider using:

- more precise measurement equipment,
- more *independent variables* in any mathematical model,
- larger sample sizes, or
- an IPMVP Option that is less affected by unknown variables.

[31] Italicized statistical terms in this Appendix are defined in Appendix B-1.3

B-1.3 Definitions of Statistical Terms

Sample Mean ($\overline{Y}$): The most widely used measure of the central tendency of a series of observations. *Sample mean* is determined by adding up the individual data points (Y_i) and dividing by the total number of these data points (n), as follows:

$$\bar{Y} = \frac{\sum Y_i}{n} \quad \text{B-1}$$

Sample Variance (S^2): *Sample variance* measures the extent to which observed values differ from each other, i.e., variability or dispersion. The greater the variability, the greater the uncertainty in the *mean*. *Sample variance*, the most important measure of variability, is found by averaging the squares of the individual deviations from the *mean*. The reason these deviations from the *mean* are squared is simply to eliminate the negative values (when a value is below the *mean*) so they do not cancel out the positive values (when a value is above the *mean*). *Sample variance* is computed as follows:

$$S^2 = \frac{\sum (Y_i - \bar{Y})^2}{n-1} \quad \text{B-2}$$

Sample Standard Deviation (s): This is simply the square root of the *sample variance*. This brings the variability measure back to the units of the data (e.g., if the *variance* units are $(kWh)^2$, the s*tandard deviation* units would be kWh).

$$s = \sqrt{S^2} \quad \text{B-3}$$

Sample Standard Error (SE): This is the *sample standard deviation* divided by $\sqrt{n}$. This measure is used in estimating *precision of a sample mean*. It is also denoted as $\bar{s}$, or the "sample standard deviation of the mean" in most statistics textbooks.

$$SE = \frac{s}{\sqrt{n}} \quad \text{B-4}$$

Sample Standard Deviation of the Total (s_{tot}): Many times we are interested in the statistical properties of a *total* rather than a *mean*. The *sample standard deviation of a total* is used to define the precision about a sample total. It is defined as the square root of the sample size, $\sqrt{n}$, times the sample standard deviation:

$$s_{tot} = \sqrt{n} \cdot s \quad \text{B-5}$$

Coefficent of Variation (cv): The coefficient of variation is simply the standard deviation of a distribution expressed as a percentage of the mean. For instance, the cv of a sample total would be the [s_{tot}] ÷ [sample total]; the cv of a sample mean would be the [$SE_{\bar{Y}}$] ÷ [sample mean]; etc. The general formula is:

$$cv = \frac{s}{\bar{Y}} \quad \text{B-6}$$

Precision: *Precision* is the measure of the *absolute* or *relative* range within which the true value is expected to occur with some specified level of *confidence*. *Confidence* level refers to the probability that the quoted range contains the estimated parameter.

Absolute precision is computed from *sample standard error* using a "*t*" value from the "*t*-distribution" Table B-1:

$$t \times SE_{\bar{Y}} \quad \text{B-7}$$

Table B.1
t-table

Degrees of Freedom DF	Confidence Level				Degrees of Freedom DF	Confidence Level			
	95%	90%	80%	50%		95%	90%	80%	50%
1	12.71	6.31	3.08	1.00	16	2.12	1.75	1.34	0.69
2	4.30	2.92	1.89	0.82	17	2.11	1.74	1.33	0.69
3	3.18	2.35	1.64	0.76	18	2.10	1.73	1.33	0.69
4	2.78	2.13	1.53	0.74	19	2.09	1.73	1.33	0.69
5	2.57	2.02	1.48	0.73	21	2.08	1.72	1.32	0.69
6	2.45	1.94	1.44	0.72	23	2.07	1.71	1.32	0.69
7	2.36	1.89	1.41	0.71	25	2.06	1.71	1.32	0.68
8	2.31	1.86	1.40	0.71	27	2.05	1.70	1.31	0.68
9	2.26	1.83	1.38	0.70	31	2.04	1.70	1.31	0.68
10	2.23	1.81	1.37	0.70	35	2.03	1.69	1.31	0.68
11	2.20	1.80	1.36	0.70	41	2.02	1.68	1.30	0.68
12	2.18	1.78	1.36	0.70	49	2.01	1.68	1.30	0.68
13	2.16	1.77	1.35	0.69	60	2.00	1.67	1.30	0.68
14	2.14	1.76	1.35	0.69	120	1.98	1.66	1.29	0.68
15	2.13	1.75	1.34	0.69	∞	1.96	1.64	1.28	0.67

Note: Calculate DF using the following,
- **DF = n - 1 (for a sample distribution)**
- **DF = n - p - 1 (for a regression model)**

Where,
n = sample size
p = # regression model variables

In general the true value of any statistical estimate is expected, with a given *confidence* level, to fall with the range defined by

Range = estimate ± *absolute precision* B-8

Where "estimate" is any empirically derived value of a parameter of interest (e.g., total consumption, average number of units produced).

Relative precision is the *absolute precision* divided by the estimate:

$$\frac{t * SE}{Estimate} \qquad \text{B-9}$$

See an example use of *relative precision* in Appendix A-3. As an example of the use of these terms, consider the data in Table B-2 from 12 monthly readings of a meter, and related analysis of the difference between each reading and the *mean* of the readings (1,000):

	Actual	Computed Differences From the Mean	
	Reading	Raw	Squared
1	950	-50	2,500
2	1,090	90	8,100
3	850	-150	22,500
4	920	-80	6,400
5	1,120	120	14,400
6	820	-180	32,400
7	760	-240	57,600
8	1,210	210	44,100
9	1,040	40	1,600
10	930	-70	4,900
11	1,110	110	12,100
12	1,200	200	40,000
Total	12,000		246,600

Table B-2 Example data and analysis

The *Mean* value is: $\bar{Y} = \frac{\sum Y_i}{n} = \frac{12{,}000}{12} = 1{,}000$

The *Variance* (S^2) is: $S^2 = \frac{\sum (Y_i - \bar{Y})^2}{n-1} = \frac{246{,}600}{12-1} = 22{,}418$

The *Standard Deviation* (s) is: $s = \sqrt{S^2} = \sqrt{22{,}418} = 150$

The *Standard Error* is: $SE = \frac{s}{\sqrt{n}} = \frac{150}{\sqrt{12}} = 43$

Table B-1 shows that "t" is 1.80 for 12 data points (DF = 11) and a 90% confidence level. Therefore:

the *Absolute Precision* is: $t \times SE = 1.80 \times 43 = 77$ and

the *Relative Precision* is: $\frac{t \times SE}{estimate} = \frac{77}{1{,}000} = 7.7\%$

So, there is 90% *confidence* that the true *mean*-monthly consumption lies in the range between 923 and 1,077 kWh. It can be said with 90% *confidence* that the *mean* value of the 12 observations is 1,000 ±7.7%. Similarly it could be said:

- with 95% *confidence* that the *mean* value of the 12 observations is 1,000 ±9.5%, or
- with 80% *confidence* that the *mean* value of the 12 observations is 1,000 ±5.8%, or
- with 50% *confidence* that the *mean* value of the 12 observations is 1,000 ±3.0%.

B-2 Modeling

Mathematical modeling is used in *M&V* to prepare the *routine-adjustments* term in the various versions of Equation 1 in Chapter 4. Modeling involves finding a mathematical relationship between dependent and *independent variables*. The dependent variable, usually *energy*, is modeled as being governed by one or more *independent variable(s)* X_i, (also known as 'explanatory' variables). This type of modeling is called *regression analysis*.

In *regression analysis*, the model attempts to "explain" the variation in *energy* resulting from variations in the individual *independent variables* (X_i). For example, if one of the *X*'s is production level, the model would assess whether the variation of *energy* from its *mean* is caused by changes in production level. The model quantifies the causation. For example, when production increases by one unit, energy consumption increases by "*b*" units, where "*b*" is called the regression coefficient.

The most common models are linear regressions of the form:

$$Y = b_o + b_1X_1 + b_2X_2 + \ldots.. + b_pX_p + e$$

where:

- Y is the dependent variable, usually in the form of *energy* use during a specific time period (e.g., 30 days, 1 week, 1 day, 1 hour, etc.)
- X_{it} (i = 1, 2, 3, … p) represents the 'p' *independent variables* such as weather, production, occupancy, metering period length, etc.
- b_i (i = 0, 1, 2, … p) represents the coefficients derived for each *independent variable*, and one fixed coefficient (b_0) unrelated to the *independent variables*
- e represents the residual errors that remain unexplained after accounting for the impact of the various *independent variables*. *Regression analysis* finds the set of b_i values that minimizes the sum of squared residual-error terms (thus regression models are also called least-squares models).

An example of the above model for a building's *energy* use is:

monthly energy consumption = 342,000 + (63 x *HDD*) + (103 x *CDD*) + (222 x Occupancy)

HDD and CDD are heating and cooling *degree days*, respectively. Occupancy is a measure of percent occupancy in the building. In this model 342,000 is an estimate of baseload in kWh, 63 measures the change in consumption for one additional HDD, 103 measures the change in consumption for one additional CDD, and 222 measures the change in consumption per 1% change in occupancy.

Appendix B-6 presents an example of a *regression analysis* report for a single *independent variable*, from common spreadsheet software.

B-2.1 Modeling Errors

When using regression models, as described above, several types of errors may be introduced as listed below.

1. The model is built on values that are outside the probable range of the variables to be used. A mathematical model should only be constructed using reasonable values of the dependent and *independent variables*.
2. The mathematical model may not include relevant *independent variables,* introducing the possibility of biased relationships (omitted variable bias).
3. The model may include some variables that are irrelevant.
4. The model may use inappropriate functional form.
5. The model may be based on insufficient or unrepresentative data.

Each of these types of modeling errors is discussed below.

B-2.1.1 Using Out of Range Data

If the model is built on data that are not representative of the normal *energy* behavior of the facility, then the predictions may not be relied upon. This may include inclusion of outliers, or values that are well outside the range of reasonableness. Data should be screened before building the model.

B-2.1.2 Omission of Relevant Variables

In *M&V*, *regression analysis* is used to account for changes in *energy* use. Most complex *energy* using systems are affected by innumerable *independent variables*. Regression models cannot hope to include all *independent variables.* Even if it were possible, the model would be too complex to be useful and would require excessive data gathering activities. The practical approach is to include only *independent variable(s)* thought to significantly impact *energy*.

