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Concepts and Options for Determining Energy and Water Savings (M&V Protocol)

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International Performance Measurement & Verification Protocol

Concepts and Options for Determining Energy and Water Savings
Volume I

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Table of Contents

DISCLAIMER

This Protocol serves as a framework to determine energy and water savings resulting from the implementation of an energy efficiency program. It is also intended to help monitor the performance of renewable energy systems and to enhance indoor environmental quality in buildings. The IPMVP does not create any legal rights or impose any legal obligations on any person or other legal entity. IPMVP has no legal authority or legal obligation to oversee, monitor or ensure compliance with provisions negotiated and included in contractual arrangements between third persons or third parties. It is the responsibility of the parties to a particular contract to reach agreement as to what, if any, of this protocol is included in the contract and to ensure compliance.

Chapter 1 Introduction

1.1 Overview

Energy efficiency offers the largest and most cost-effective opportunity for both industrialized and developing nations to limit the enormous financial, health and environmental costs associated with burning fossil fuels. Available, cost-effective investments in energy and water efficiency globally are estimated to be tens of billions of dollars per year. However, the actual investment level is far less, representing only a fraction of the existing, financially attractive opportunities for energy savings investments. In the interest of brevity, throughout this document the terms "energy" and "energy savings" represent both energy and water. Although there are differences between energy efficiency measures and water efficiency measures, they share many common attributes and are often part of the same project.

If all cost-effective efficiency investments were made public and commercial buildings in the U.S., for example, efficiency project spending would roughly triple, and within a decade would result in savings of $20 billion per year in energy and water costs, create over 100,000 permanent new jobs and significantly cut pollution. For developing countries with rapid economic growth and surging energy consumption, energy and water efficient design offers a very cost effective way to control the exploding costs of building power and water treatment plants, while limiting the expense of future energy imports and the widespread health and environmental damages and costs that result from burning fossil fuels.

These efficiency opportunities and their inherent benefits prompted the U.S. Department of Energy in early 1994 to begin working with industry to develop a consensus approach to measuring and verifying efficiency investments in order to overcome existing barriers to efficiency. The International Performance Measurement and Verification Protocol (IPMVP, or sometimes called the MVP) was first published in 1996, and contained methodologies that were compiled by the technical committee that comprised of hundreds of industry experts, initially from the United States, Canada and Mexico.

In 1996 and 1997, twenty national organizations from a dozen countries worked together to revise, extend and publish a new version of the IPMVP in December 1997. This second version has been widely adopted internationally, and has become the standard M&V documents in countries ranging from Brazil to Romania. According to Mykola Raptsun, former Deputy Chairman of State Committee of Ukraine Energy Conservation, now President of ARENA-ECO, the Ukrainian energy efficiency center:

The IPMVP has broad application for businessmen, energy managers, law makers and educators and could become the national standard document for M&V. It has been important in helping the growth of the energy efficiency industry in Ukraine.

North America’s energy service companies have adopted the IPMVP as the industry standard approach to measurement and verification (M&V).

According to Steve Schiller, President of Schiller Associates, a leading energy efficiency consulting firm:

[In the United States], *referencing the International Performance Measurement and Verification Protocol (IPMVP) has become essentially a requirement associated with developing both individual energy efficiency performance contracting projects as well as performance contracting programs. Almost all performance-contracting firms now state that their work complies with the IPMVP Thus, in a few short years the IPMVP has become the de- facto protocol for measurement and verification of performance contracts.*

Institutions such as the World Bank and International Finance Corporation (IFC) have found the Protocol beneficial and are incorporating it as a required part of new energy efficiency projects. According to Russell Sturm, Senior Projects Officer, Environmental Projects Unit, International Finance Corporation:

"In our work at the Environmental Projects Unit of the IFC, we seek investments in the emerging ESCO markets of the developing and transition economies of the world. While these markets hold promise, the challenges on the road to commercial viability are formidable. IPMVP provides the foundation necessary to build credibility for this emerging industry, helping us to establish a level of comfort among local players that is essential for broadbased acceptance in the marketplace."

The IPMVP has been translated into Bulgarian, Chinese, Czech, Japanese, Korean, Polish, Portuguese, Romanian, Russian, Spanish and Ukrainian. The translated versions of the IPMVP in some of these languages are available through the website www.ipmvp.org.

As a result of strong and widespread interest, participation in developing this third edition has expanded to include a global network of professionals from around the world and includes national organizations from 16 countries and hundreds of individual experts from more than 25 nations. The work was drafted by volunteers serving on committees composed of leading international experts in their respective fields. Overall responsibility and direction is provided by the Executive Committee, composed of a dozen international experts who share a goal of strengthening and fostering the rapid growth of the energy and water efficiency industries. Our Financial Advisory Subcommittee has helped ensure that this document is valuable to the financial community in facilitating and enhancing efficiency investment financing.

1.2 Why Measure And Verify?

"You cannot manage what you do not measure" - Jack Welch, CEO of General Electric

When firms invest in energy efficiency, their executives naturally want to know how much they have saved and how long their savings will last. The determination of energy savings requires both accurate measurement and replicable methodology, known as a measurement and verification protocol.

The long-term success of energy and water management projects is often hampered by the inability of project partners to agree on an accurate, successful M&V Plan. This M&V Protocol discusses procedures that, when implemented, help buyers, sellers and financiers of energy and water projects to agree on an

M&V Plan and quantify savings from Energy Conservation Measure (ECM) and Water Conservation Measure (WCM).

Simply put, the purpose of the IPMVP is to increase investment in energy efficiency and renewable energy. The IPMVP does so in at least six ways:

a) Increase energy savings

Accurate determination of savings gives facility owners and managers valuable feedback on the operation of their facility, allowing them to adjust facility management to deliver higher levels of energy savings, greater persistence of savings and reduced variability of savings. A growing body of data shows that better measurement and verification results in significantly higher levels of savings, greater persistence of savings over time and lower variability of savings (Kats et al. 1997 and 1999, Haberl et al. 1996). Logically this makes sense, since real time measurement at multiple measurement points provides a strong diagnostic tool for building managers that allows them to better understand, monitor and adjust energy systems to increase and maintain savings. This finding is consistent with the experience of the US Federal Energy Management Programs and reflects the very extensive long term *metering*[1] work done at the Texas A&M University Loan Star program (Claridge et al. 1996). Greater persistence and lower variability, in turn, can form the technical basis for rewarding energy efficiency projects which employ superior M&V techniques for determining energy savings.

b) Reduce cost of financing of projects

In early 1994, our financial advisors expressed concern that existing protocols (and those under development) created a patchwork of inconsistent and sometimes unreliable efficiency installation and measurement practices. This situation reduced reliability and performance of efficiency investments, increased project transaction costs, and prevented the development of new forms of lower cost financing. IPMVP is a response to this situation, providing guidance on risk management information helpful in structuring project financing contracts.

By providing greater and more reliable savings and a common approach to determining savings, widespread adoption of this Protocol has already made efficiency investments more reliable and profitable, and has fostered the development of new types of lower cost financing. By more clearly defining project M&V and defining generally accepted M&V methods, this Protocol provides lending institutions confidence in the credible assessment of savings and measurement of performance. This assessment and measurement then becomes the security which backs financing. If a sufficient level of confidence can be achieved, the door may be opened to "off-balance-sheet financing" where project debt does not appear on the credit line of the host facility - historically a major hurdle to energy efficiency project implementation.

The IPMVP is an important part of the credit equation for most lenders since it provides an established and independent mechanism to determine energy

1. The terms in italics are defined in Chapter 6.1

savings. For example, the US Department of Energy's Office of Energy Efficiency and Renewable Energy, in partnership with Virginia's Commonwealth Competition Council and New Jersey-based M/A Structured Finance Corp. has developed a pilot program for a $50 million pooled financing program for energy efficiency projects for K-12 schools and publicly owned colleges and universities. The goal of the program is to provide an off-balance sheet and procurement-friendly method of financing these projects for the public sector. The guidelines in the IPMVP have allowed participating financial institutions to lend on the basis of the energy savings, an important consideration in an off-balance sheet financing.The IPMVP provides the confidence and standardization to allow these institutions to fund upgrades based on future pooled energy savings, with borrowing "off-balance sheet" for the academic institutions.

c) Encourage better project engineering

Since good M&V practices are intimately related to good design of retrofit projects, IPMVP's direction on M&V practice encourages the good design of energy management projects. Good M&V design, and ongoing *monitoring* of performance will help in the creation of projects that work effectively for owners and users of the spaces or processes affected. Good energy management methods help reduce maintenance problems in facilities allowing them to run efficiently. Among the improvements that may be noted by complete engineering design of ECMs is an improvement in indoor air quality in occupied space.

d) Help demonstrate and capture the value of reduced emissions from energy efficiency and renewable energy investments.

Emissions reduced by efficiency projects include CO_2, the primary greenhouse gas (causing global warming), SO_2, NOx and mercury. The failure to include the costs/benefits of these emissions has distorted price and market signals, and has resulted in a misallocation of energy investments and prevented a more rational and cost-effective energy investment strategy around the world. Determining the level of reduction of pollutants requires the ability to estimate with confidence actual energy savings.

The IPMVP provides a framework for calculating energy reductions before (baseline) and after the implementation of projects. The IPMVP can help achieve and document emissions reductions from projects that reduce energy consumption and help energy efficiency investments be recognized as an emission management strategy. Such profile will also help attract funding for energy efficiency projects through the sale of documented emission credits.

e) 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 activities. Such public acceptance encourages investors to consider investing in energy efficiency projects or the emission credits they may create. By enhancing savings, good M&V practice also brings more attention to the public benefits provided by good energy management, such as improved community health, reduced environmental degradation, and increased employment.

f) Help national and industry organizations promote and achieve resource efficiency and environmental objectives

The IPMVP is being widely adopted by national and regional government agencies and by industry and trade organizations to help increase investment in energy efficiency and achieve environmental and health benefits. Chapter 1.4 provides examples of how the IPMVP is being used by a range of institutions in one country - the United States.

1.2.1 Role of Protocol

This Protocol:

- Provides energy efficiency project buyers, sellers and financiers a common set of terms to discuss key M&V project-related issues and establishes methods which can be used in energy performance contracts.
- Defines broad techniques for determining savings from both a "whole facility" and an individual technology.
- Applies to a variety of facilities including residential, commercial, institutional and industrial buildings, and industrial processes.
- Provides outline procedures which i) can be applied to similar projects throughout all geographic regions, and ii) are internationally accepted, impartial and reliable.
- Presents procedures, with varying levels of accuracy and cost, for measuring and/or verifying: i) baseline and project installation conditions, and ii) long-term energy savings.
- Provides a comprehensive approach to ensuring that building indoor environmental quality issues are addressed in all phases of ECM design, implementation and maintenance.
- Creates a living document that includes a set of methodologies and procedures that enable the document to evolve over time.