Omission of a relevant *independent variable* may be an important error. The example model in Appendix B-2 tries to explain the variations in monthly energy use using several *X* variables. If a relevant *independent variable* is missing (e.g., HDD), then the model will fail to account for a significant portion of the variation in *energy*. The deficient model will also attribute some of the variation that is due to the missing variable to the variable(s) that are included in the model. The effect will be a less accurate model. .

There are no obvious indications of this problem in the standard statistical tests (except maybe a low R^2, see B-2.2.1 below). Experience and knowledge of the engineering of the system whose performance is being measured is most valuable here.

There may be cases where a relationship is known to exist with a variable recorded during the *baseline period*. However the variable is not included in the model due to lack of budget to continue to gather the data in the *reporting period*. Such omission of a relevant variable should be noted and justified in the *M&V Plan*.

B-2.1.3 Inclusion of Irrelevant Variables

Sometimes models include irrelevant *independent variable(s)*. If the irrelevant variable has no relationship (correlation) with the included relevant variables, then it will have minimal impact on the model. However, if the irrelevant variable is correlated with other relevant variables in the model, it may bias the coefficients of the relevant variables.

Use caution in adding more *independent variables* into a *regression analysis* just because they are available. To judge the relevance of independent variables requires both experience and intuition. However, the associated *t-statistic* (see B-2.2.3 below) is one way of confirming the relevance of particular *independent variables* included in a model. Experience in *energy* analysis for the type of facility involved in any *M&V* program is is necessary to determine the relevance of independent variables.

B-2.1.4 Functional Form

It is possible to model a relationship using the incorrect functional form. For example, a linear relationship might be incorrectly used in modeling an underlying physical relationship that is non-linear. For example, electricity consumption and ambient temperature tend to have a non-linear (often 'U' shaped) relationship with outdoor temperature over a one-year period in buildings that are both heated and cooled electrically. (Electricity use is high for both low and high ambient temperatures, while relatively low in mid seasons.) Modeling this non-linear relationship with a single linear model would introduce unnecessary error. Instead, separate linear models should be derived for each season.

It may also be appropriate to try higher order relationships, e.g., $Y = f(X, X^2, X^3)$.

The modeler needs to assess different functional forms and select the most appropriate among them using the evaluation measures presented in Appendix B-2.2, below.

B-2.1.5 Data Shortage

Errors may also occur from insufficient data either in terms of quantity (i.e., too few data points) or time (e.g., using summer months in the model and trying to extrapolate to winter months). The data used in modeling should be representative of the range of operations of the facility. The time period covered by the model needs to include various possible seasons, types of use, etc. This may call for either extension of the time periods used or increasing sample sizes.

B-2.2 Evaluating Regression Models

In order to evaluate how well a particular regression model explains the relationship between *energy* use and *independent variable(s)*, three tests may be performed as described below. Appendix B-6 provides evaluation of an example regression model.

B-2.2.1 Coefficient of Determination (R^2)

The first step in assessing the accuracy of a model is to examine the Coefficient of Determination, R^2, a measure of the extent to which variations in the dependent variable Y from its *mean* value are explained by the regression model. Mathematically, R^2 is:

$$R^2 = \frac{Explained\ \ Variation\ \ in\ \ Y}{Total\ \ Variation\ \ in\ \ Y}$$

or more explicitly:

$$R^2 = \frac{\sum(\hat{Y}_i - \bar{Y})^2}{\sum(Y_i - \bar{Y})^2} \qquad \text{B-10}$$

where:

- $\hat{Y}_i$ = model predicted *energy* value for a particular data point using the measured value of the *independent variable* (i.e., obtained by plugging the *X* values into the regression model)
- $\bar{Y}$ = *mean* of the *n* measured *energy* values, found using equation B-1
- Y_i = actual observed (e.g., using a meter) value of *energy*

All statistical packages and spreadsheet *regression-analysis* tools compute the value of R^2.

The range of possible values for R^2 is 0.0 to 1.0. An R^2 of 0.0 means none of the variation is explained by the model, therefore the model provides no guidance in understanding the variations in *Y* (i.e., the selected *independent variable(s)* give no explanation of the causes of the observed variations in *Y*). On the other hand, an R^2 of 1.0 means the model explains 100% of the variations in *Y*, (i.e., the model predicts *Y* with total certainty, for any given set of values of the *independent variable(s)*). Neither of these limiting values of R^2 is likely with real data.

In general, the greater the coefficient of determination, the better the model describes the relationship of the *independent variables* and the dependent variable. Though there is no universal standard for a minimum acceptable R^2 value, 0.75 is often considered a reasonable indicator of a good causal relationship amongst the *energy* and *independent variables*.

The R^2 test should only be used as an initial check. Models should not be rejected or accepted solely on the basis of R^2. Finally, a low R^2 is an indication that some relevant variable(s) are not included, or that the functional form of the model (e.g., linear) is not appropriate. In this situation it would be logical to consider additional *independent variables* or a different functional form.

B-2.2.2 Standard Error of the Estimate

When a model is used to predict an *energy* value (*Y*) for given *independent variable(s)*, the accuracy of the prediction is measured by the *standard error of the estimate* ($SE_{\hat{Y}}$). This accuracy measure is provided by all standard regression packages and spreadsheets.

Once the value(s) of *independent variable(s)* are plugged into the regression model to estimate an *energy* value ($\hat{Y}$), an approximation of the range of possible values for $\hat{Y}$ can be computed using equation B-8 as:

$$\hat{Y} \pm t \times SE_{\hat{Y}}$$

where:

- $\hat{Y}$ is the predicted value of *energy* (Y) from the regression model
- t is the value obtained from the t-tables (see Table B-1)
- $SE_{\hat{Y}}$ is the *standard error of the estimate* (prediction). It is computed as:

$$SE_{\hat{Y}} = \sqrt{\frac{\sum(\hat{Y}_i - Y_i)^2}{n-p-1}} \quad \text{B-11}$$

where *p* is the number of *independent variables* in the regression equation.

This statistic is often referred to as the root-mean squared error *(RMSE*).

Dividing the *RMSE* by the average *energy* use produces the coefficient of variation of *RMSE*, or the *CV(RMSE)*.

$$CV(RMSE) = \frac{SE_{\hat{Y}}}{\bar{Y}} \quad \text{B-12}$$

A similar measure is the mean bias error (*MBE*) defined as:

$$MBE = \frac{\sum(\hat{Y}_i - Y_i)}{n} \quad \text{B-13}$$

The *MBE* is a good indicator of overall bias in the regression estimate. Positive *MBE* indicates that regression estimates tend to overstate the actual values. Overall positive bias does tend to cancel out negative bias. The *RMSE* does not suffer from this cancellation problem.

All three measures may be used in evaluating the calibration of simulation models in Option D.

B-2.2.3 t-statistic

Since regression-model coefficients (b_k) are statistical estimates of the true relationship between an individual *X* variable and *Y*, they are subject to variation. The accuracy of the estimate is measured by the *standard error of the coefficient* and the associated value of the *t-statistic*. A *t-statistic* is a statistical test to determine whether an estimate has statistical significance. Once a value is estimated using the test, it can be compared against *critical t-values* from a *t-table* (Table B-1).

The *standard error of each coefficient* is computed by regression software. The following equation applies for the case of one independent variable.

$$SE_b = \sqrt{\frac{\sum(Y_i - \hat{Y})^2 / (n-2)}{\sum(X_i - \bar{X})^2}} \quad \text{B-14}$$

For cases with more than one *independent variable*, the equation provides reasonable approximation when the independent variables are truly independent (i.e., not correlated). Otherwise, the equation gets very complex and the *M&V* analyst is better off using a software package to compute the *standard errors* of the coefficients.

The range within which the true value of the coefficient, b falls is found using equation B-8 as:

$$b \pm t \times SE_b$$

The *standard error of the coefficient*, *b*, also leads to the calculation of the *t-statistic*. This test ultimately determines if the computed coefficient is statistically significant. The *t-statistic* is computed by all statistical software using the following equation:

$$\text{t-statistic} = \frac{b}{SE_b} \qquad \text{B-15}$$

Once the *t-statistic* is estimated, it can be compared against critical t values from Table B-1. If the absolute value of the *t-statistic* exceeds the appropriate number from Table B-1, then it should be concluded that the estimate is statistically valid.

A rule of thumb states that the absolute value of a *t-statistic* result of 2 or more implies that the estimated coefficient is significant relative to its *standard error*, and therefore that a relationship does exist between *Y* and the particular *X* related to the coefficient. It can then be concluded that the estimated b is not zero. However, at a *t-statistic* of about 2, the *precision* in the value of the coefficient is about ±100%: not much of a vote of confidence in the value of b. To obtain a better precision of say ±10%, the *t-statistic* values must be around 20, or the *standard error* of b has to be no more than 0.1 of b itself.

To improve the *t-statistic* result:

- Select *independent variable(s)* with the strongest relationship to *energy*;
- Select *independent variable(s)* whose values span the widest possible range (if *X* does not vary at all in the regression model, *b* cannot be estimated and the *t-statistic* will be poor);
- Gather and use more data points to develop the model; or
- Select a different functional form for the model; for example, one which separately determines coefficient(s) for each season in a building that is significantly affected by seasonal weather changes.

B-3 Sampling

Sampling creates errors because not all units under study are measured. The simplest sampling situation is that of randomly selecting *n* units from a total population of *N* units. In a random sample, each unit has the same probability $\left(n/N\right)$ of being included in the sample.

In general, the *standard error* is inversely proportional to $\sqrt{n}$. That is, increasing the sample size by a factor "*f*" will reduce the *standard error* (improve the precision of the estimate) by a factor of $\sqrt{f}$.

B-3.1 Sample Size Determination

You can minimize sampling error by increasing the fraction of the population that is sampled $\left(n/N\right)$. Increasing the sample size increases cost, of course. Several issues are critical in optimizing sample sizes. The following steps should be followed in setting the sample size.

1. **Select a homogeneous population.** In order for sampling to be cost effective, the measured units should be expected to be the same as the entire population. If there are two

different types of units in the population, they should be grouped and sampled separately. For example, when designing a sampling program to measure the operating periods of room lighting controlled by occupancy sensors, rooms occupied more or less continuously (e.g., multiple person offices) should be separately sampled from those which are only occasionally occupied (e.g., meeting rooms).

2. **Determine the desired *precision* and *confidence* levels** for the estimate (e.g., hours of use) to be reported. *Precision* refers to the error bound around the true estimate (i.e., ±x% range around the estimate). Higher *precision* requires larger sample. *Confidence* refers to the probability that the estimate will fall in the range of *precision* (i.e., the probability that the estimate will indeed fall in the ±x% range defined by the *precision* statement). Higher probability also requires larger samples. For example, if you want 90% *confidence* and ±10% *precision*, you mean that the range defined for the estimate (±10%) will contain the true value for the whole group (which is not observed) with a probability of 90%. As an example, in estimating the lighting hours at a *facility*, it was decided to use sampling because it was too expensive to measure the operating hours of all lighting circuits. Metering a sample of circuits provided an estimate of the true operating hours. To meet a 90/10 uncertainty criterion (*confidence* and *precision*) the sample size is determined such that, once the operating hours are estimated by sampling, the range of sample estimate (±10%) has to have a 90% chance of capturing the true hours of use .

   The conventional approach is to design sampling to achieve a 90% *confidence* level and ±10% *precision*. However, the *M&V Plan* needs to consider the limits created by the budget (see Chapter 8.5). Improving *precision* from say ±20% to ±10% will increase sample size by 4 times, while improving it to ±2% will increase sample size by 100 times. (This is a result of the sample error being inversely proportional to $\sqrt{n}$.) Selecting the appropriate sampling criteria requires balancing accuracy requirements with *M&V* costs.

3. **Decide on the level of disaggregation**. Establish whether the *confidence* and *precision* level criteria should be applied to the measurement of all components, or to various sub-groups of components. See Appendix B-5.2. Review the *precision* and *confidence* criteria chosen in 2.

4. **Calculate Initial Sample Size**. Based on the information above, an initial estimate of the overall sample size can be determined using the following equation:

$$n_0 = \frac{z^2 * cv^2}{e^2} \qquad \text{B-16}$$

   where:

   - n_o is the initial estimate of the required sample size, before sampling begins
   - *cv* is the *coefficient of variance*, defined as the *standard deviation* of the readings divided by the *mean*. Until the actual *mean* and *standard deviation* of the population can be estimated from actual samples, 0.5 may be used as an initial estimate for *cv*.
   - *e* is the desired level of *precision*.
   - *z* is the standard normal distribution value from Table B-1, with an infinite number of readings, and for the desired *confidence* level. For example z is 1.96 for a 95% *confidence* level (1.64 for 90%, 1.28 for 80%, and 0.67 for 50% *confidence)*.

   For example, for 90% *confidence* with 10% *precision*, and a *cv* of 0.5, the initial estimate of required sample size (n_o) is

$$n_o = \frac{1.64^2 \times 0.5^2}{0.1^2} = 67$$

In some cases (e.g., metering of lighting hours or use), it may be desirable to initially conduct a small sample for the sole purpose of estimating a *cv* value to assist in planning the sampling program. Also values from previous *M&V* work may be used as appropriate initial estimates of *cv*.

5. **Adjust initial sample size estimate for small populations**. The necessary sample size can be reduced if the entire population being sampled is no more than 20 times the size of the sample. For the initial sample size example, above, (n_o = 67), if the population (*N*) from which it is being sampled is only 200, the population is only 3 times the size of the sample. Therefore the "Finite Population Adjustment" can be applied. This adjustment reduces the sample size (*n*) as follows:

$$n = \frac{n_0 N}{n_0 + N} \qquad \text{B-17}$$

Applying this finite population adjustment to the above example reduces the sample size (*n*) required to meet the 90%/±10% criterion to 50. See an example use of this adjustment in Appendix A-3-1.

6. **Finalize Sample Size**. Because the initial sample size (n_o) is determined using an assumed *cv*, it is critical to remember that the actual *cv* of the population being sampled may be different. Therefore a different actual sample size may be needed to meet the *precision* criterion. If the actual *cv* turns out to be less than the initial assumption in step 4, the required sample size will be unnecessarily large to meet the *precision* goals. If the actual *cv* turns out to be larger than assumed, then the *precision* goal will not be met unless the sample size increases beyond the value computed by Equations B-16 and B-17.

   As sampling continues, the *mean* and *standard deviation* of the readings should be computed. The actual *cv* and required sample size (Equations B-16 and B-17) should be re-computed. This re-computation may allow early curtailment of the sampling process. It may also lead to a requirement to conduct more sampling than originally planned. To maintain *M&V* costs within budget it may be appropriate to establish a maximum sample size. If this maximum is actually reached after the above re-computations, the *savings* report(s) should note the actual *precision* achieved by the sampling.

B-4 Metering

Energy quantities and *independent variables* are often measured as part of an *M&V* program, using meters. No meter is 100% accurate, though more sophisticated meters may increase the accuracy towards 100%. The accuracy of selected meters is published by the meter manufacturer, from laboratory tests. Proper meter sizing, for the range of possible quantities to be measured, ensures that collected data fall within known and acceptable error limits (or *precision*).

Manufacturers typically rate *precision* as either a fraction of the current reading or as a fraction of the maximum reading on the meter's scale. In this latter case it is important to consider where the typical readings fall on the meter's scale before computing the *precision* of typical readings.

Over-sizing of meters whose *precision* is stated relative to maximum reading will significantly reduce the *precision* of the actual metering.

The readings of many meter systems will 'drift' over time due to mechanical wear. Periodic re-calibration against a known standard is required to adjust for this drift. It is important to maintain the *precision* of meters in the field through routine maintenance, and calibration against known standards.

In addition to accuracy of the meter element itself, other possibly unknown effects can reduce meter system *precision*:

- poor placement of the meter so it does not get a representative 'view' of the quantity it is supposed to measure (e.g., a fluid flow meter's readings are affected by proximity to an elbow in the pipe)
- data telemetry errors which randomly or systematically clip off meter data

As a result of such unquantifiable metering errors, it is important to realize that manufacturer-quoted *precision* probably overstates the *precision* of the actual readings in the field. However there is no way to quantify these other effects.

Manufacturer *precision* statements should be in accordance with the relevant industry standard for their product. Care should be taken to determine the *confidence* level used in quoting a meter's *precision.* Unless stated otherwise, the *confidence* is likely to be 95%.

When a single measurement is used in a *savings* computation, rather than the *mean* of several measurements, the methods of Appendix B-5 are used to combine uncertainties of several components. The *standard error* of the measured value is:

$$SE = \frac{meter\ relative\ precision \times measured\ value}{t} \qquad \text{B-18}$$

Where t is based on the large sampling done by the meter manufacturer when developing its relative precision statement. Therefore the Table B-1 value of t should be for infinite sample sizes.

When making multiple readings with a meter, the observed values contain both meter error and variations in the phenomenon being measured. The *mean* of the readings likewise contains both effects. The *standard error* of the estimated *mean* value of the measurements is found using equation B-4.

Chapters 4.8.3 and 8.11 further discuss metering and provide references to other useful readings on metering.

B-5 Combining Components of Uncertainty

Both the measurement and adjustment components in Equation 1 of Chapter 4 can introduce uncertainty in reporting *savings*. The uncertainties in the individual components can be combined to enable overall statements of *savings'* uncertainty. This combination can be performed by expressing the uncertainty of each component in terms of its *standard error*.

The components must be independent to use the following methods for combining uncertainties. Independence means that whatever random errors affect one of the components are unrelated to the errors affecting other components.

If the reported *savings* is the sum or difference of several independently determined components (*C*) (i.e., $Savings = C_1 \pm C_2 \pm ... \pm C_p$), then the *standard error* of the reported *savings* can be estimated by:

SE(*Savings*) = $\sqrt{SE(C_1)^2 + SE(C_2)^2 + ... + SE(C_p)^2}$ B-19

For example, if *savings* are computed using Equation 1b) of Chapter 4 as the difference between the *adjusted-baseline energy* and measured *reporting-period energy*, the *standard error* of the difference (*savings*) is computed as:

$$SE(Savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(reporting\ period\ energy)^2}$$

The *SE* (*adjusted baseline*) comes from the *standard erro*r of the estimate derived from Equation B-11. The *SE* (*reporting period energy*) comes from the meter accuracy using Equation B-18.

If the reported *savings* estimate is a <u>product</u> of several independently determined components (C_i) (i.e., $Savings = C_1 * C_2 * ... * C_p$), then the relative *standard error* of the *savings* is given approximately by:

$$\frac{SE(Savings)}{Savings} \approx \sqrt{\left(\frac{SE(C_1)}{C_1}\right)^2 + \left(\frac{SE(C_2)}{C_2}\right)^2 + ...+ \left(\frac{SE(C_p)}{C_p}\right)^2} \qquad \text{B-20}$$

A good example of this situation is the determination of lighting *savings* as:

Savings = Δ Watts x Hours

If the *M&V Plan* requires measurement of hours of use, then “Hours” will be a value with a *standard error*. If the *M&V Plan* also includes measurement of the change in wattage, then ΔWatts will also be a value with a *standard error*. Relative *standard error* of *savings* will be computed using the formula above as follows:

$$\frac{SE(Savings)}{Savings} = \sqrt{\left(\frac{SE(\Delta Watts)}{\Delta Watts}\right)^2 + \left(\frac{SE(Hours)}{Hours}\right)^2}$$

When a number of savings results are totaled and they all have the same *Standard Error*, equation B-5 or B-19 can be used to find the estimated *Standard Error* of the total reported.

Total SE(*Savings*) = $\sqrt{SE(savings_1)^2 + SE(savings_2)^2 + ... + SE(savings_N)^2}$ =

$\sqrt{N} \times SE(Savings)$

Where *N* is the number of *savings* results with the same *Standard Error* that are added together.