1.2.2 Audience for Protocol

The target audience for this Protocol includes:

— Facility Energy Managers
— Project Developers and/or Implementers
— ESCOs (Energy Service Companies)
— WASCOs (Water Service Companies)
— Non-Governmental Organizations (NGOs)
— Finance Firms
— Development Banks
— Consultants
— Government Policy Makers

— Utility Executives
— Environmental Managers
— Researchers

1.3 IPMVP Role In International Climate Change Mitigation

International efforts to reduce greenhouse gas emissions have also increased the need for standardized tools such as the IPMVP, to cost-effectively measure the economic and environmental benefits of energy efficiency projects. The vast majority of climate scientists have concluded that "the balance of evidence suggests that human activities are having a discernible influence on global climate" (IPCC, 1995). Responding to the mounting scientific call for action to reduce emissions of greenhouse gases (primarily those from fossil fuel use), the industrialized nations recently committed to binding emissions targets and timetables. The flexible, market mechanisms to reduce greenhouse gas emissions included in the 1997 Kyoto Protocol to the U.N. Framework Convention on Climate Change (FCCC) makes the need for an international consensus on M&V protocol more urgent.

Guidelines have recently been developed by the Lawrence Berkeley National Laboratory that addresses the monitoring, evaluation, reporting, verification, and certification of energy efficiency projects for climate change mitigation (Vine and Sathaye, 1999). The LBNL study determined that the IPMVP is the preferred international approach for monitoring and evaluating energy efficiency projects because of its international acceptance, because it covers many key issues in monitoring and evaluation and because it allows for flexibility.

The IPMVP Adjustment Committee will be working through 2000 to build on the leading intentional consensus approach to implementing, measuring and verifying efficiency investments to come up with agreed on estimates of future energy savings and emissions reductions. By achieving agreement on this issue, this committee will make a necessary and important contribution to establishing a framework on which international greenhouse gas trading can be built. For more information, contact Ed Vine (elvine@lbl.gov).

1.4 Relationship to U.S. Programs

The MVP is intended to include a framework approach that complements more detailed national, or regional energy efficiency guidelines in any country that it is used in. Following are the examples drawn from the US.

ASHRAE Guideline 14

IPMVP is complemented by the work of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) in the form of its draft Guideline 14P Measurement of Energy and Demand Savings. In contrast to the ASHRAE document, which focuses at a very technical level, the IPMVP establishes a general framework and terminology to assist buyers and sellers of M&V services. ASHRAE’s Guideline 14 has completed its first public review and hence was available publicly for a period in the middle of 2000. The ASHRAE Guideline is expected to be fully available in 2001. It is advised that the reader use the ASHRAE or other relevant document, as well as others referenced herein, to help formulate a successful M&V Plan.

Federal Energy Management Program

The U.S. Department of Energy's Federal Energy Management Program (FEMP) was established, in part, to reduce energy costs to the U.S. Government from operating Federal facilities. FEMP assists Federal energy managers by identifying and procuring energy-saving projects.

The FEMP M&V Guideline follows the IPMVP, and provides guidance and methods for measuring and verifying the energy and cost savings associated with federal agency performance contracts. It is intended for federal energy managers, federal procurement officers, and contractors implementing performance contracts at federal facilities. Assistance is provided on choosing M&V methods that provide an appropriate level of accuracy for protection of the project investment. The FEMP M&V Guideline has two primary uses:

- It serves as a reference document for specifying M&V methods and procedures in delivery orders, requests for proposals (RFPs), and performance contracts.
- It is a resource for those developing project-specific M&V plans for federal performance contracting projects.

The first FEMP M&V Guideline was published in 1996, a new version has been published in 2000, Version 2.2, and contains the following updates to the 1996 version:

- A discussion of performance contracting responsibility issues and how they affect risk allocation.
- Quick M&V guidelines including procedural outlines, content checklists, and option summary tables.
- Measure-specific guidelines for assessing the most appropriate *M&V Option* for common measures.
- New M&V strategies and methods for cogeneration, new construction, operations and maintenance, renewable energy systems, and water conservation projects.

In addition to being a requirement for efficiency investments in U.S. Federal buildings, the FEMP Guideline provides a model for how to develop a specific application of the IPMVP. To secure a copy of the FEMP guideline, call 800-DOE-EREC.

State Performance Contracting Programs

Many states in the US have incorporated the IPMVP as an important part of a number of their energy efficiency programs and services for commercial, industrial and institutional customers. They use IPMVP as the basis of determining energy savings in energy performance contracting. IPMVP has been valuable in standardizing project performance metrics and has become an important component for facilitating wider acceptance of energy performance contracts that can reduce private sector transaction costs. IPMVP has helped cut transactions costs, improve project performance and has been important in securing low cost financing for our programs. Many states require that M&V Plans be developed for projects funded under the Standard Performance Contract Program. The New York State EnVest program, for example, is structured to be consistent with IPMVP and New York State Energy Research & Development Authority (NYSERDA) strongly recommends the use of IPMVP for institutional projects.

Other states which have incorporated IPMVP in state energy performance contracting and other energy efficiency programs are California, Colorado, Oregon, Texas, and Wisconsin.

Environmental Evaluation Initiatives in Buildings.

The IPMVP is being integrated into the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED") Rating system, which is rapidly becoming the national green building design standard.

The USGBC-developed LEED" program provides a comprehensive green building rating system. In order to win a rating, a building must comply with several measures, including the IPMVP, for energy efficiency and water measures. Buildings are then rated on a range of environmental and life cycle issues to determine if the building achieves one of the LEED" performance levels. Applicants to LEED" will receive a point for complying with the IPMVP. For more information, please visit their website at www.usgbc.org.

Chapter 2 The Importance of M&V in Financing Energy and Water Efficiency

2.1 Financing Energy and Water Efficiency

The key to unlocking the enormous potential for energy and water efficiency worldwide is securing financing. Good measurement practices and verifiability are some of the important elements in providing the confidence needed to secure funding for projects. Securing financing requires confidence that energy efficiency investments will result in a savings stream sufficient to make debt payments. Measurement and verification practices allow project performance risks to be understood, managed, and allocated among the parties.

It is important that each M&V Plan clearly describe the tolerances associated with the measurement and savings determination methods. There can be significant variances in the tolerances within each of the measurement options presented in this protocol. Users are advised to understand the pros and cons of each option and the tolerance of the particular measurement method proposed. Each participant is then equipped to make an appropriate business decision about the risk and reward of an investment.

Energy and water efficiency projects meet a range of objectives, including upgrading equipment, improving performance, helping to achieve environmental compliance, or simply saving energy and money. All projects have one thing in common, an initial financial investment. The type of investment may be an internal allocation of funds (in-house project) or it may be a complex contractual agreement with an ESCO and/or third-party financier.

All types of financial investments have a common goal - making money or a "return" on investment. Rate of return is measured by various financial yardsticks such as simple payback, return on investment (ROI) or internal rate of return (IRR). The expected rate of return is governed by the risk associated with the investment. Typically, the higher the project risk, the greater the return demanded. Risk takes a variety of forms in efficiency projects. Most risks can be measured; it is the accuracy of the measurement (tolerance) that is important. Many risks associated with investing in an energy or water efficiency project can be measured using tools common to the finance industry, such as internal rate of return or customer credit-worthiness. M&V, as defined in this Protocol, is primarily focused on risks that affect the measurement or determination of savings from energy or water efficiency programs. These risks are defined in the terms of the contracts between the participants.

This Protocol provides guidance on obtaining information needed to reduce and manage measurement uncertainties in order to structure project financing contracts. The value of ECM performance data can range from useful to absolutely critical, depending on the financing method and which party has accepted the contractual risk. For example, an ESCO typically will not be concerned about operating hours if the owner takes responsibility for equipment operation, though these risks should be highlighted and understood by the parties. Different investments require different measures of performance.

Accordingly, this Protocol provides four M&V Options to accommodate a variety of contractual arrangements.

Although this Protocol formalizes basic M&V language and techniques, it is not meant to prescribe an M&V Option for every type of ECM. Instead, this document offers Options available, provides guidance on which Option to choose and helps clarify the relationship of various M&V Options to the risks assumed by relevant parties, and thus places bounds on the financial risks of the deal.

2.2 Definition and Role of Performance Contracts

When efficiency projects include a guarantee of performance, it is classified as a performance contract. It is important to recognize that there are two separate instruments in such transactions - the lending instrument and the guarantee. The lending takes place between the financier and the owner, or the ESCO. The guarantee is typically provided to the owner by the ESCO. Usually it guarantees the amount of energy that will be saved at some defined pricing level, and/or that energy savings will be sufficient to meet the financing payment obligations. However a guarantee may be as simple as a piece of equipment that is capable of operating at a stated level of efficiency ("rating of performance").

There are many types of financing in use with performance contracts. This Protocol does not recommend any particular approach, because the choice depends on many considerations beyond the scope of M&V disciplines. The availability of third-party financing in general, however, and the variety of applicable financial instruments, is growing. Those seeking financing of projects with measurable and verifiable savings should have no difficulty obtaining expert advice from more than one specialist, at least in the U.S.

Energy savings are commonly defined as reductions in energy use. Energy cost savings are reductions in the cost of energy and related O&M expenses, from a base cost established through a methodology set forth in an energy performance contract. (Energy saving activities may also reduce other costs such as pollution/health care costs through lowering of atmospheric emissions from boilers.) "Energy savings" and "energy cost savings" when defined in a performance contract are typically contractual terms.

Performance of equipment, both before and after a retrofit, can be measured with varying degrees of accuracy. Savings are often computed as energy cost avoidance and are the calculated difference between i) the measured performance and/or load of of energy-using systems and ii) the amount of energy that the systems would have used in the absence of the ECM, such difference being multiplied by current unit prices for energy supplied. The *baseyear*[1] energy usage is defined using measured equipment performance data prior to the ECM coupled with assumptions about how that equipment would have operated in the *post-retrofit period*. Often, baseyear assumptions must incorporate expected and/or unforeseen changes that may alter the energy savings calculation. In these cases, the contract defines which party is responsible for the elements of the ECM that lead to energy savings and cost avoidance.

1. The terms in italics are defined in Chapter 6.1

Broadly speaking, energy efficiency projects have two elements, performance and operation:

- performance of the project is related to its efficiency, defined with a metric such as improvements in lumens/watt or in tons of cooling per kW of demand.
- operation of the project is related to its actual usage, defined as operation hours, ton hours etc.

Typically, an ESCO is responsible for the performance of any equipment or systems it installs. Depending on the energy performance contract, either the ESCO or the Owner may be responsible for the operation of the equipment. It is important to allow for changes in equipment operation that may result from factors outside either party's control, such as weather. Responsibility for maintenance may be assigned to either party or shared. Consider four categories of variables that account for all of the changes that might affect energy cost avoidance:

1 ESCO-controlled variables - retrofit performance
2 Owner-controlled variables - facility characteristics, operation
3 ESCO and/or owner controlled variable - maintenance
4 Variables that are outside of either party's control - weather, energy prices, natural disaster

The M&V Plan should clearly identify these variables for all ECMs before the project is implemented. The M&V process requires the skills of professionals familiar with measurement and collection techniques, data manipulation, interpretation, and technology performance. In some circumstances, it may be preferable that a third party be obtained by the owner to judge whether energy performance contract terms are appropriate and, later, are being applied correctly. In order to adequately understand the implications of various measurement strategies, the M&V professional should have a thorough understanding of the ECMs being installed and the services provided.

2.3 Financial Risk Measurement

When creating financed energy efficiency project agreements, the parties enter into a contract defining and allocating risk among the parties. Generally, the lender will be looking for the most straight forward allocation of risks. In financing efficiency projects, most risks (beyond general creditworthiness of the parties) relate to one basic issue: will the project perform to expectation? Performance related risks that are scattered among several participants may make project financing more difficult. Usually, the lender wants the risk of performance to be between the ESCO and the owner only, acting as "Consultant" to the the owner. It is diffecult for a lender to assess creditworthiness if payments can be impacted by a variety of parties. In such cases the lender will price the financing to the creditworthiness of the lowest common denominator.

2.3.1 Ability to Pay

Debt service coverage, which is the ratio of the projected cash savings to repayment amount, is a critical measure of the project's financial viability. It serves as an indicator of the project's ability to be supported solely by the savings. When coverage falls below a certain level, (125% for example), the project will be subject to increased scrutiny by financiers. Most important to the calculation of coverage is the confidence with which savings are estimated and ultimately measured (or stipulated).

2.3.2 Construction Risks

Terms (risks) embodied in common construction contracts are also present in a financed energy efficiency project, if construction financing is used. (Often permanent financing is initiated after construction is finished and accepted.) Basic risks and questions include:

- Who is responsible for the design? Who builds what, by when?
- Who pays whom, how much and when?
- What cost overruns are likely, what contingencies are in the construction budget, and what recourse does the financier have in event of overruns?
- What is the maximum construction delay, what can cause it and how can it be cured.

Performance bonds cover the risk associated with the first item for both owners and lenders. Escrow and progress payment contracts cover risks associated with the second item. Lenders are interested in liquidated damage provisions and payment and performance bonds as a way to limit potential losses from construction delays.

2.3.3 Performance Risks

As discussed in Chapter 2.2, when an *energy savings performance contract* is used, capturing the effect of "change" is particularly important. For example, consider which party estimated the savings and which party carries the financial impact of: i) a change in operating hours, ii) a change in weather, iii) a degradation in chiller efficiency, iv) a change that requires compliance with new or existing standards, v) a partial facility closure, vi) an expansion to a third production shift, vii) quality of maintenance, etc. The financial impact of these changes can be either positive or negative. The contract must be clear who wins or loses. For example, an ESCO may not get credit for the savings created by actions of the owner. Similarly an ESCO should not be required to cover the higher costs incurred due to the owner's increased or decreased usage outside the parameters of the project; e.g, a new computer lab or, fewer shifts worked.

Energy savings estimates are usually based on an assumption that the facility will operate on a predicted schedule, or load profile. Changes to this schedule will affect project generated savings. Assignment of responsibility for these changes is a critical contract component. As well, these are all risks that need to be evaluated by each party in advance and accounted for using performance measurement as specified using an appropriate M&V method. Often these are examined in detail after implementation, when it is too late. For example, an executed contract may stipulate that the owner is responsible for the operating hours of a lighting system, and the ESCO is responsible for ensuring that the system power draw is correct. For this contract, Option A M&V method (as introduced in Chapter 3.4.1) is appropriate. Cost avoidance is calculated using a stipulated value for operating hours and the measured change in the power draw of the lighting system.

Chapter 3 Basic Concepts and Methodology

3.1 Introduction

Energy or demand savings are determined by comparing measured energy use or demand before and after implementation of an energy savings program. In general:

$$\text{Energy Savings} = \text{Baseyear Energy Use} - \text{Post-Retrofit Energy Use} \pm \text{Adjustments} \qquad \text{Eq. 1}$$

The "Adjustments" term in this general equation brings energy use in the two time periods to the same set of conditions. Conditions commonly affecting energy use are weather, occupancy, plant throughput, and equipment operations required by these conditions. Adjustments may be positive or negative.

Adjustments are derived from identifiable physical facts. The adjustments are made either routinely such as for weather changes, or as necessary such as when a second shift is added, occupants are added to the space, or increased usage of electrical equipment in the building.

Adjustments are commonly made to restate baseyear energy use under post-retrofit conditions. Such adjustment process yields savings which are often described as "avoided energy use" of the post-retrofit period. The level of such savings are dependent on post-retrofit period operating conditions.

Adjustments may also be made to an agreed fixed set of conditions such as those of the baseyear or some other period. The level of savings computed in this situation is unaffected by post-retrofit period conditions, but reflects operation under a set of conditions which must be established in advance.

There are many other considerations and choices to make in determining savings. Chapter 3.4 describes four basic Options, any one of which may be adapted to a particular savings determination task. Chapter 4 gives guidance on common issues such as balancing costs and accuracy with the value of the energy savings program being evaluated. Chapter 5 reviews metering and instrumentation issues.

3.2 Basic Approach

Proper savings determination is a necessary part of good design of the savings program itself. Therefore the basic approach in savings determination is closely linked with some elements of program design. The basic approach common to all good savings determination entails the following steps:

1 Select the IPMVP Option (see Chapter 3.4) that is consistent with the intended scope of the project, and determine whether adjustment will be made to post-retrofit conditions or to some other set of conditions. (These fundamental decisions may be written into the terms of an energy performance contract.)

2 Gather relevant energy and operating data from the baseyear and record it in a way that can be accessed in the future.

3. Design the energy savings program. This design should include documentation of both the design intent and methods to be used for demonstrating achievement of the design intent.
4. Prepare a Measurement Plan, and a Verification Plan if necessary, (commonly together called an "M&V Plan"). The M&V Plan fundamentally defines the meaning of the word "savings" for each project. It will contain the results of steps 1 through 3 above, and will define the subsequent steps 5 through 8 (see Chapter 3.3).
5. Design, install and test any special measurement equipment needed under the M&V Plan.
6. After the energy savings program is implemented, inspect the installed equipment and revised operating procedures to ensure that they conform with the design intent defined in step 3. This process is commonly called "commissioning." ASHRAE defines good practice in commissioning most building modifications (ASHRAE 1996).
7. Gather energy and operating data from the post-retrofit period, consistent with that of the baseyear and as defined in the M&V Plan. The inspections needed for gathering these data should include periodic repetition of commissioning activities to ensure equipment is functioning as planned.
8. Compute and report savings in accordance with the M&V Plan.

Steps 7 and 8 are repeated periodically when a savings report is needed.

Savings are deemed to be statistically valid if the result of equation (1) is greater than the expected variances (noise) in the baseyear data. Chapter 4.2 discusses some methods of assessing this noise level. If noise is excessive, the unexplained random behavior of the facility is high and the resultant savings determination is unreliable. Where this criterion is not expected to be met, consideration should be given to using more independent variables in the model, or selecting an IPMVP Option that is less affected by unknown variables.

The balance of this document fleshes out some key details of this basic approach to determining savings.

Once a savings report has been prepared, a third party may verify that it complies with the M&V Plan. This third party should also verify that the M&V Plan itself is consistent with the objectives of the project.

3.3 M&V Plan

The preparation of an M&V Plan is central to proper savings determination and the basis for verification. Advance planning ensures that all data needed for proper savings determination will be available after implementation of the energy savings program, within an acceptable budget.

Data from the baseyear and details of the ECMs may be lost over time. Therefore it is important to properly record them for future reference, should conditions change or ECMs fail. Documentation should be prepared in a fashion that is easily accessed by verifiers and other persons not involved in its development, since several years may pass before these data are needed.

An M&V Plan should include:

- A description of the ECM and its intended result.
- Identification of the boundaries of the savings determination. The boundaries 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 buildings. The nature of any energy effects beyond the boundaries should be described and their possible impacts estimated.
- Documentation of the facility's *baseyear conditions* and resultant *baseyear energy data*. In performance contracts, baseyear energy use and baseyear conditions may be defined by either the owner or the ESCO, providing the other party is given adequate opportunity to verify it. A preliminary energy audit used for establishing the objectives of a savings program or terms of an energy performance contract is typically not adequate for planning M&V activities. Usually a more comprehensive audit is required to gather the baseyear information relevant to M&V:

  — energy consumption and demand profiles

  — occupancy type, density and periods

  — space conditions or plant throughput for each operating period and season. (For example in a building this would include light level and color, space temperature humidity and ventilation. An assessment of thermal comfort and/or indoor air quality (IAQ) may also prove useful in cases where the new system does not perform as well as the old inefficient system. See Volume II.)

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

  — equipment operating practices (schedules and setpoint, actual temperatures/pressures)

  — significant equipment problems or outages.

  The extent of the information to be recorded is determined by the boundaries or scope of the savings determination. The baseyear documentation typically requires well documented audits, surveys, inspections and/or spot or short-term metering activities. Where whole building Option is employed (Chapter 3.4.3 or Chapter 3.4.4), all building equipment and conditions should be documented.
- Identification of any planned changes to conditions of the baseyear, such as night time temperatures.
- Identification of the post-retrofit period. This period may be as short as a one minute test following commissioning of an ECM, or as long as the time required to recover the investment cost of the ECM program.
- Establishment of the set of conditions to which all energy measurements will be adjusted. The conditions may be those of the post-retrofit period or some other set of fixed conditions. As discussed in the introductory remarks of Chapter 3, this choice determines whether reported savings are "avoided costs" or energy reductions under defined conditions.
- Documentation of the design intent of the ECM(s) and the commissioning procedures that will be used to verify successful implementation of each ECM.

- Specification of which Option from Chapter 3.4 will be used to determine savings.
- Specification of the exact data analysis procedures, algorithms and assumptions. For each mathematical model used, report all of its terms and the range of independent variables over which it is valid.
- Specification of the metering points, period(s) of metering, meter characteristics, meter reading and witnessing protocol, meter commissioning procedure, routine calibration process and method of dealing with lost data.
- For Option A, report the values to be used for any stipulated parameters. Show the overall significance of these parameters to the total expected saving and describe the uncertainty inherent in the stipulation.
- For Option D, report the name and version number of the simulation software to be used. Provide a paper and electronic copy of the input files, output files, and reference the weather files used for the simulation, noting which input parameters were measured and which assumed. Describe the process of obtaining any measured data. Report the accuracy with which the simulation results match the energy use data used for calibration.
- Specification of quality assurance procedures.
- Quantification of the expected accuracy associated with the measurement, data capture and analysis. Also describe qualitatively the expected impact of factors affecting the accuracy of results but which cannot be quantified.
- Specification of how results will be reported and documented. A sample of each report should be included.
- Specification of the data that will be available for another party to verify reported savings, if needed.
- Where the nature of future changes can be anticipated, methods for making the relevant non-routine *Baseline Adjustments*[1] should be defined.
- Definition of the budget and resource requirements for the savings determination, both initial setup costs and ongoing costs throughout the post-retrofit period.

When planning a savings measurement process, it is helpful to consider the nature of the facility’s energy use pattern, and the ECM s impacts thereon. Consideration of the amount of variation in energy patterns and the change needing to be assessed will help to establish the amount of effort needed to determine savings. The following three examples show the range of scenarios that may arise.