Once the *standard error* of the *savings* is determined from the above procedures, it is possible to make appropriate concluding statements about the relative amount of uncertainty inherent in the *savings*, using the mathematics of the standard normal distribution curve, Figure B-1, or data in Table B-1. For example, one can compute three values:

1. the *absolute* or *relative precision* of the total *saving*, for a given level of *confidence* (e.g., 90%), computed using the relevant t value from Table B-1 and Equation B-7 or B-9, respectively.
2. *Probable Error* (*PE*), defined as the 50% confidence range. *Probable Error* represents the most likely amount of error. That is, it is equally likely that error will be larger or smaller than the *PE*. (ASHRAE, 1997). Table B-1 shows that 50% *confidence* level is achieved at t = 0.67 for samples sizes larger than 120, or 0.67 *standard errors* from the *mean* value. So the range of *probable error* in reported *savings* using Equation B-8 is ±0.67 x SE (*Savings*).
3. The 90% *Confidence* Limit (*CL*), defined as the range where we are 90% certain that random effects did not produce the observed difference. From Table B-1 using Equation B-8, *CL* is ±1.64 x SE(*Savings*) for sample sizes larger than 120.

B-5.1 Assessing Interactions of Multiple Components of Uncertainty

Equations B-19 and B-20 for combining uncertainty components can be used to estimate how errors in one component will affect the accuracy of the overall *savings* report. *M&V* resources can then be designed to cost-effectively reduce error in reported *savings*. Such design considerations would take into account the costs and the effects on *savings precision* of possible improvements in the *precision* of each component.

Software applications written for common spreadsheet tools allow for easy assessment of the net error associated with the combination of multiple components of uncertainty, using Monte Carlo techniques. Monte Carlo analysis allows the assessment of multiple “what if” scenarios revealing a range of possible outcomes, their probability of occurring, and which component has the most effect on the final output. Such analysis identifies where resources need to be allocated to control error.

A simple illustration of “what if” analysis is presented below for a lighting retrofit. A nominally 96 watt light fixture is replaced with a nominal 64-watt fixture. If the fixture operates for 10 hours every day, the annual *savings* would be computed as:

$$Annual\ Savings = \frac{(96-64)\times 10\times 365}{1{,}000} = 117kWh$$

The new 64-watt fixture’s wattage is consistent and easily measured with accuracy. However there is much variation among the old-fixture wattages and among the hours of use in different locations. Old-fixture wattages and hours of use are not easily measured with certainty. Therefore the *savings* will also not be known with certainty. The *M&V* design challenge is to determine the impact on reported *savings* if the measurement of either of these uncertain quantities is in error by plausible amounts.

Figure B2 shows a sensitivity analysis of the *savings* for the two parameters, old-fixture watts, and hours of use. Each is varied by up to 30% and the impact on *savings* is shown. It can be seen that *savings* are significantly more sensitive to variation in old-fixture wattage than to hours of use. A 30% wattage error produces a 90% *savings* error, while a 30% error in operating hours produces only a 30% *savings* error.

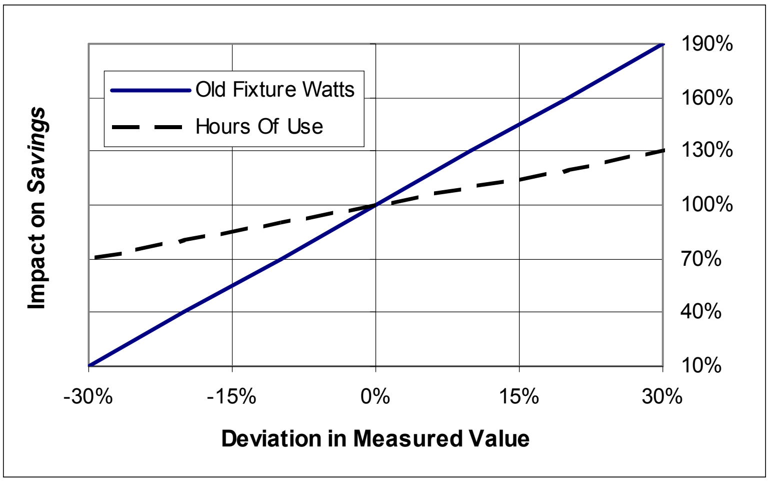


Figure B-2. Example Sensitivity Analysis – Lighting Savings

If the proposed M&V method will yield readings of old-fixture wattage with a range of uncertainty of ±5%, the range of electricity *savings* uncertainty will be ±15%. In other words, if the old-fixture wattage could be between 91 and 101 watts, the *savings* could be between 99 and 135 kWh annually. The range of uncertainty on the *savings* is 36 kWh (135 - 99). If the marginal value of electricity is 10 cents per kWh, the uncertainty range is about $3.60 annually. If the wattage of the old fixture could be estimated with greater *precision* for significantly less than $3.60, then it may be worth enhanced-measurement efforts, depending on the number of years of *savings* being considered.

Figure B2 shows that the hours-of-use term has less of an impact on final *savings* in this example (the hours-of-use line is flatter indicating lower sensitivity). It is plausible that the error in measurement of operating hours is ±20%, so the energy-*savings* uncertainty range is also ±20% or ±23 kWh (= 20% of 117 kWh). The range in *savings* is about 46 kWh (= 2 x 23 kWh), worth $4.60 per year. Again it may be warranted to increase the accuracy in measuring the hours of use if it can be done for significantly less than $4.60, depending upon the number of years of *savings* being considered.

The range of possible *savings* errors from errors in measuring operating hours (46 kWh) is greater than from the error in measuring the old-fixture wattages (36 kWh). This is the opposite effect from what might be expected based on the greater sensitivity of *savings* to wattage than to hours of use, as seen in Figure B2. This difference arises because the plausible error of measuring operating hours (±20%) is much larger than the plausible error of measuring old-fixture wattages (±5%).

Sensitivity analysis such as the above can take many forms. The preceding simple example was used to show the principles. Monte Carlo simulation, allows complex consideration of many different parameters, allowing *M&V* design to focus expenditures where most needed to improve the overall accuracy of *savings* reports.

B-5.2 Establishing Targets for Quantifiable *Savings* Uncertainty

As discussed in Appendix B-1, not all uncertainties can be quantified. However, those that can be quantified provide guidance in *M&V Plan*ning. By considering the *M&V* cost of various optional approaches to uncertainty, the M&V program can produce the type of information that is acceptable to all readers of the *savings* report, including those who have to pay for the *M&V* reports. Ultimately, any *M&V Plan* should report the expected level of quantifiable uncertainty (see Chapter 5).

Determination of *energy savings* requires estimating a difference in *energy* levels, rather than simply measuring the level of *energy* itself. In general, calculating a difference to suit a target *relative precision* criterion requires better *absolute precision* in the component measurements than the *absolute precision* required of the difference. For example, suppose the average load is around 500 kW, and the anticipated *savings* are around 100 kW. A ±10% error with 90% *confidence* ("90/10") criterion can be applied two ways:

- If applied to the load measurements, *absolute precision* must be 50 kW (10% of 500 kW) at 90% *confidence*.
- If applied to the reported *savings, absolute precision* in the *savings* must be 10 kW (10% of 100 kW) at the same 90% *confidence* level. To achieve this 10 kW *absolute precision in reported savings* requires component measurement *absolute precisions* of 7 kW (using Equation B-19, if both components are to have the same *precision*).

Clearly the application of the 90/10 *confidence/precision* criterion at the level of the *savings* requires much more precision in the load measurement than a 90/10 requirement at the level of the load.

The *precision* criterion may be applied not only to *energy savings*, but also to parameters that determine *savings*. For example, suppose the *savings* amount is the product of the number (*N*) of units, hours (*H*) of operation, and change (*C*) in watts: *Savings* = *N* x *H* x *C*. The 90/10 criterion could be applied separately to each of these parameters. However, achieving 90/10 *precision* for each of these parameters separately does not imply that 90/10 is achieved for the *savings*, which is the parameter of ultimate interest. In fact using Equation B-20, the *precision* at 90% *confidence* would only be ±17%. On the other hand, if the number of units and change in watts are assumed to be known without error, 90/10 *precision* for hours implies 90/10 *precision* for *savings*.

The *precision* standard could be imposed at various levels. The choice of level of disaggregation dramatically affects the *M&V* design and associated costs. In general, data collection requirements increase if *precision* requirements are imposed on each component. If the primary goal is to control *savings precision* for a project as a whole, it is not necessary to impose the same *precision* requirement on each component.

B-6 Example Uncertainty Analysis

To illustrate the use of the various statistical tools for uncertainty analysis, Table B-3 shows an example spreadsheet regression model output. It is a regression of a building's 12 monthly electric-utility consumption-meter values and cooling *degree days* (CDD) over a one-year period. This is just a partial spreadsheet output. Specific values of interest are highlighted in italics.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.97
R Square	*0.93*
Adjusted R Square	0.92
Standard Error	*367.50*
Observations	12.00

	Coefficients	*Standard Error*	*T Stat*	*Lower 95%*	*Upper 95%*
Intercept	*5,634.15*	151.96	37.08	5,295.56	5,972.74
CDD	*7.94*	*0.68*	*11.64*	*6.42*	*9.45*

Table B-3 Example Regression Analysis Spreadsheet Output

For A Baseline of 12 Monthly kWh and CDD Data Points the derived regression model is:

Monthly electricity consumption = 5,634.15 + (7.94 x CDD)

The coefficient of determination, R^2, (shown as "R Square" in Table B-3) is quite high at 0.93, indicating that 93% of the variation in the 12 energy data points is explained by the model using CDD data. This fact implies a very strong relationship and that the model may be used to estimate adjustment terms in the relevant form of Equation 1 in Chapter 4.

The estimated coefficient of 7.94 kWh per CDD has a *standard error* of 0.68. This SE leads to a *t-statistic* (shown as "T stat" in Table B-3) of 11.64. This *t-statistic* is then compared to the appropriate critical *t* value in Table B-1 (*t* = 2.2 for 12 data points and 95% *confidence*). Because 11.64 exceeds 2.2, CDD is a highly significant *independent variable*. The spreadsheet also shows that the range for the coefficient at the 95% level of *confidence* is 6.42 to 9.45, and implies a *relative precision* of ±19% (= (7.94 - 6.42) / 7.94). In other words, we are 95% *confident* that each additional CDD increases kWh consumption between 6.42 and 9.45 kWh.