- **ECM reduces a constant load without changing its operating hours.** Example: Lighting project where lamps and ballasts in an office building are changed, but the operating hours of the lights do not change.
- **ECM reduces operating hours while load is unchanged.** Example: Automatic controls shut down air handling equipment or lighting during unoccupied periods.

1. The terms in italics are defined in Chapter 6.1

- **ECM reduces both equipment load and operating hours.** Example: Resetting of temperature on hot water radiation system reduces overheating, thereby reducing boiler load and operating periods.

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

It is important to realistically anticipate costs and effort associated with completing metering and data analysis activities. Time and budget requirements are often underestimated leading to incomplete data collection. It is better to complete a less accurate and less expensive savings determination than to have an incomplete or poorly done, yet theoretically more accurate determination that requires substantially more resources, experience and/or budget than available. Chapter 4.11 addresses cost/benefit tradeoffs.

Typical contents of four M&V Plans are outlined in the four examples shown in Appendix A.

3.4 Methods

The Energy Use quantities in Equation 1 can be "measured" by one or more of the following techniques:

- Utility or fuel supplier invoices or meter readings.
- Special meters isolating a retrofit or portion of a facility from the rest of the facility. Measurements may be periodic for short intervals, or continuous throughout the post-retrofit period.
- 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 factored together to compute the equipment's energy use.
- Computer simulation which is calibrated to some actual performance data for the system or facility being modeled, e.g., DOE-2 analysis for buildings.
- Agreed assumptions or stipulations of ECM parameters that are well known. The boundaries of the savings determination, the responsibilities of the parties involved in project implementation, and the significance of possible assumption error will determine where assumptions can reasonably replace actual measurement. For example, in an ECM involving the installation of more efficient light fixtures without changing lighting periods, savings can be determined by simply metering the lighting circuit power draw before and after retrofit while assuming the circuit operates for an agreed period of time. This example involves stipulation of operating periods, while equipment performance is measured.

The Adjustments term in equation (1) can be of two different types:

- **Routine** Adjustments for changes in parameters that can be expected to happen throughout the post-retrofit period and for which a relationship with energy use/demand can be identified. These changes are often seasonal or cyclical, such as weather or occupancy variations. This protocol defines four basic Options for deriving routine adjustments. Table 1 summarizes the various Options.

- **Non-routine** Adjustments for changes in parameters which cannot be predicted and for which a significant impact on energy use/demand is expected. Non-routine adjustments should be based on known and agreed changes to the facility. Chapter 4.8 presents a general approach for handling non-routine adjustments, commonly called "baseline adjustments.

Table 1: Overview of M&V Options

M&V Option	How Savings Are Calculated	Typical Applications
A. Partially Measured Retrofit Isolation Savings are determined by partial field measurement of the energy use of the system(s) to which an ECM was applied, separate from the energy use of the rest of the facility. Measurements may be either short-term or continuous. Partial measurement means that some but not all parameter(s) may be stipulated, if the total impact of possible stipulation error(s) is not significant to the resultant savings. Careful review of ECM design and installation will ensure that stipulated values fairly represent the probable actual value. Stipulations should be shown in the M&V Plan along with analysis of the significance of the error they may introduce.	Engineering calculations using short term or continuous post-retrofit measurements and stipulations.	Lighting retrofit where power draw is measured periodically. Operating hours of the lights are assumed to be one half hour per day longer than store open hours.
B. Retrofit Isolation Savings are determined by field measurement of the energy use of the systems to which the ECM was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.	Engineering calculations using short term or continuous measurements	Application of controls to vary the load on a constant speed pump using a variable speed drive. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor. In the baseyear this meter is in place for a week to verify constant loading. The meter is in place throughout the post-retrofit period to track variations in energy use.
C. Whole Facility Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken throughout the post-retrofit period.	Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis.	Multifaceted energy management program affecting many systems in a building. Energy use is measured by the gas and electric utility meters for a twelve month baseyear period and throughout the post-retrofit period.
D. Calibrated Simulation Savings are determined through simulation of the energy use of components or the whole facility. Simulation routines must be 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 and/or end-use metering.	Multifaceted energy management program affecting many systems in a building but where no baseyear data are available. Post-retrofit period energy use is measured by the gas and electric utility meters. Baseyear energy use is determined by simulation using a model calibrated by the post-retrofit period utility data.

Options A and B focus on the performance of specific ECMs. They involve measuring the energy use of systems affected by each ECM separate from that of the rest of the facility. Option C assesses the energy savings at the whole facility level. Option D is based on simulations of the energy performance of equipment or whole facilities to enable determination of savings when baseyear or post-retrofit data are unreliable or unavailable.

An example of the use of each of the four Options is contained in Appendix A.

3.4.1 Option A: Partially Measured Retrofit Isolation

Option A involves isolation of the energy use of the equipment affected by an ECM from the energy use of the rest of the facility. Measurement equipment is used to isolate all relevant energy flows in the pre-retrofit and post-retrofit periods. Only partial measurement is used under Option A, with some parameter(s) being stipulated rather than measured. However such stipulation can only be made where it can be shown that the combined impact of the plausible errors from all such stipulations will not significantly affect overall reported savings.

3.4.1.1 Option A: Isolation Metering

Measurement equipment must be used to isolate the energy use of the equipment affected by the ECM from the energy use of the rest of the facility. The isolation metering should reflect the boundary between equipment which the ECM affects and that which it does not affect. For example, a lighting load reduction often has a related impact on HVAC system energy use, but the boundary for measurement may be defined to encompass only the lighting electricity. However if the boundary of the savings determination encompasses HVAC effects, measurement or stipulation will be required for both the lighting and HVAC energy flows.

Chapter 5 discusses metering issues.

3.4.1.2 Option A: Measurement vs. Stipulation

Some, but not all parameters of energy use may be stipulated under Option A. The decision of which parameters to measure and which to stipulate should consider the significance of the impact of all such stipulations on the overall reported savings. The stipulated values and analysis of their significance should be included in the M&V Plan (See Chapter 3.2).

Stipulation may be based on historical data, such as recorded operating hours from the baseyear. Wherever a parameter is not measured in the facility for the baseyear or post-retrofit period it should be treated as a stipulated value and the impact of possible error in the stipulation assessed relative to the expected savings.

Engineering estimates or mathematical modeling may be used to assess the significance of stipulation of any parameter in the reported savings. For example if a piece of equipment's operating hours are considered for stipulation, but may be between 2,100 and 2,300 hours per year, the estimated savings at 2,100 and 2,300 hours should be computed and the difference evaluated for its significance to the expected savings. The impact of all such possible stipulations should be totaled before determining whether sufficient measurement is in place.

The selection of factor(s) to measure may also be considered relative to the duties of a contractor undertaking some ECM performance risk. Where a factor is significant to assessing a contractor's performance, it should be measured, while other factors beyond the ESCO's control should be considered for stipulation.

3.4.1.3 Installation Verification

Since stipulation is allowed under this Option, great care is needed to review the engineering design and installation to ensure that the stipulations are realistic and achievable, i.e. the equipment truly has the potential to perform as assumed.

At defined intervals during the post-retrofit 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 stipulations. The frequency of these re-inspections can be determined by the likelihood of change. 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 savings determination involving the sampling of the performance of fixtures and a count of the number of fixtures. In this case the continued existence of the fixtures and lamps is critical to the savings determination. Therefore periodic counts of the number of fixtures in place with all lamps burning would be appropriate. Similarly, where the performance of controls equipment is assumed but subject to being overridden, regular inspections or recordings of control settings are critical to limiting the uncertainty created by the stipulations.

3.4.1.4 Option A: Measurement Interval

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 post-retrofit 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.

If less than continuous measurement is used, the location of the measurement and the exact nature 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. Lighting fixtures provide an example of constant power flow, assuming they have no dimming capability. However lighting operating periods may not be constant, for example outdoor lighting controlled by a photocell operates for shorter periods in seasons of long daylight than in seasons of short daylight. Where a parameter may change seasonally, such as this photocell case, measurements should be made under appropriate seasonal conditions.

Where a parameter may vary daily or hourly, as in most heating or cooling systems, continuous metering may be simplest. However for weather dependent loads, measurements may be taken over a long enough period to adequately characterize the load pattern (i.e., weekday/weekend and weather-dependent characteristics of the load) and repeated as necessary through the post-retrofit 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).

3.4.1.5 Option A: Sampling

Where multiple versions of the same installation are included within the boundaries of a savings determination, statistically valid samples may be used as valid measurements of the total parameter. Such situation may arise, for example, where individual light fixtures are measured before and after retrofit to assess their power draw, while the total lighting power draw cannot be read at the electrical panel due to the presence of non-lighting loads on the same panel. Providing that a statistically significant sample of fixtures is measured before and after ECM installation, these data may be used as the 'measurement' of total lighting power draw. Appendix B discusses the statistical issues involved in sampling.

3.4.1.6 Option A: Uncertainty

Chapter 4.2 reviews the general issues surrounding uncertainty of savings determination. However, specific factors driving the uncertainty of Option A methods are:

- The magnitude of effects beyond the boundary of the retrofit isolation. For example, the significance of the mechanical cooling energy associated with a reduction in lighting power depends on the length of the mechanical cooling season and the number of hours of operation of the cooling equipment each day.
- The significance of the error introduced by possible variations between the stipulated and true values of parameters. This uncertainty is controlled through careful review of the ECM design, careful inspection of its implementation after installation and periodically thereafter.
- The variability in the measured parameters, if less than continuous measurement is employed. This uncertainty can be minimized through periodic measurements made frequently enough at the outset of the project to adequately characterize the variability.
- The degree to which the measured sample represents all components of an ECM

Savings uncertainty under Option A is generally inversely proportional to the complexity of the ECM and variability of operations in both the baseyear and post-retrofit period. Thus, the savings from a simple lighting retrofit may typically be more accurately determined with Option A than the savings from a chiller retrofit, since lighting stipulations may have less uncertainty.

3.4.1.7 Option A: Cost

Savings determinations under Option A can be less costly than under other Options, since the cost of deriving a stipulation may be less than the cost of making measurements. However in some situations where stipulation is the only possible route, the derivation of a good stipulation may require more cost than direct measurement. Cost of retrofit isolation should consider all elements:

proper meter installation, commissioning and maintenance, proper stipulation analysis, and the ongoing cost to read and record data.

Portable meters may be used so that their costs can be shared with other objectives. However, meters which are permanently installed may be useful in the facility to provide feedback to operating staff or automated control equipment for optimization of systems or billing of special users.

Savings determination cost is driven by the complexity of the ECM and the number of energy flows crossing the boundary of the ECM or retrofit isolation.

Cost is also driven by the frequency of measurement, whether continuous or periodic. Annual costs should be expected to be highest at the beginning of the post-retrofit period. At this stage in a project measurement processes are being refined, and closer monitoring of performance is needed to optimize ECM operation. Some projects may cease reporting savings after a defined "test" period, though metering may be left in place for real time feedback to operating staff.

The appropriate cost for each savings determination should be determined in proportion to the expected savings their potential variability.