The *standard error of the estimate* using the regression formula is 367.5. The average CDDs per month is 162 (not shown in output). To predict what electric consumption would have been under average cooling conditions, for example, this CDD value is inserted into the regression model:

Predicted consumption = 5,634 + (7.94 x 162)
= 6,920 kWh per average cooling degree day month

Using a Table B-1 *t*-value of 2.2, for 12 data points and a 95% *confidence* level, the range of possible predictions is:

Range of predictions = 6,920 ± (2.2 x 367.5) = 6,112 to 7,729 kWh.

The *absolute precision* is approximately ±809 kWh (= 2.2 x 367.5) and the *relative precision* is ±12% (= 809 / 6,920). The spreadsheet described value for the *standard error of the estimate* provided the information needed to compute the *relative precision* expected from use of the regression model for any one month, in this case 12%.

If *reporting-period* consumption was 4,300 kWh, *savings* computed using Chapter 4, Equation 1b) will be:

Savings = 6,920 – 4,300 = 2,600 kWh

Since the utility meter was used to obtain the *reporting-period* electricity value, its reported values may be treated as 100% accurate (SE = 0%) because the utility meter defines the amounts paid, regardless of meter error. The SE of the *savings* number will be:

$$SE(monthly\ savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(reporting\ period\ consumption)^2}$$

$$= \sqrt{367.5^2 + 0^2} = 367.5$$

Using *t* of 2.2, the range of possible monthly *savings* is

Range of *savings* = 2,620 ± (2.2 x 367.5)
= 2,620 ± -810 = 1,810 to 3,430

To determine the *precision* of the annual total of monthly *savings*, it is assumed that the *standard error* of each month's *savings* will be the same. The annual reported *savings* then have a *standard error* of:

$$\text{SE (annual } savings\text{)} = \sqrt{12 \times 367.5^2} = 1{,}273 \text{ kWh}$$

Since *t* derives from the model of the *baseline*, it remains at the 2.2 value used above. Therefore the *absolute precision* in annual *savings* is 2.2 x 1,273 = 2,801 kWh.

Assuming equal monthly *savings* of 2,620 kWh, annual *savings* are 31,440 kWh, and the *relative precision* of the annual *savings* report is 9% (= (2,801 / 31,440) x 100).

APPENDIX C REGION-SPECIFIC MATERIALS

This Appendix contains materials unique to the various regions of the world from which EVO has received credible contributions. These contributions may be updated separately from the rest of this Volume, so a date of publication is shown for each part. EVO encourages all regions of the world to submit materials that highlight unique aspects of M&V in their areas.

C-1 United States of America - April 2007, updated October 2011

Addition to Chapter 1.3 "IPMVP's Relationship To Other M&V Guidelines"

- ASHRAE, Guideline 14-2002 Measurement of Energy and Demand Savings (see Reference 3 in Chapter 10). This American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. document provides complementary detail for IPMVP. Guideline 14 had many of the same original authors as IPMVP. Though Guideline 14 provides technical detail following many of the same concepts of IPMVP, it does not use the same Option names as IPMVP. Guideline 14 is a unique and useful resource for *M&V* professionals around the world and is available for purchase through ASHRAE's bookstore at http://resourcecenter.ashrae.org/store/ashrae/.
- M&V Guidelines: Measurement and Verification for Federal Energy Projects, Version 2.2 - 2000 (see Reference 27 in Chapter 10). The U.S. Department of Energy's Federal Energy Management Program (FEMP) was established, in part, to reduce energy costs of operating U.S. government federal facilities. The FEMP M&V Guideline was first published in 1996 with many of the same authors as IPMVP. It provides detailed guidance on specific *M&V* methods for a variety of *ECM*s. The FEMP Guide is generally consistent with the IPMVP framework, except that it does not require site measurment of energy use for two specific *ECM*s. The Lawrence Berkeley National Laboratory website (http://ateam.lbl.gov/mv/) contains the FEMP M&V Guideline, and a number of other M&V resource documents, including one on the estimations used in Option A, and an M&V checklist.
- The U.S. State Of California's Public Utilities Commission's California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals (April 2006). This document provides guidance for evaluating efficiency programs implemented by a utility. It shows the role IPMVP for individual site *M&V*. The Protocol can be found at the California Measurement Advisory Council (CALMAC) website http://www.calmac.org.
- The Greenhouse Gas Protocol for Project Accounting (2005), jointly developed by the World Resources Institute and the World Business Council for Sustainable Development. The IPMVP Technical Committee was represented on the advisory committee for this document which defines means of reporting the greenhouse gas impact of carbon emission reduction and carbon sequestration projects. See www.ghgprotocol.org.

Addition to Chapters 1.2, Appendix D.6 and D.7

A widely referenced program for rating the sustainability of building designs or operations is the Leadership in Energy and Environmental Design (LEED™) of the U.S. Green Buildings Council.

Addition to Chapter 4.3, Item 6.

ORNL (1999) and ASHRAE Guideline 1-1996 define good practice in commissioning most building modifications.

Addition to Chapter 4.7, last paragraph.

ASHRAE (2002) provides more technical details on a similar retrofit isolation method

Addition to Chapter 4.7

Specific applications of retrofit-isolation techniques to common *ECMs* chosen by the United States Department of Energy are shown in Section III of FEMP (2000). Note however that FEMP's applications LE-A-01, LC-A-01 and CH-A-01 are not consistent with IPMVP because they require no measurement.

ASHRAE (2002) provides more detailed specifications for a similar method.

Addition to Chapter 4.8.1

Chapter 2.2.1 of FEMP (2000) summarizes common duties borne by parties to an *energy-performance contract*. The United States Federal Energy Management Program has also published Detailed Guidelines for FEMP *M&V* Option A (2002) giving further guidance on *estimation* issues faced by U.S. federal agencies. (Note: the FEMP guidelines call *estimated values* "stipulations.")

Addition to Chapter 4.9

Resources that provide detailed methods for defining new construction baselines, include: ASHRAE Standard 90.1 Appendix G – Performance Rating Method, the COMNET Commercial Building Energy Modeling Guidelines and Procedures and the Title-24 Alternative Calculation Manual. In addition, it is becoming more commonplace that commercially-available simulatioin programs are capable of automatically generating a minimally-compliant baseline building based on an as-designed building model per various rating methods.

ASHRAE (2002) provides more technical details on a similar method and on calibrating simulation models to utility bills.

Addition to Chapter 4.9.1

Information on building simulation programs in common use in different parts of the world can be found in Chapter 6.3 of ASHRAE (2002).

Addition to Chapter 4.9.2, Item 5.

ASHRAE (2002), Chapter 6.3, gives more information on calibration accuracy.

Addition to Chapter 4.9.1

Information on different types of building simulation models can be found in Chapter 32 of the ASHRAE Handbook (2005). The United States Department of Energy (DOE) also maintains a current list of public-domain software and proprietary building-energy-simulation programs at www.eren.doe.gov/buildings/tools_directory.

ASHRAE's simplified energy-analysis procedure may also be used if the building's heat losses, heat gains, internal loads, and HVAC systems are simple.

Other types of special-purpose programs are used to simulate *energy* use of HVAC components. See ASHRAE's HVAC02 toolkit (Brandemuehl 1993), and for boiler/chiller equipment HVAC01 toolkit (Bourdouxhe 1994a, 1994b, 1995). Simplified component air-side HVAC models are also available in a report by Knebel (1983). Equations for numerous other models have been identified as well (ASHRAE 1989, SEL 1996).

Addition to Chapter 4.9.2. Item 2

The process of obtaining and preparing actual weather data is described in depth in the *User News* Vol. 20, No. 1, which is published by Lawrence Berkeley National Laboratory and can be found at http://gundog.lbl.gov under Newsletters. Free actual weather data are available from U.S. D.O.E. at http://www.eere.energy.gov/buildings/energyplus/cfm/weatherdata/weather_request.cfm. Actual weather data can also be purchased. One source is the U.S. National Climatic Data Center at http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html.

One valid method for adjusting an average weather file to resemble actual weather data is found in the WeatherMaker utility program, part of the U.S. National Renewable Energy Laboratory's software package Energy-10, available at http://www.nrel.gov/buildings/energy10/.

Addition to 8.3

Methods of quantifying, evaluating and reducing some of these uncertainties are discussed in this document's Appendix B, and ASHRAE (2002), section 5.2.11.[32] See also Reddy & Claridge (2000) that applies standard-error-analysis methods to the typical *savings* determination.

Addtion to Chapter 8.10

The U.S. Department of Energy's Building Energy Standards and Guidelines Program (BSGP), available at www.eren.doe.gov/buildings/codes_standards/buildings, provides information about U.S. residential, commercial and Federal building codes.

C-2 France - Juillet 2009

Dans tout *Plan de M&V*, l'identification de l'option choisie doit se faire au moyen de la date de publication ou du numéro de version, ainsi que de la référence du Volume de l'IPMVP, dans l'édition nationale correspondante. Exemple : IPMVP Volume I EVO 10000-1:2012:F

Chapitre 1.4

1.4A1 Benchmarks, certificats et tests régionaux

HQE : www.assohqe.org

Chapitre 4.9 Option D

4.9A1: Information relative aux différents types de modèles de simulation dans le Bâtiment

Liste des logiciels conseillés par l'ADEME (en cours d'établissement) : http://194.117.223.129

4.9A2 : Modèles de composants applicables

Liste des logiciels conseillés par l'ADEME (en cours d'établissement) : http://194.117.223.129

4.9A3 : Modèles et sources de données météorologiques applicables

Metéo-France : https://espacepro.meteofrance.com/espace_service/visite

[32] It should be noted that, different from ASHRAE Guideline 14, IPMVP does not require inclusion of uncertainty reporting in savings reports.

COSTIC : http://www.costic.com/dju/presentation.html

4.9A4 : Méthodes de calibration applicables

Compléments méthodologiques : voir ASHRAE 2002, 1051RP

4.9A5 : Niveaux de précision minimaux recommandés

ASHRAE 2002

C-3 España - 2009

En el desarrollo del IPMVP en España, aunque no existe una normativa específica para la Medida y verificación de proyectos eficientes existen particularidades y utilidades propias de su legislación y normativa que conviene conocer.