3.4.1.8 Option A: Best Applications

Option A is best applied where:

- the performance of only the systems affected by the ECM is of concern, either due to the responsibilities assigned to the parties in a 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 between ECMs or with other facility equipment can be measured or assumed to be not significant.
- isolation of the ECM from the rest of the facility and stipulation of key factors may avoid possibly difficult non-routine Baseline Adjustments for future changes to the facility.
- the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.
- submeters already exist to isolate energy use of systems.
- meters added for isolation purposes will be used for other purposes such as operational feedback or tenant billing.
- the uncertainty created by stipulations is acceptable.
- the continued effectiveness of the ECM can be assessed by routine visual inspection of stipulated parameters.
- stipulation of some parameters is less costly than measurement of them in Option B or simulation in Option D.

3.4.2 Option B: Retrofit Isolation

The savings determination techniques of Option B are identical to those of Option A except that no stipulations are allowed under Option B. In other words, full measurement is required.

Short term or continuous metering may be used under Option B. Continuous metering provides greater certainty in reported savings and more data about equipment operation. These data can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit 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).

Option B involves full measurement of the impact of the ECM. Therefore there is less need to verify the potential to perform than in Option A. The suggested installation verifications of Chapter 3.4.1.3 may be relaxed by eliminating ongoing re-inspections after the commissioning inspection.

The savings created by most types of ECMs can be determined with Option B. However, the degree of difficulty and costs associated with verification increases proportionately as metering complexity increases. Option B methods will generally be more difficult and costly than Option A. However Option B may produce less uncertain results where load and savings patterns are variable. Additional costs may be justifiable if a contractor is responsible for all aspects of ECM effectiveness.

ASHRAE's Guideline 14P is expected to provide technical details on a similar method (ASHRAE 2000).

3.4.2.1 Option B: Best Applications

Option B is best applied where:

- the performance of only the systems affected by the ECM is of concern, either due to the responsibilities assigned to the parties in a 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 between ECMs or with other facility equipment can be measured or assumed to be immaterial.
- isolation of the ECM from the rest of the facility may avoid possibly difficult non-routine Baseline Adjustments for future changes to the facility.
- the independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.
- submeters already exist to isolate energy use of systems.
- meters added for isolation purposes will be used for other purposes such as operational feedback or tenant billing.
- measurement of parameters is less costly than simulation in Option D.

3.4.3 Option C: Whole Building

Option C involves use of utility meters or whole building sub-meters to assess the energy performance of a total building. Option C assesses the impact of any type of ECM, but not individually if more than one is applied to an energy meter. This Option determines the collective savings of all ECMs applied to the part of the facility monitored by the energy meter. Also, since whole building meters are used, savings reported under Option C include the impact of any other changes made in facility energy use (positive or negative).

Option C may be used in cases where there is a high degree of interaction between installed ECMs or between ECMs and the rest of the building, or the isolation and measurement of individual ECM(s) is difficult or too costly.

This Option is intended for projects where savings are expected to be large enough to be discernible from the random or unexplained energy variations that are normally found at the level of the whole facility meter. The larger the saving, or the smaller the unexplained variations in the baseyear, the easier it will be to identify savings. Also the longer the period of savings analysis after ECM installation, the less significant is the impact of short term unexplained variations. Typically savings should be more than 10% of the baseyear energy use if they are to be separated from the noise in baseyear data.

Periodic inspections should be made of all equipment and operations in the facility after ECM installation. These inspections will identify changes from baseyear conditions or intended operations. Accounting for changes (other than those caused by the ECMs) is the major challenge associated with Option C - particularly when savings are to be monitored for long periods. See also Chapter 4.8 on Baseline Adjustments.

ASHRAE's Guideline 14P is expected to provide technical details on a similar method (ASHRAE 2000).

3.4.3.1 Option C: Energy Data

Each energy flow into a building is measured separately by the utility or energy supplier. Where utility supply is only measured at a central point in a campus style facility, sub-meters are needed at each building or group of buildings on campus for which individual building performance is to be assessed.

Several meters may be used to measure the flow of one energy type into a building. To the extent any meter supplies energy use to a system that interacts with other energy systems directly or indirectly, it must be included in the whole building savings determinations. Meters serving non-interacting energy flows for which savings are not to be determined can be ignored, such as separately metered outdoor lighting circuits. If several different meters are read on separate days, then each meter having a unique billing period should be separately analyzed. The results can be combined after each individual analysis.

Savings should be determined separately for each meter or sub-meter serving a building so that performance changes can be assessed for separately metered parts of the facility. Where a meter measures 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 so combined, it should be recognized that small consumption meters often do not have demand data associated with them so the totalized consumption data will no longer provide meaningful load factor information.

If energy data are missing from the post-retrofit period, a post-retrofit model can be created to fill in missing data. However the reported savings for the period should identify the report as "estimated."

Where changes to electric demand represent a significant amount of the calculated cost savings, the utility bill recorded demand may not be an adequate source of data due to the difficulties of deriving accurate models from single monthly demand readings. In this situation, the time of utility meter peaking must be known for each month so that the special demand recording equipment can be synchronized with the utility's resetting of the demand. Also the minimum time step for any demand recording meter should match the utility's demand time interval (see Chapter 5.2).

3.4.3.2 Option C: Energy Invoices

Energy data are often derived from utility meters, either through direct reading of the meter, or from utility invoices. Where utility bills are the source of energy use data, it should be recognized that a utility's needs for accuracy in meter reading may not be the same as that of savings determination. Utility bills can contain estimated data, especially for small accounts. Sometimes it cannot be determined from the bill itself that data come from an estimate rather than a meter reading. Unreported estimated meter readings create unknown errors for the month(s) of the estimate and the subsequent month when an actual reading is made. However the first bill with an actual reading after one or more estimates will correct the previous errors in energy quantities. When the fact of an estimate is shown on a utility bill, the associated savings report should reflect this fact.

Where electrical meter estimates are made, no valid data exist for electrical demand.

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

3.4.3.3 Option C: Independent Variables

Characteristics of a facility's use or the environment which govern energy consumption are called independent variables. Common independent variables are weather and occupancy. Weather has many dimensions, but for whole building analysis weather is most often just outdoor temperature and possibly humidity depending upon the climate of the facility. Occupancy may be defined in many ways, such as: hotel room occupancy factor, office building core occupancy hours or maximum hours, number of occupied days (weekdays/weekends), or restaurant sales.

To the extent that independent variables have a cyclical nature to them, the significance of their impact on energy use can be assessed through mathematical modeling. Parameters found to have a significant effect in the baseyear period should be included in the routine adjustments when applying equation (1) for determining savings. Parameters having a less predictable but potentially significant effect should be measured and recorded in the baseyear conditions and post-retrofit periods so that non-routine baseline adjustments can be made if needed (see Chapter 4.8)

Independent variables should be measured and recorded at the same time as the energy meters. For example, weather data should be recorded daily so it can be totaled to correspond with the exact monthly energy metering period which may be different from the calendar month. Monthly mean temperature data for a non-calendar month would introduce unnecessary error into the model.

The number of independent variables to consider in the model of the baseyear data can be determined by regression analysis and other forms of mathematical modeling (Rabl 1988, Rabl and Rialhe 1992, ASHRAE 1997, Fels 1986, Ruch and Claridge 1991, Claridge et al. 1994).

3.4.3.4 Option C: Data Analysis and Models

The adjustment term of equation (1) under Option C is calculated by developing a valid model of each meter's baseyear energy use and/or demand. A model may be as simple as an ordered list of twelve actual baseyear monthly electrical demands without any adjustment factors. However they can often be a set of factors derived from regression analysis correlating energy use to one or more parameters such as *degree days*, metering period length, occupancy, and building operating mode (summer/winter). Models can also involve several sets of regression parameters each valid over a defined range of conditions such as ambient temperature, in the case of buildings, since buildings often use energy differently in different seasons.

Option C usually requires 12, 24, or 36 (i.e., one full year or multiple years) of continuous baseyear daily or monthly energy data, and continuous data during the post-retrofit period (Fels 1986) since models with more or less data (i.e., 13, 14, 15 or 9,10, 11 months) can cause the regression to have a statistical bias. Meter data can be hourly, daily or monthly whole-building data. Hourly data should be aggregated at least to the daily level to control the number of independent variables required to produce a reasonable model of the baseyear, without significant impact on the uncertainty in computed savings (Katipamula 1996, Kissock et al. 1992). Scatter found in daily data is often attributable to the weekly cycle of most facilities.

Many models appropriate for Option C are possible. To select the one most suited to the application, statistical evaluation indices should be considered, such as R^2 or *CV (RMSE)* (see Appendix B). 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 (1997).

Statistical validity of the selected model should be assessed and demonstrated by reference to published statistical literature.

In certain types of facilities (such as schools) where there is a significant difference between the facility's energy use during the school year and summer break, separate *regression models* may need to be developed for different usage periods (Landman and Haberl 1996a; 1996b).

3.4.3.5 Option C: Computation of Routine Adjustments

The following steps are used to calculate the Adjustments term in Equation 1 for Option C.

1 Develop the appropriate model for the baseyear energy data and selected significant driving conditions (see Chapter 3.4.3.2 and Chapter 3.4.3.3).

2 Insert the post-retrofit period's independent variables (e.g. ambient temperature, metering period length) into the baseyear model from 1, above. This process derives the energy use that would have happened under post-retrofit conditions if the ECM had not been installed. (Note if some other set of conditions is selected for reporting savings (Chapter 3) the independent

variables for this set of conditions would be used in place of the post-retrofit independent variables.)

3 Subtract the baseyear's energy use from the result of 2, above, for each month.

3.4.3.6 Option C: Cost

The cost of Option C methods depends on whether the energy data come from utility bills or other special whole building meters. If such special whole building sub-meters were in place anyway there may be no extra cost, providing they are properly read, recorded and maintained. The primary cost elements in Option C are i) utility bill or data management and running of the model with each month's utility data, and ii) tracking and adjusting for conditions which change after the baseyear.

3.4.3.7 Option C: Best Applications

Option C is best applied where:

- the energy performance of the whole facility is to be assessed, not just the ECMs.
- there are many different types of ECMs in one building.
- the ECMs involve diffuse activities which cannot easily be isolated for the rest of the facility, such as operator training or wall and window upgrades.
- the savings are large enough to be separated from noise in the baseyear data during the time of monitoring.
- interactive effects between ECMs or with other facility equipment is substantial making isolation techniques of Options A and B excessively complex.
- major future changes to the facility are not expected during the period of savings determination. A system of tracking key operating conditions can be established to facilitate possible future non-routine Baseline Adjustments.
- reasonable correlations can be found between energy use and other independent variables

3.4.4 Option D: Calibrated Simulation

Option D involves the use of computer simulation software to predict facility energy use for one or both of the energy use terms in Equation 1. Such *simulation model* must be "calibrated" so that it predicts an energy use and demand pattern that reasonably matches actual utility consumption and demand data from either the baseyear or a post-retrofit year.

Option D may be used to assess the performance of all ECMs in a facility, akin to Option C. However, different from Option C, multiple runs of the simulation tool in Option D allow estimates of 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 Chapter 3.4.1.1.

Option D is useful where:

- Baseyear energy data do not exist or are unavailable. Such situation may arise for a new facility containing particular energy efficiency measures needing to be assessed separately from the rest of the facility. It may also arise in a centrally metered campus of facilities where no individual facility meter exists in the baseyear period, but where individual meters will be available after ECM installation.
- Post-retrofit energy use data are unavailable or obscured by factors whose influence will be difficult to quantify. For example, such situation may arise where it would be too difficult to assess the impact of future facility usage changes that might significantly affect energy use. Industrial process changes or uncontrolled significant equipment additions often make the computation of future significant baseline adjustments so imprecise that the error in savings determination is excessive.
- The expected energy savings are not large enough to be separated from the facility's utility meter using Option C.
- It is desired to determine the savings associated with individual ECMs but Options A or B isolation and measurements are too difficult or costly.

If the post-retrofit energy use is predicted by the simulation software, the determined savings are actually maintained only if the simulated operating methods are maintained. Periodic inspections should be made of all equipment and operations in the facility after ECM installation (see Chapter 3.4.1.3). These inspections will identify changes from baseyear conditions and variances from modeled equipment performance.

The adjustments term in equation (1) is computed by running the simulation model under appropriate sets of conditions as needed to bring the two energy use terms to a common set of conditions.

Accurate computer modeling and calibration to measured 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:

1 Simulation analysis needs to be conducted by trained personnel who are experienced with the particular software and calibration techniques.

2 Input data should represent the best available information including as much as possible of actual performance data from key components in the facility.

3 The simulation needs to be adjusted ("calibrated") so its results match both the demand and consumption data from monthly utility bills within acceptable tolerances. The use of actual weather data may be necessary in cases where the actual weather data varies significantly from the average year weather data used in the simulation. Close agreement between predicted and actual annual total energy use is usually insufficient demonstration that the simulation adequately predicts the energy behavior of the facility.

4 Simulation analyses need to be well documented with paper and electronic copies of input and output files as well as the survey and metering/monitoring data used to define and calibrate the model. The particular version number of the software should be declared if it is publicly

available so that any other party can fully review the many computations within the simulation.

ASHRAE's Guideline 14P is expected to provide technical details on a similar method (ASHRAE 2000).

3.4.4.1 Option D: Types of Simulation Programs

Information on the different types of building simulation models can be found in the ASHRAE Handbook (1997). DOE also maintains a current list of public domain and proprietary building energy simulation programs. This information can be obtained by accessing DOE's information server at www.eren.doe.gov/buildings/tools_directory.

Whole building simulation programs usually involve hourly calculation techniques. However techniques using ASHRAE's simplified energy analysis procedure may also be used if the building heat losses/gains, internal loads and HVAC systems are simple. ASHRAE's procedure features modified bin methods and simplified HVAC system models.

Many other types of special purpose programs may be used to simulate energy use and operating conditions of individual components or industrial processes. HVAC component models are available from ASHRAE in its HVAC02 toolkit (Brandemuehl 1993), and for boiler/chiller equipment in the 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).

Any software used must be well documented and well understood by the user.

3.4.4.2 Option D: Calibration

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

Calibration is achieved by verifying that the simulation model reasonably predicts the energy use of the facility by comparing model results to a set of calibration data. This calibration data should at a minimum be measured energy consumption and demand data, for the portion of the facility being simulated. Calibration of building simulations is usually done with 12 monthly utility bills. The calibration data set should be documented along with a description of its source(s).

Other operating data from the facility can be used as simulation input data as part of the calibration data set. These data might include operating characteristics and profiles of key variables such as use and occupancy, weather, known loads, equipment operating periods and efficiency. Some variables may be measured for short intervals, recorded for a day week or month, or extracted from existing operating logs. Accuracy of measurement equipment should be verified for critical measurements. If resources permit, actual building ventilation and infiltration should be measured since these quantities often vary widely from expectations. Snap-shot measurements will significantly improve simulation accuracy. Where resources are limited, on/off tests can be used to determine snap-shot end-use measurements of lighting, receptacle plug loads and motor control centers. These tests can be performed over a weekend using a data logger or EMCS to record whole-building electricity use, usually at one-minute intervals, and in some instances with inexpensive portable loggers that are synchronized to a common time stamp (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 shown below.

1 Assume other input parameters and document them.
2 Verify that the simulation predicts reasonable operating results such as space or process temperature/ humidity.
3 Compare simulated energy and demand results with metered data, on an hourly or monthly basis. Use actual weather data when conditions vary significantly from average year weather data. Assess patterns in the differences between simulation and calibration data. Bar charts, monthly percent difference time-series graphs and monthly x-y scatter plots give visual presentations which aid the identification of error patterns.
4 Revise assumed input data in step 1 and repeat steps 2 and 3 to bring predicted results reasonably close to actual energy use and demand. More actual operating data from the facility may also be needed to improve the calibration.

Buildings types which may not be easily simulated include those with:

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

Some building ECMs cannot be simulated without great difficulty, such as:

- addition of radiant barriers in an attic, and
- HVAC system changes not enabled by the fixed options within some whole-building hourly simulation programs.

The creation and calibration of a simulation can be time consuming. The use of monthly data for calibration is usually less costly than hourly calibration. Calibrations based on monthly utility data can achieve an approximate mean bias error (MBE) of ±20% compared to monthly energy use. Hourly calibrations can achieve ±10% to ±20% CV (RMSE) of hourly energy use, or ±1% to ±5% of the monthly utility bill.

3.4.4.3 Option D: Best Applications

Option D is best applied where:

- either baseyear or post-retrofit energy data unavailable or unreliable.
- there are too many ECMs to assess using Options A or B.
- the ECMs involve diffuse activities which cannot easily be isolated for the rest of the facility, such as operator training or wall and window upgrades.

- the impact of each ECM on its own is to be estimated within a multiple ECM project and the costs of Options A or B are excessive.
- interactive effects between ECMs or with other facility equipment is complex making isolation techniques of Options A and B excessively complex.
- major future changes to the facility are expected during the period of savings determination and no realistic means can be found to track or account for their energy impact.
- an experienced energy simulation professional is available and adequately funded for gathering suitable input data and calibrating the simulation model.
- the facility and the ECMs can be modeled by well documented simulation software, and reasonable calibration can be achieved against actual metered energy and demand data.

3.5 Adherence with IPMVP

The IPMVP is a framework of definitions and methods for assessing energy savings. The IPMVP framework was designed to allow users to develop an M&V plan for a specific project. The IPMVP was written to allow maximum flexibility in creating M&V plans that meet the needs of individual projects, but also adhere to the principles of accuracy, transparency and repeatability. In the case where users are required to demonstrate adherence, or wish to claim adherence with the IPMVP, the following issues should be addressed.

- The two parties should identify the organization/person responsible for M&V activities. This organization/person should be responsible for approving the site-specific M&V plan, and making sure that the M&V plan is followed for the duration of the contract.
- The M&V plan should clearly state which IPMVP Option (or combination of Options) and methods (linear regression, multiple regression, bin method etc.) will be used to determine the energy savings.
- The two parties should agree on a site-specific plan that specifies the metering/monitoring to be conducted. The plan should clearly state how the baseyear energy use and baseyear conditions are to be established including: what measurements are to be taken, how the data are to be used, what variables are to be stipulated and the basis for stipulation. The plan should provide information on the metering equipment, its calibration, the location of measurements, duration of the metering period, accuracy of the measurement process, etc.
- The M&V plan should specify the details of how calculations should be made by stating the variables (run-time hours, electrical consumption in a lighting fixture, kW/ton, etc.) that should be measured and any associated assumptions.
- The two parties should agree on how quality assurance should be maintained and replicability confirmed.
- The M&V plan should list the reports to be prepared, their contents and formats, and a stipulated time frame during which they should be furnished.
- All terminology should be consistent with IPMVP definitions.

Chapter 4 Common Issues[1]

4.1 Factors Affecting Savings Performance

Many factors affect the performance of equipment and achievement of savings. Depending upon the scope of the savings determination (its boundaries), the range of parameters of concern can be very focused (specific ECMs) or as wide as the whole facility.

Parameters that are predictable and measurable can be used for routine adjustments in Equation 1 of Chapter 3. Such adjustments reduce the variability in reported savings, or provide a greater degree of certainty in reported savings. Unpredictable parameters within the boundaries of a savings determination may require future non-routine Baseline Adjustments (e.g. future loss of tenants). Unmeasured parameters give rise to savings fluctuations for which no adjustment can be computed, only guessed (e.g. air infiltration rate).

Therefore, when planning an M&V process, consideration should be given to 1) predictability, 2) measurability and 3) likely impact of all plausible factors in each category below:

- Weather
- Occupancy level, schedule
- Installed equipment intensity, schedule
- Occupant or user demand for services (e.g. space temperature, plant throughput)
- Ability of the ECM as designed to achieve the intended savings
- ECM implementation effectiveness in meeting the design intent
- Occupant or operator cooperation in using ECM related equipment in accordance with direction
- Occupant or operator cooperation in using non-ECM related equipment in accordance with direction
- Equipment deterioration, both ECM related equipment and non-ECM related
- Equipment life, both ECM and non-ECM related

4.2 Evaluating Savings Uncertainty

The effort undertaken in determining savings should focus on managing the uncertainty created in the determination process. ECMs with which the facility staff are familiar may require less effort than other, uncommon ECMs.

The savings determination process itself introduces uncertainties through

- Instrumentation Error
- Modeling Error

1. Common issues arising when using the Options laid out in Chapter 3 are discussed in this Section. Measurement issues are in Chapter 5.

- Sampling Error
- Planned and Unplanned assumptions

Methods of quantifying the first three errors are discussed in Appendix B. As used in this protocol, sampling error concerns do not refer to rigorous statistical procedures, but to the best practices as addressed in Appendix B.See also Reddy & Claridge (2000) that applies standard error analysis methods to the typical savings determination scenario.

The last category of error above, encompasses all the unquantifiable errors associated with stipulations, and the assumptions necessary for measurement and savings determination.

It is feasible to quantify many but not all dimensions of the uncertainty in savings determination. Therefore when planning an M&V process, consideration should be given to quantifying the quantifiable uncertainty factors and qualitatively assessing the unquantifiable. The objective is to consider all factors creating uncertainty, either qualitatively or quantitatively.

The accuracy of a savings estimate can be improved in two general ways. One is by reducing biases, by using better information or by using measured values in place of assumed or stipulated values. The second way is by reducing random errors, either by increasing the sample sizes, using a more efficient sample design or applying better measurement techniques. In most cases, improving accuracy by any of these means increases M&V cost. Such extra cost should be justified by the value of the improved information (see Chapter 4.11).

Quantified uncertainty should be expressed in a statistically meaningful way, namely declaring both accuracy and confidence levels. For example, "The quantifiable error is found, with 90% confidence, to be +20%." A statistical precision statement without a confidence level is meaningless since accuracy can sound very good if the confidence level is low.

The appropriate level of accuracy for any savings determination is established by the concerned parties. Appendix B discusses some issues in establishing a level of uncertainty.