Por ello, se anexa información específica de España:

Anexos al Capítulo 4.9.1

Para la obtención de la escala de calificación energética de edificios, en España, se ha realizado un estudio específico en el que se detalla el procedimiento utilizado para obtener los límites de dicha escala en función del tipo de edificio considerado y de la climatología de la localidad. Este procedimiento ha tomado en consideración las escalas que en la actualidad se sopesan en otros países y, en particular, la propuesta que figura en el documento del CEN prEN 15217 “Energy performance of buildings: Methods for expresing energy preformance and for energy certification of buildings”.

La determinación del nivel de eficiencia energética correspondiente a un edificio puede realizarse empleando dos opciones:

- La opción general, de carácter prestacional, a través de un programa informático; y la opción simplificada, de carácter prescriptivo, que desarrolla la metodología de cálculo de la calificación de eficiencia energética de una manera indirecta.
- La opción general se basa en la utilización de programas informáticos que cumplen los requisitos exigidos en la metodología de cálculo dada en el RD 47/2007. Se ha desarrollado un programa informático de referencia denominado Calener, promovido por el Ministerio de Industria, Turismo y Comercio a través del IDAE y la Dirección General de Arquitectura y Política de Vivienda del Ministerio de Vivienda.

Este programa cuenta con dos versiones:

- Calener_VYP, para edificios de Viviendas y del Pequeño y Mediano Terciario (Equipos autónomos).
- Calener_GT, para grandes edificios del sector terciario.

La utilización de programas informáticos distintos a los de referencia está sujeta a la aprobación de los mismos por parte de la Comisión Asesora para la Certificación Energética de Edificios. Esta aprobación se hará de acuerdo con los criterios que se establece en el Documento de Condiciones de Aceptación de Procedimientos Alternativos a Líder y Calener.

El Programa informatico Calener es una herramienta promovida por el Ministerio de Industria, Turismo y Comercio, a través del IDAE , y por el Ministerio de Vivienda, que permite determinar el nivel de eficiencia energética correspondiente a un edificio. El programa consta de dos herramientas informaticas para una utilización mas fácil por el usuarioNT.

Se puede encontrar en la web del Ministerio de Industria, Turismo y Comercio, en http://www.mityc.es/energia/desarrollo/EficienciaEnergetica/CertificacionEnergetica/ProgramaCalener/Paginas/DocumentosReconocidos.aspx

El programa LIDER es una aplicación que permite verificar el cumplimiento de la exigencia "Limitación de la demanda energética" regulada en el DB-HE1 del nuevo Código Técnico de Edificación.

Dicho programa está incluido dentro el CALENER – VYP que se encuentra en la referencia anterior, aunque se puede obtener independientemente en la web http://www.codigotecnico.org/index.php?id=33

Anexos al Capítulo 4.9.2. Item 2

Los datos meteorológicos en tiempo real están disponibles en la web de la Agencia Estatal de Meteorología, dependiente del Ministerio de Medio Ambiente, Medio Rural y Marino en la web http://www.aemet.es/es/eltiempo/observacion/ultimosdatos?k=mad

Para la obtención de datos meteorológicos históricos igualmente en la Agencia Estatal de Meteorología, dependiente del Ministerio de Medio Ambiente, Medio Rural y Marino en la web http://www.aemet.es/es/elclima/datosclimatologicos/resumenes

Anexos al Capítulo 8.10

La normativa y legislación española referente al Código Técnico de la Edificación (CTE) se encuentra en la web del Ministerio de Vivienda en http://www.mviv.es/es/index.php?option=com_content&task=view&id=552&Itemid=226

Respecto al Reglamento de Instalaciones Térmicas de los Edificios (RITE) están disponibles en la web del Ministerio de Industria, Turismo y Comercio, en http://www.mityc.es/energia/desarrollo/EficienciaEnergetica/RITE/Paginas/InstalacionesTermicas.aspx.

C-3.1 Catalunya - Setembre 2010

Pel desenvolupament de l'IPMVP a Catalunya es podrà utilitzar tota la informació específica a la que es fa referència a l'apartat C-3 d'Espanya.

A més de la normativa europea, per fer possible la transició cap a un model energètic més sostenible s'hauran de tenir presents les normatives i decrets específics per a Catalunya, tant les que fan referència a la totalitat de les empreses com les que fan referència als edificis públics:

- Directiva 2006/32/CE del Parlament Europeu i del Consell, de 5 d'abril de 2006 sobre l'eficiència de l'ús final de l'energia i els serveis energètics, la qual deroga la Directiva 93/76/CEE del Consell.
- Decret 21/2006, de 14 de febrer, pel qual es regula l'adopció de criteris ambientals i d'ecoeficiència en els edificis. (Decret d'Ecoeficiència)

- Directiva 2002/91/CE del Parlament Europeu i del Consell, de 16 de desembre de 2002, relativa a l'eficiència energètica dels edificis.

Annex al capítol 4.9.2

Per a l'obtenció de dades meteorològiques, històriques o del any en curs, a més de la Delegació Territorial a Catalunya de l'Agència Estatal de Meteorologia (http://www.aemet.es) tel.: 93.221.14.72, es recomana consultar el servei meteorològic català: http://www.meteocat.cat

C-4 Romania - July 2010

Addition to Chapter 1.3, "IPMVP's Relationship To Other M&V Guidelines"

Another useful document for the reader of IPMVP is the Romanian National Energy Balance Elaboration Guide. The National Guide describes the way to perform an energy balance, energy audit and how to accomplish the measurement.

Addition to Chapter 4.7, "Calibration"

Devices are calibrated according to the recognized authority, the National Institute of Metrology that has as main mission the provision of scientific basis for uniformity and accuracy of measurement in Romania. Therefore calibration action must comply with its assessed laws.

Addition to Chapter 10.2, "Measurement References"

Measurements are made according to the Electric Energy Measurements Rules and Thermal Energy Measurements Rules, elaborated by ANRE (Romanian Energy Regulatory Authority) and using the Code for Electric Energy Measurement elaborated also by ANRE.

For the electric energy measurement, the rules are according to:

CEI 60044-1 Current transformers
CEI 60186 Voltage transformers
CEI 60044-2 Inductive voltage transformers
CEI 60687 Alternating current static watt-hour meters for active energy classes 0.2S and 0.5S
CEI 61036 Alternating current static watt-hour meters for active energy classes 1 and 2
CEI 61268 Alternating current static watt-hour meters for reactive energy classes 2 and 3
CEI 60521 Class 0.5, 1 and 2 alternating current watt-hour meters
CEI 60870 - 2 - 1 Telecontrol equipment and systems. Part 2: Operating conditions. Section 1: Power supply and electromagnetic compatibility.
CEI 60870 - 4 Telecontrol equipment and systems. Part 4: Performance requirements.
CEI 60870 - 5 Telecontrol equipment and systems. Part 5: Transmission protocols.
CEI 61107 Data exchange for meter reading, tariff and load control. Direct local data exchange
CEI 61334-4 Distribution automation using distribution line carrier systems. Part 4: Data communication protocols
CEI 62056-61 Electricity metering – data exchange for meter reading, tariff and load control – Part 61: Object identification system (OBIS)
CEI 62056-62 Electricity metering – data exchange for meter reading, tariff and load control – Part 62: Interface classes
CEI 62056-46 Electricity metering – data exchange for meter reading, tariff and load control – Part 46: Data Link layer using HDLC protocol

CEI 62056-53	Electricity metering – data exchange for meter reading, tariff and load control – Part 53: COSEM Application Layer
CEI 62056-21	Electricity metering – data exchange for meter reading, tariff and load control – Part 21: Direct local data exchange
CEI 62056-42	Electricity metering – data exchange for meter reading, tariff and load control – Part 42: Physical layer services and procedures for connection oriented asynchronous data exchange

For the thermal energy measurement, the rules are according to:

SR EN 1434 –1 Thermal energy meters, Part 1: General View. (1998)
STAS 6696 Taking samples (measurements) (1986)
EN 1434–2,3,4,5,6 Heat meters (1997)
ISO/IEC 7480 Information technology – Telecommunications and information exchange between systems -- Start-stop transmission signal quality at DTE/DCE interfaces (1991)
ISO/IEC 7498-1 Information technology -- Open Systems Interconnection – Basic Reference Model: The Basic Model (1994)
PE 002 Regulation for the provision and use of thermal energy (1994)
PE 003 Nomenclature of inspections, testing and proof of installation, commissioning and start-up of power plants (1984)
PE 502-8 Norms for providing technological facilities with measuring devices and automation. Heat Points (1998)
SC 001 Framework solutions for metering installation to plumbing and heating installations in existing buildings (1996)
SC 002 Framework solutions for metering water consumption, natural gas and thermal energy associated with installations from apartment blocks (1998)
OIML R 75 (International Recommendation) Thermal energy meters (1988)
NTM-3-159-94 Metrological verification of thermal energy meters (1994)

Addition to Chapter 8.7, “Data for Emission Trading”

CO_2 emissions are measured, monitored and traded according to the National Allocation Plan Regarding Greenhouse Gas Emission Certificates, that can be found at the following website: http://www.anpm.ro/Files/TEXT%20Anexe%20HG_NAP_ro-%20FINAL_20098183817246.pdf
Certificate trading is made according to EU legislation.