For buildings, one or more full years of energy use and weather data should be used to construct regression models. Shorter periods introduce more uncertainty through not having data on all operating modes. The best predictors of both cooling and heating annual energy use are models from data sets with mean temperatures close to the annual mean temperature. The range of variation of daily temperature values in the data set seems to be of secondary importance. One month data sets in spring and fall, when the above condition applies, can be better predictors of annual energy use than five month data sets from winter and summer.

The required length of the metering or monitoring period depends on the type of ECM. If, for instance, the ECM affects a system that operated according to a well-defined schedule under a constant load, such as a constant-speed exhaust fan motor, the period required to determine annual savings could be quite short. In this case, short-term energy savings can be easily extrapolated to the entire year. However, if the project's energy use varies both across day and seasons, as with air-conditioning equipment, a much longer metering or monitoring period may be required to characterize the system. In this case, long-term data are used to determine annual energy savings.

If the energy consumption of the metered equipment or systems varies by more than ten percent from month to month, additional measurements must be taken at sufficient detail and over a long enough period of time to identify and document the source of the variances. Any major energy consumption variances due to seasonal production increases or periodic fluctuations in occupancy or use must also be tracked and recorded.

4.3 Minimum Energy Standards

When a certain level of efficiency is required either by law or the owner's standard practice, savings may be based on the difference between the post-retrofit energy use and the minimum standard. In these situations, baseyear energy use may be set equal to or less than the applicable minimum energy standards. 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 residential, commercial and Federal building codes.

4.4 Minimum Operating Conditions

An energy efficiency program should not compromise the operations of the facility to which it is applied without the agreement of the facility users, whether building occupants or industrial process managers. Therefore the M&V Plan should record the agreed conditions that will be maintained (see Chapter 3.3).

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

4.5 Energy Prices

Energy cost savings may be calculated by applying the price of each energy or demand unit to the determined savings. The price of energy should be the energy provider s rate schedule or an appropriate simplification thereof. Appropriate simplifications use marginal prices which consider all aspects of billing affected by metered amounts, such as consumption charges, demand charges, transformer credits, power factor, demand ratchets, early payment discounts.

An example of the energy cost savings calculation is contained in Appendix A (Option D).

4.6 Verification by a Third Party

Where the firm performing the energy savings determinations has more experience than the owner, the owner may seek assistance in reviewing savings reports. Such assistance should begin at the time of first review of the M&V Plan, to ensure that the design for the savings determination process will meet the owner's objectives. The review should continue with the routine savings reports and baseline adjustments. Full review of baseline adjustments requires good understanding of the facility and it operations. For this latter purpose, owner summaries of operating conditions will reduce the scope, work and cost of the third party verifier.

An energy performance contract requires that both parties believe the information on which the payments are based is valid and accurate. An experienced third party may be helpful to ensure agreement of measurement validity. Should conflicts arise over the course of the project payback period, this third party can help to resolve differences.

Third party savings verifiers are typically engineering consultants with experience and knowledge in verifying ECM savings, ECM technologies and, where relevant, energy performance contracting. Many are members of industry professional societies, though there is not yet any accreditation program for M&V professionals.

4.7 Data for Emission Trading

The IPMVP has already been recognized as valuable in some regions for verifying savings and securing financial benefits allowed under emissions trading programs, and is expected to be a part of an international trading regime. Application of this Protocol can provide increased confidence in the measurement of actual energy savings, and therefore provide greater confidence in determining associated reductions in emissions. It is becoming an important element in international greenhouse gas emission mitigation and trading programs because of the broad international participation in its development, and its growing adoption internationally.

Combined with the specific M&V Plan of each project, this Protocol enhances consistency of reporting and enables verification of energy savings. However to verify an emission credit this Protocol and the project's M&V Plan must be used in conjunction with the credit 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 savings determination process:

- Electrical savings should be split into peak period and off peak periods, and ozone season non-ozone season when NOx or VOCs are involved. These periods will be defined by the relevant trading program.
- 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.
- Savings should be separated into those that are 'surplus' or 'additional' to normal behavior and those that are simply 'business as usual' or needed to comply with existing regulations. These terms will be defined by the relevant trading program. For example, where equipment minimum efficiency standards limit the efficiency of new equipment on the market these standards may form the reference case for determining tradable credits derived from energy savings.
- Segregate energy savings at each 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.

4.8 Baseline Adjustments (Non-Routine)

Conditions which vary in a predictable fashion are normally included within the basic mathematical model used for routine adjustments, described in Chapter 3.4. Where unexpected or one-time changes occur they may require non-routine adjustments, normally called simply Baseline Adjustments.

Examples of situations often needing Baseline Adjustments are: i) changes in the amount of space being heated or air conditioned, ii) changes in the amount or use of equipment iii) changes in environmental conditions (lighting levels, set-point temperatures, etc.) for the sake of standards compliance, and iv) changes in occupancy, schedule or throughput.

Baseline Adjustments are not needed where:

- the variable is included in the mathematical model developed for the project
- changes affect a variable that was stipulated in the M&V Plan. For example if the number of ton-hours of cooling were stipulated for a chiller efficiency ECM, an increase in the cooling ton-hours will not affect the savings determined by the agreed simplified method, though actual savings will change.
- changes occur to equipment beyond the boundary of the savings determination. For example if the boundary includes only the lighting system, for a lighting retrofit, addition of personal computers to the space will not affect the savings determination.

Baseyear conditions need to be well documented in the M&V Plan so that proper adjustments can be made (see Chapter 3.3). It is also important to have a method of tracking and reporting changes to these conditions. This tracking of conditions may be performed by one or more of the facility owner, the agent determining savings, or a third party verifier. It should be established in the M&V Plan who will track and report each condition recorded for the baseyear and what, if any other aspects of facility operation will be monitored.

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

Non-routine Baseline Adjustments are determined from actual or assumed physical changes in equipment or operations. Sometimes it may be difficult to identify the impact of changes. If the facility’s energy consumption record is used to identify such changes, the impact of the ECMs on the metered energy consumption must first be removed by Option B techniques.

4.9 Weather Data

Where monthly energy measurements are used, weather data should be recorded daily and matched to the actual energy metering period.

For monthly or daily analysis, government published weather data should be treated as the most accurate and verifiable. However weather data from such source may not be available as quickly as site monitored weather data.

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

4.10 Cost

The cost of determining savings depend on many factors such as:

- IPMVP Option selected
- ECM number, complexity and amount of interaction amongst them
- number of energy flows across the boundary drawn around the ECM to isolate it from the rest of the facility in Options A, B or D when applied to a system only
- level of detail and effort associated with establishing baseyear 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 stipulations used in Option A or the calibrated simulations of Option D
- number and complexity of independent variables which are accounted for in mathematical models
- duration of metering and reporting activities
- accuracy requirements
- savings report requirements
- process of reviewing or verifying reported savings
- experience and professional qualifications of the people conducting the savings determination

Often these costs can be shared with other objectives such as real time control, operational feedback, or tenant sub-billing.

It is difficult to generalize about costs for the different IPMVP Options since each project will have its own unique set of constraints. However it should be an objective of M&V Planning to design the process to incur no more cost than needed to provide adequate certainty and verifiability in the reported savings, consistent with the overall budget for the ECMs. Typically however it would not be expected that average annual savings determination costs exceed more than about 10% of the average annual savings being assessed.

Table 2 highlights key cost governing factors unique to each Option, or not listed above.

Table 2: Unique Elements of M&V Costs

Option A	Number of measurement points Complexity of stipulation Frequency of post-retrofit inspection
Option B	Number of measurement points
Option C	Number of meters Number of independent variables needed to account for most of the variability in energy data.
Option D	Number and complexity of systems simulated. Number of field measurements needed to provide input data. Skill of professional simulator in achieving calibration

Commonly, since Option A involves stipulation, it will involve fewer measurement points and lower cost, providing stipulation and inspection costs do not dominate.

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

When multiple ECMs are installed at one site, it may be less costly to use the whole building methods of Options C or D than to isolate and measure multiple ECMs with Options A or B.

Though development and calibration of an Option D simulation model is often a time consuming process, it may have other uses such as for designing the ECMs themselves or designing a new facility.

Where a contractor (ESCO) is responsible for only certain aspects of project performance, other aspects may not have to be measured for contractual purposes, though the owner may still wish to measure all aspects for its own sake. In this situation, the costs of measurement may be shared between owner and contractor.

4.11 Balancing Uncertainty and Cost

The acceptable level of uncertainty required in a savings calculation is a function of the level of savings and the cost-effectiveness of decreasing uncertainty. For example, suppose a project has an expected savings of $100,000 per year and that a basic M&V approach had an accuracy no better than ±25% with 90% confidence, or $25,000 per year. To improve the accuracy to within $10,000 it may be seen as reasonable to spend an extra $5,000 per year on M&V but not $30,000 per year. The quantity of savings at stake therefore places limits on the target expenditure for M&V.

Further benefits of activities to reduce uncertainty may be the availability of better feedback to operations, enabling an enhancement of savings or other operational variables. The information may also be useful in assessing equipment sizing for planning plant expansions or replacement of equipment. It may also allow higher payments to be made under an energy performance contract based on measured vs conservative stipulated values. Additional investments for improved accuracy should not exceed the expected increase in value. This issue is discussed in more detail by Goldberg (1996b).

Discussions and definitions of site-specific M&V plans should include consideration of accuracy requirements for M&V activities and the importance of relating M&V costs and accuracy to the value of ECM savings. However it should be recognized that not all uncertainties can be quantified (see Chapter 4.2). Therefore both quantitative and qualitative uncertainty statements must be considered when considering M&V cost options for each project.

For a given savings determination model at a specific site, there will be an optimal savings determination plan. The method to identify that Plan includes iterative consideration of sensitivity of the savings uncertainty to each variable, estimating the cost of metering specified variables in the model and a criteria for valuing reduced uncertainty (e.g. risk-adjusting saving per a given formula).

Chapter 5 Measurement Issues

5.1 Using Utility Meters

Whole building energy measurements can utilize the same meters that the local power company uses to bill the owner if they are equipped or modified to provide an output that can be recorded by the facility's monitoring equipment. The "energy/pulse" constant of the pulse transmitter should be calibrated against a known reference such as similar data recorded by the power company s revenue meter.

5.2 Electric Demand

Electric demand measurement methods vary amongst utilities. The method used by any sub-meter or modeling routine should replicate the method the power company uses for the relevant billing meter. For example, if the local power company is calculating peak demand using a 15 minute "fixed window," then the recording equipment should be set to record data every 15 minutes. However if the power company uses a "sliding window" to record electric demand data, the data recorder should have sliding window recording capabilities. Such sliding window capability can be duplicated by recording data on one minute fixed window intervals and then recreating the sliding 15 minute window using post-processing software. Most often 15 minute fixed window measurements will represent sliding 15 minute data reasonably well. 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 in a sliding window interval and not in a fixed window. After processing the data for the demand analysis, the 15 minute data can then be converted to hourly data for archiving and further analysis against hourly weather data.