C-5 Bulgaria - July 2010

EU Directives – applicable in Bulgaria as references for measurement, energy efficiency, and equipment standards:

2004/22/EC	Measuring instruments
2006/95/EC	Directive 2006/95/EC of the European Parliament and of the Council of 12 December 2006 on the harmonization of the laws of Member States relating to electrical equipment designed for use within certain voltage limits (codified version)
2000/55/EC	Energy efficiency requirements for ballasts for fluorescent lighting
96/57/EC	Energy efficiency requirements for household electric

	refrigerators, freezers and combinations thereof
92/42/EEC	Efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels
BDS EN 12261:2003	Gas flow meters
BDS EN 12261:2003/A1:2006	
BDS EN 12261:2003/AC:2003	
BDS EN 12405-1:2006	
BDS EN 12405-1:2006/A1:2006	
BDS EN 12480:2003	
BDS EN 12480:2003/A1:2006	
BDS EN 1359:2000	
BDS EN 1359:2000/A1:2006	
BDS EN 14154-1:2006+A1:2007	Water meters
BDS EN 14236:2009	Ultrasonic domestic gas meters
BDS EN 1434:2007	Heat meters
BDS EN 50470-1:2006	AC Electrical energy measurement
90/396/EC	Appliances burning gaseous fuels
87/404/EC	Simple pressure vessels
97/23/EC	Pressure equipment
92/75/EC	Energy labeling of household appliances
BDS EN 50294:1998/A2:2004	Lighting measurement
BDS EN 50294:2003	
BDS EN 50294:2003/A1:2003	

C-6 Czech Republic - September 2010

Referenced standards, procedures and guidelines should be replaced by European or Czech standards wherever necessary, legally required or practical. However other references in IPMVP are nevertheless informative. The most important Czech technical standards are as follows:

In the field of measuring and control tools and instruments:

ČSN 2500 In general
ČSN 2501 Verification of measuring instruments and measuring devices in general
ČSN 2502 Verification of certain measuring instruments and measuring devices
ČSN 2509 Measuring instrument accessories and record papers
ČSN 2570 Pressure gauges in general and accessories
ČSN 2572 Pressure gauges
ČSN 2574 Analyzing equipments
ČSN 2575 Volume measuring
ČSN 2576 Volumetric weight and density measuring
ČSN 2577 Liquid and gas flows in hollow sections measuring
ČSN 2578 Instruments for liquid and gas flows and quantities measuring
ČSN 2580 Thermometers in general, components
ČSN 2581 Glass liquid thermometers
ČSN 2582 Pressure-type thermometers, with contacts and for transformers
ČSN 2583 Thermocouple and resistance thermometers
ČSN 2585 Calorimeter and indicators for heating cost distribution

In the field of metrology:

ČSN 9921	Testing of ammeters, voltmeters, wattmeters
ČSN 9931	Glass thermometers
ČSN 9941	Weighing instruments
ČSN 9947	Mean absolute pressure measuring instruments
ČSN 9968	Gas flow-meters and gas volume-meters
ČSN 9971	Photometric measuring instruments
ČSN 9980	General provisions, nomenclature, symbols and units of measurement of physical-chemical properties of materials

Related to energy:

ČSN 01 1300	Legal units of measurement
ČSN 06 0210	Calculation of heat losses in buildings with central space heating
ČSN 07 0021	Hot water boilers
ČSN 07 0240	Hot water and low-pressure steam boilers
ČSN 07 0305	Evaluation of boiler losses
ČSN 07 0610	Heat exchangers water-water, steam-water
ČSN 10 5004	Compressors
ČSN 11 0010	Pumps
ČSN 12 0000	HVAC systems
ČSN 33 2000	Electrical regulations
ČSN 38 0526	Heat supply - principles
ČSN 38 5502	Gas fuels
ČSN 65 7991	Oil products, fuel oils
ČSN 73 0540	Thermal protection of buildings - parts 1, 2, 3, 4
ČSN 73 0550	Thermal properties of building structures and buildings – calculation methods
ČSN 73 0560	Thermal properties of building structures and buildings – industrial buildings
ČSN EN 835	Heat cost allocators for the determination of the consumption of room heating radiators - appliances without an electrical energy supply, based on the liquid evaporation principle
ČSN EN 834	Heat cost allocators for the determination of the consumption of room heating radiators. Appliances with electrical energy supply

Addition to Chapter 8.7, "Data for Emission Trading"

Verification of CO2 under the EU Emission Trading Scheme must follow the relevant binding procedures set by the EU and national authorities (Act No 695/2004 Coll., as updated).

C-7 Croatia - September 2010

Addition to Chapter 4.7 "Calibration"

Replace the first sentence with: "Meters should be calibrated as recommended by the equipment manufacturer, in a laboratory approved by the Croatian agency for metering (Hrvatski zavod za mjeriteljstvo) and with a valid certificate."

Addition to Chapter 9 "Definitions"

<u>Baseline energy</u> - at the end of definition add "Baseline energy consumption according to Croatian Law on efficient energy end-use" "Osnovna potrošnja energije prema Zakonu o učinkovitom korištenju energije u neposrednoj potrošnji"

Energy - at the end of definition add “See definition in Croatian Law on efficient energy end-use” “vidi definiciju u Zakonu o učinkovitom korištenju energije u neposrednoj potrošnji”

C-8 Poland - September 2010

Requirements for measurements and measuring instruments:

a. Ordinance of Minister of Economy on fundamental requirements for measuring instruments (Dz.U. 2007 nr 3 poz. 27; Law Gazette of 2007 No 3, item 27) and amendments (Dz.U. 2010 nr 163 poz. 1103; Law Gazette of 2010 No 163, item 1103).
b. Law amending law of measures (Dz.U. 2010 nr 66 poz. 421; Law Gazette of 2010 No 66, item 421).
c. Ordinance of Cabinet amending ordinance on legal units of measures (Dz.U. 2010 nr 9 poz. 61; Law Gazette of 2010 No 9, item 61)
d. Ordinances of the Minister of Economy on meter requirements, calculation units, and testing during legal metrology inspection for:
    - gas meters: Dz.U. 2008 nr 18 poz. 115; Law Gazette of 2008 No 18, item 115
    - true energy AC electricity meters: Dz.U. 2008 nr 11 poz. 63; Law Gazette of 2008 No 11, item 63
    - liquid flow meters, other than water: Dz.U. 2008 nr 4 poz. 23; Law Gazette of 2008 No 4, item 23.

APPENDIX D USERS OF IPMVP

Though the application of IPMVP is unique to each project, certain types of users will have similar methods in their *M&V Plans* and implementation. This appendix outlines some of the key ways this document may be used by the following user groups:

- Energy performance contractors and their building customers
- Energy performance contractors and their industrial process customers
- Energy users doing their own retrofits and wanting to account for *savings*
- Facility managers properly accounting for energy budget variances
- New building designers
- New building designers seeking recognition for the sustainability of their designs
- Existing building managers seeking recognition for the environmnetal quality of their building operations
- Utility demand side management program designers and managers
- Water efficiency project developers
- Emission reduction trading program designers
- Energy user's seeking ISO 50001 certification

This Appendix uses terms explained in Volume I Chapters as noted in brackets, or as defined in Chapter 9 for italicized words.

D-1 Energy-Performance Contractors and Their Building Customers

The primary purpose of *M&V* in the context of building *energy-performance contract*s is presenting the actual monetary performance of a retrofit project. The *M&V Plan* becomes part of the *energy-performance contract's* terms, and defines the measurements and computations to determine payments or demonstrate compliance with a guaranteed level of performance.

M&V costs may be controlled by considering the responsibilities of all parties to the contract. Where some parameters can be estimated with accuracy sufficient for all parties, Option A (Chapter 4.8.1) may be most economical. For example, a contractor undertaking to improve the efficiency of a chiller plant may simply be required to demonstrate the before and after retrofit chiller efficiency, without consideration of the ongoing energy use, which is driven by cooling loads that are not the contractor's responsibility. However if the contractor agrees to reduce chiller plant energy use, comparison of before and after chiller plant energy use would be required. In this latter case Option B (Chapter 4.8.2) would be used if chiller plant energy meters are used, or Option C (Chapter 4.9) if whole *facility* (utility) meters are used to measure total building energy performance.

Where the *energy-performance contract* focuses on total facility performance, or where it is difficult to evaluate the effects or several *ECMs*, Option C would be used. Care should be taken to ensure that the *M&V Plan* (Chapter 5) lists baseline *static factors* and assigns responsibility for their monitoring throughout the *reporting period*. However for new construction, Option D would be used (Chapter 4.10 or IPMVP Volume III Part I). Where central metering exists on a multiple building campus and no individual building meters are yet in place, Option D (Chapter 4.10) can be used, so that the retrofit does not have to be held up to obtain new sub-meter *baseline* data for a year before planning the retrofit.

Measurements may be made throughout the term of the *energy-performance contract* or for a contract defined test period shortly after retrofit. The longer the *reporting period* (Chapter 4.5.2), or the broader the *boundary of measurement* (Chapter 4.4), the more attention must be paid to the possibility of *baseline* change after retrofit. This possibility requires good advance recording of *static factors* in the *M&V Plan* and diligent monitoring of conditions after retrofit (Chapter 8.2).

The complexity of the *M&V* system's meter design (Chapters 4.8.3 and 8.11) and computations should also consider *M&V* costs, the expected magnitude of the *savings*, project economics and desired accuracy of reporting (Chapters 8.3 - 8.5, and Appendix B).

The prices used for monetizing the energy/water/demand units saved should be those established in the contract (Chapter 8.1).

Where an energy user feels it does not have the capability to review an *M&V Plan* or *savings* report, it may hire a verifier, separate from the *energy-performance contractor* (Chapter 8.6).

Appendix A contains examples IPMVP applications to buildings (Sections A-7, A-8, A-9, while A-2, A-3 and A-6 relate to technologies found in most buildings).

D-2 Energy-Performance Contractors and Their Industrial Customers

The primary purpose of *M&V* for industrial *energy-performance contact*s is usually to demonstrate the short-term performance of a retrofit project. Following such demonstration the plant management takes over responsibility for operation, and usually does not seek an ongoing relationship with an ESCO. The *M&V Plan* becomes part of the *energy performance contract* terms, and defines the measurements and computations to determine payments or demonstrate compliance with any guaranteed level of performance.

Industrial processes often involve complex relationships between energy use and a wider range of energy-governing variables than do buildings. In addition to weather, parameters such as product type, raw material variations, production rate and shift scheduling may be considered. Use caution selecting the *independent variables* to be used (Appendix B-2.1). The analysis becomes very difficult if attempting to identify savings at the main plant *energy* meters, especially if there is more than one product type being produced in the plant.

ECM-Isolation Options (Chapter 4.8) help to minimize the complications from production variables that are usually unrelated to terms of the performance contract. Retrofit Isolation narrows the *measurement boundary* to just those systems whose *energy* performance can be easily compared to production variables. The installation of isolation meters for *M&V* may also provide helpful feedback for process control.

M&V costs may be controlled by considering the responsibilities of all parties to the *energy-performance contract*. Where some parameters can be estimated with accuracy sufficient for all parties, Option A (Chapter 4.8.1) may be most economical. For example, a contractor who agrees to increase furnace <u>efficiency</u> may demonstrate the change in furnace energy use at peak load after installation of a flue gas heat recovery device. He is not responsible for ongoing energy use of the furnace, which is governed by production parameters beyond his control. However, if the contractor agrees instead to reduce furnace <u>energy use</u>, retrofitted furnace <u>energy use</u> is compared to the predicted energy requirements of the original furnace over a time period. In this latter case Option B (Chapter 4.8.2) governs the agreement if a meter measures the furnace's fuel consumption. Option C (Chapter 4.9) governs the agreement if main plant utility meters or departmental sub-meters measure total energy performance of the plant or a department within the plant.

Take care when using ECM-Isolation techniques to consider all energy flows affected by the *ECM* (Chapter 4.4), including *interactive effects*.

*Energy-performance contract*s in industrial plants often require measurements for a short *reporting period* after retrofit. Longer *reporting periods* (Chapter 4.5.2), or broader *boundaries of measurement* (Chapter 4.4), require more attention to possible *baseline* change after retrofit.

Good advance recording of *static factors* in the *M&V Plan* (Chapter 5) and diligent monitoring of conditions after retrofit (Chapter 8.2) will help identify *baseline* change.

Plant managers would normally employ long-term energy monitoring to continuously minimize energy waste. *Energy-performance contractors* may focus instead on short-term monitoring to demonstrate their performance (Chapter 4.5.2).

For retrofits that may be easily turned off temporarily, such as a heat recovery device, sequential short-term tests, which use the On/Off Test technique (Chapter 4.5.3), can demonstrate performance.

The complexity of the *M&V* system's meter design (Chapters 4.8.3 and 8.12) and computations should also consider *M&V* costs, the expected magnitude of the *savings*, project economics and desired accuracy of reporting (Chapters 8.3 - 8.5 and Appendix B).

The prices used for valuing the *savings* should be those established in the *energy performance contract* (Chapter 8.1).

The *energy* user may hire a verifier, separate from the *energy-performance contractor* (Chapter 8.6) when he or she lacks the ability to review an *M&V Plan* or *savings* report.

Appendix A contains examples of industrial applications of IPMVP (Sections A-4, A-5, while A-2, A-3.1 and A-6 relate to technologies found in most industrial plants).

D-3 Industrial and Building Energy Users Doing Their Own Retrofits

E*nergy* users often install ECMs themselves. When they are confident about achieving the planned *savings, a* 'no *M&V*' approach leaves the entire budget available for retrofits. However energy users may need to justify investments, add credibility to requests for future investments, or quantify uncertain performance.

M&V design issues would be similar to those described in Chapters 1.4.1. or 1.4.2, above, except that there is no division of responsibility between *energy* user and an *energy performance contractor*. Reporting costs may be lower because of less formal reporting.

D-4 Facility Managers Accounting For Energy/Water Budget Variances

To manage *energy* costs successfully, a *facility* manager should understand the relationship between *energy* use and *facility* operating parameters. Important operating parameters include occupancy, production rate, and weather. If a facility manager neglects these *independent variables*, he or she may struggle to explain variances from predicted *energy* budgets. He/she also risks future budgeting errors. *Baseline adjustments* are also necessary to account for non-routine changes at the *facility*.

Even if no *savings* are planned, the calculation techniques of Chapter 4 can help to explain *energy*-budget variances. Therefore, *M&V Plans* (Chapter 5) are useful with or without retrofits. Whole facility, Option C methods (Chapter 4.9), may be used, based on main (utility) meters or sub-meters for major sections of the facility. If sub-meters are in place on specific pieces of equipment (Chapter 4.8) they may help allocate costs to user departments or tenants within the *facility* (using Option A or B approaches).

Components critical to the variations in the overall *energy* budget may be isolated for separate metering of either their *energy* use (Option B, Chapter 4.8.2) or of a key parameter of *energy* use (Option A, Chapter 4.8.1). Both of these cases call for long-term metering. Pay close attention to the cost of maintaining and calibrating meters and managing data received from the meters (see Chapter 4.8.3 and 8.12).

D-5 New Building Designers

New building investors often wish to compare their performance to what it would have been if they had not included some specific *energy* efficiency features in the design. The absence of real *baseline* data normally requires the use of Option D (Chapter 4.10) to develop a *baseline*. The computer simulation skills needed to properly apply Option D might normally be on the design team at the time of design. However the critical element of Option D is the calibration of the simulation against data gathered after a one-year period. Therefore it is important to ensure that the simulation skills remain available until calibration is achieved.

Following the first year of steady operation it would be normal to use the actual *energy* data of the first steady year as a new *baseline,* switching to using Option C (Chapter 4.9) to determine changes from the first year's new *baseline*.

All the challenges for new buildings are addressed in more depth in IPMVP Volume III Part I, New Construction, including different methods for special situations.

D-6 New Building Designers Seeking Recognition for Their Sustainable Designs

Building designers may seek to have their designs recognized under a sustainable design program. To qualify, the building may need to have an *M&V* system that adheres to IPMVP. IPMVP adherence is defined in Chapter 7 as preparation of an *M&V Plan* (Chapter 5) using IPMVP terminology, and then following the *M&V Plan.*

The designer would also follow the guidance above in Chapter 1.4.5 and IPMVP Volume III Part I.

D-7 Existing Building Managers Seeking Recognition for the Environmental Quality of their Building Operations

Managers of existing buildings may seek recognition for the environmental quality of their operating methods. To qualify they may need to have an M&V system that adheres to IPMVP. IPMVP adherence is defined in Chapter 7 as preparation of an *M&V Plan* (Chapter 5) using IPMVP terminology and then following the *M&V Plan*. IPMVP's Retrofit Isolation type *M&V* (Chapter 4.8) may also assist in obtaining recogntion for the number of installed sub-meters.

Option C (Chapter 4.9) would provide the total facility performance monitoring that is appropriate to existing buildings. However if no whole building meters existed before seeking recogntion, Option D (Chapter 4.10) is needed during the period of developing a *baseline* for a year after main meters are initially installed on the building.

Building managers would also follow the guidance above in Chapter 1.4.3.

D-8 Regional Efficiency-Program Designers and Managers

Designers and managers of regional or utility-company demand-side-management (DSM) programs usually need to develop rigorous ways to evaluate the effectiveness of their energy-efficiency programs. One way to evaluate a DSM program's impact is to assess the *savings* made in randomly chosen end-user *facilities*. This data can be used to project the results across the entire group of DSM program participants. Use IPMVP Options presented in Chapter 4 to assess the *savings* in the sample *facilities*.

The evaluation design for any regional program should specify which of the IPMVP Options are allowable. It should also specify the minimum required sampling, measurement, and analytical accuracies, in order to provide sufficient rigor in program reporting.

Utilities already have the whole facility data for their commodity in their databases, so may apply Option C (Chapter 4.9) on all program participants or a sample of them. However without adequate knowledge of changes within each facility, a large percentage of variation in the *savings* should be expected, especially as time elapses between the *baseline* and *reporting periods*.

EVO is monitoring the needs of the utility program evaluation community. EVO is considering development of special M&V guidance for DSM program evaluation, and for establishing baselines for measuring the 'demand response' of customers receiving utility price or curtailment signals (see Preface – EVO's Future Plans).

D-9 Water-Efficiency Project Developers

Water-efficiency *M&V* is analogous to energy-efficiency *M&V*, so uses similar *M&V* techniques. The relevant technique for any project depends upon the nature of the change being evaluated, and upon the user's situation as discussed in Chapters 1.4.1 through 1.4.5 and 1.4.8.

Water-consuming equipment is often in the control of facility users (building occupants or production managers). Therefore it can be difficult to monitor user behavior as needed to make adjustments to total-facility water use for the application of Option C methods. Retrofit Isolation methods are often more easily applied (Chapter 4.8), using a sample of the retrofits (Appendix B-3) to demonstrate the performance of an entire group of changes.

Where outdoor water use is being evaluated, the adjustments term in IPMVP Equation 1 (Chapter 4) may be related to parameters that drive water use such as rainfall.

Liquid flow measurements devices (see Chapter 8.11, Table 5) are most commonly applied in *M&V* for water efficiency projects.

D-10 Emission Trading Programs

Energy-efficiency programs can be central to helping large energy users meet their regulated emission allocation. All of the techniques of this document help energy users manage their energy use, through proper accounting (Chapters 1.4.3 and 1.4.4).

Energy-efficiency projects may also be the basis of trades in emission-reduction commodities (credits, offsets, set asides, etc). Since such trades must hold up under public scrutiny, compliance with an industry recognized protocol adds credibility to emission reduction claims.

Trading-program designers should specify compliance with IPMVP, 2002 edition or later. They may go further and require fully measured energy-*savings* approaches (i.e. Options B or C, Chapters 4.8.2 or 4.9). This further specification reduces the uncertainty in the quantification by eliminating Options using estimated or simulated values rather than measured values.

Chapter 8.7 discusses the special *M&V* design issues for emission trades.

D-11 Energy Users Seeking ISO 50001 Certification

The management methods required under ISO 50001 focus on managing total facility utility costs. IPMVP's Options C and D (Chapters 4.9 and 4.10) describe methods useful for this purpose, even if no savings are being sought. However IPMVP cautions on the challenges of detecting small changes in whole facility utility energy use data. IPMVP offers both general guidance (Chapter 4.9) and specific guidance (Appendix B-1.2) on how large total facility energy use changes must be to be reportable with any statistical validity. If expected savings are not large enough, it would be appropriate to also use sub-meters for different sections of the facility. Also IPMVP's Retrofit Isolation Options A and/or B (Chapter 4.8) would also be appropriate management tools for specific energy efficiency projects. However Chapter 4.8 cautions that Retrofit Isolation results cannot be correlated with whole facility utility bills.

INDEX

EVO thanks its current Primary Subscribers:

BC Hydro

San Diego Gas & Electric Company

Southern California Edison

Gas Natural Fenosa

Schneider Electric

Services Industriels de Genève - SIG