5.3 Instrumentation and Measurement Techniques

Special meters may be used to measure physical quantities or to submeter an energy flow. Example quantities which may have to be measured without the use of energy supplier meters are temperature, humidity, flow, pressure, equipment runtime, electricity and thermal energy. To determine energy savings with reasonable accuracy and repeatability, good measurement practices should be followed for these quantities. Such practices are continually evolving as metering equipment improves. It is recommended that the latest measurement practices be followed to support any savings determination. Appendix C provides a review of some common measurement techniques. The IPMVP web site contains relevant current references on measurement techniques."

5.4 Calibration of Instrumentation

It is highly recommended that instrumentation be calibrated with procedures developed by the National Institute of Standards and Technology (NIST). Primary standards and no less than third order NIST 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 references on calibration have been provided in Chapter 6.2, including: 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).

5.5 Data Collection Errors and Lost Data

Methodologies for data collection differ in degree of difficulty, and consequently in the amount of erroneous or missing data. No data collection is without error. The M&V Plan should consider two aspects of data collection problems:

- 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.
- establish a methodology by which missing or erroneous data will be interpolated for final analysis. In such cases, baseyear and post-retrofit models may be used to calculate savings.

5.6 Use of Energy Management Systems for Data Collection

The facility *energy management system*[1] (EMS) can provide much of the monitoring necessary for data collection. However, the system and software must be fully specified to provide this extra service as well as its primary real-time control function. For example, significant use of trending functions may impair the basic functions of the EMS. Some parameters to be monitored may not be required for control. These extra points must be specified in the design documents. Electric power metering is an 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.

Other functions that can easily be incorporated into the software are automatic recording of changes in set-points.

It is not unusual for many of the trending capabilities required for verification to be incorporated in an EMS. However adequate hardware and software capability must be provided since data trending can tie up computer processing, communication bandwidth and storage.

Facility staff should be properly trained in this use of the EMS so they too 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, EMS security arrangements should ensure that persons can only access functions for which they are competent and authorized.

1. The terms in italics are defined in Chapter 6.1

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

The EMS can record energy use with its trending capability. However, most EMSs record "change of value" (COV) event recordings 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 which are not designed for such data densities. Great care should be exercised to:

- control access and/or changes to the EMS trend log from which the energy data are extracted.
- develop post-processing routines for changing the EMS COV data into time series data for performing an analysis.
- get from the EMS supplier:
  - NIST traceable calibrations of all sensors,
  - evidence that proprietary algorithms for counting and/or totaling pulses, Btus, and kWh data 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.

Chapter 6 Definitions

6.1 Definitions

Baseline Adjustments —The non-routine adjustments (Chapter 3.4) arising during the post-retrofit period that cannot be anticipated and which require custom engineering analysis (see Chapter 4.8).

Baseyear Conditions —The set of conditions which gave rise to the energy use/demand of the baseyear.

Baseyear Energy Data —The energy consumption or demand during the baseyear.

Baseyear —A defined period of any length before implementation of the ECM(s).

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 operator personnel.

CV (RMSE) —Coefficient of Variation of the RMSE (see Appendix B)

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°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, usually chosen to reflect the temperature at which heating or cooling is no longer needed.

Energy Conservation/Efficiency Measure (ECM or EEM) —A set of activities designed to increase the energy efficiency of a facility. 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.

EMS or Energy Management System —A computer that can be programmed to control and/or monitor the operations of energy consuming equipment in a facility.

Energy Performance Contract —A contract between two or more parties where payment is based on achieving specified results; typically, guaranteed reductions in energy consumption and/or operating costs.

Energy Savings —Actual reduction in electricity use (kWh), electric demand (kW), or thermal units (Btu).

ESPC or Energy Savings Performance Contract — A term used in the United States equivalent to Energy Performance Contract.

ESCO or Energy Services Company — A firm which provides a range of energy efficiency and financing services and guarantees that the specified results will be achieved under an energy performance contract.

M&V or Measurement & Verification — The process of determining savings using one of the four IPMVP Options.

Metering — Collection of energy and water consumption data over time at a facility through the use of measurement devices.

Monitoring — The collection of data at a facility over time for the purpose of savings analysis (i.e., energy and water consumption, temperature, humidity, hours of operation, etc.)

M&V Option — One of four generic M&V approaches defined herein for energy savings determination.

Post-Retrofit Period — Any period of time following commissioning of the ECM.

R^2 — R Squared (see Appendix B)

Regression Model — Inverse mathematical model that requires data to extract parameters describing the correlation of independent and dependent variables

RMSE — Root mean square error (see Appendix B)

Simulation Model — An assembly of algorithms that calculates energy use based on engineering equations and user-defined parameters.

Verification — The process of examining the report of others to comment on its suitability for the intended purpose.

Appendix A Examples

Option A Example: Lighting Efficiency Retrofit

Situation

More efficient fixtures are installed in place of existing fixtures in a school to reduce energy requirements, while maintaining lighting levels.

M&V Plan

An M&V Plan was developed showing that Option A was to be used for savings determination because partial measurement was deemed to provide adequate accuracy. An outline of the Plan is shown below:

- The boundary of this ECM was drawn to include the ceiling mounted lighting circuits fed by the 277 volt supply, and the radiation heating system. The associated decrease in air conditioning load was considered trivial since little of the school is air conditioned, and most of it is closed for the summer months.
- The baseyear conditions are those of the 12 months immediately preceding the decision to proceed with the project. They included a lighting level survey, description location and number of lamps ballasts and fixtures.
- Engineering calculations determined that the ECM would increase boiler load by the energy equivalent of 6% of the lighting savings from November through March. This number was estimated to range between 4% and 8%.
- The boiler efficiency in winter was estimated to be 79% under typical winter conditions.
- The baseyear fuel use from the gas utility bills from November through March is 2,940 × 10^3 ft^3 (83.25 × 10^3 m^3).
- The lighting operating periods of the post-retrofit period are selected as the common set of conditions for the energy use terms in Equation 1 of Chapter 3.
- Baseyear lighting periods were established through one month logging of lighting in representative areas. Lighting period logs established the following annual load/duration data for the baseyear:

Baseyear Load/Duration	
Fraction of Lighting Load	**On Hours Per Year**
9%	240
61%	1,450
15%	2,500
6%	6,100
9%	8,760

- Due to a change in occupancy patterns planned to take effect about the same time as the ECM installation, it is assumed that the load/duration profile in the post-retrofit period will be as shown below:

Stipulated Post-retrofit Load/Duration	
Fraction of Lighting Load	**On Hours Per Year**
9%	240
61%	2,000
15%	2,500
6%	6,100
9%	8,760

- Measurements were made with a recently calibrated RMS power meter of the three phase power draw on the 277 volt lighting circuits. The manufacturer's rating on this power meter is ±2% of full scale and readings were roughly 50% of full scale. 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 28.8 kW, though 7 lamps (= 0.3 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.
- The electrical demand for lighting was assumed to be equal to the measured circuit load for ten months of the year when school is in session. This stipulation may be in error by no more than 3% since lighting is the dominant electrical load of the building. Based on the utility bills showing a demand reduction during July and August, the minimal use of the facility during these months, and the other equipment used during the summer, it was assumed that the July and August lighting circuit demand is only 50% of the measured circuit load.
- The possible errors in the above stipulated post-retrofit lighting load/duration profile are:
  - only half of the anticipated growth from 1,450 hrs to 2,000 hrs may happen, and
  - the 9% load fraction may be switched on for 400 hours.
- These possible errors could affect the post-retrofit energy use by as much as about 2,500 kWh, which represents 8.2% of the expected 30,000 kWh annual savings. The impact of assumptions of the lighting impact on the electrical demand meter for all twelve months of the baseyear and post-retrofit years might affect total reported demand savings by as much as 3%. Neither of these stipulation impacts is considered significant for the project.
- Estimated accuracy of the power measurements is ±4%.
- The savings calculation process shown below was summarized in the M&V Plan.

- Savings are to be computed annually for the subsequent year using a re-measurement of the lighting electrical load immediately after ECM completion and on each anniversary thereafter.
- The electrical power readings on the baseyear and all future years will be made by a contract electrician. All data and analyses are available for inspection. As a check on the readings, building maintenance staff will also measure the electrical load at the same times as the contractor. If there is a difference of more than 4% between staff and contractor readings, a second contractor reading will be made and the proper value selected between the two contractor readings.
- This savings determination process is expected to require an electrician 5 hours each year to make the readings and calibrate the measurement equipment. Total cost each year is expected to be $200 including reporting.

Baseyear Electricity Use/Demand

The baseyear energy use for Equation 1 is computed by multiplying the 28.8 baseyear load by baseyear load/duration data, above. The computation is shown below.

Baseyear Energy Use			
Fraction of Lighting Load	**kW**	**On Hours Per Year**	**kWh**
9%	2.6	240	622
61%	17.6	1,450	25,474
15%	4.3	2,500	10,800
6%	1.7	6,100	10,541
9%	2.6	8,760	22,703
Total (100%)	**28.8**		**70,140**

The baseyear demand is 28.8 kW for each of 10 months and 14.4 kW for each of July and August, bringing the total demand to 317 kW-mo.

Post-Retrofit Electricity Use/Demand

After installation of the ECM, the lighting circuit power was re-measured as in the baseyear. The power draw was 16.2 kW with all lights on and none burned out. With the same 1% burnout rate as in the baseyear, the post-retrofit period maximum power would be 16.0 kW (=16.2 × 0.99). Therefore the post-retrofit annual energy use for Equation 1 is computed by multiplying the 16.0 kW post-retrofit load by the stipulated post-retrofit load/duration data. The computation is shown below.

Post-Retrofit Energy Use			
Fraction of Lighting Load	**KW**	**On Hours Per Year**	**kWh**
9%	1.4	240	346
61%	9.8	2,000	19,520
15%	2.4	2,500	6,000
6%	1.0	6,100	5,860
9%	1.4	8,760	12,614
Total	**16.0**		**44,340**

The post-retrofit demand is 16.0 kW for each of 10 months and 8.0 kW for each of July and August, bringing the total demand to 176 kW-mo.

Post-Retrofit Fuel Use

Fuel increases resulting from the lighting ECM are derived from the electrical energy savings. The unadjusted electrical savings are 70,140 – 44,340 = 25,800 kWh per year. Assuming these savings are achieved uniformly over a 10 month period, the typical winter month electrical savings are 25,800/10 = 2,580 kWh/month. The associated boiler load increase is 6% of these electrical savings for November through March, namely:

= 6% × 2,580 kWh/mo × 5 months = 774 kWh equivalent

Extra boiler input energy is:

= 774 kWh ÷ 79% = 980 kWh equivalent units of fuel
= 3,344,000 Btu or 3,000 ft^3 (84.95 m^3) of natural gas

Therefore total post-retrofit fuel use is estimated to be 2,940 + 3 = 2,943 x 10^3 ft^3 (83.34 10^3 m^3).

Routine Adjustments

Routine adjustments are needed to bring baseyear energy use to the conditions of the stipulated post-retrofit period.

By applying the 28.8 kW baseyear electrical load to the stipulated post-retrofit load/duration data, the routine adjustment for the longer operating hours is derived, as shown below:

Baseyear Energy Use at Stipulated Post-Retrofit Conditions				At Baseyear Conditions	Adjustment
Fraction of Lighting Load	**kW**	**On Hours Per Year**	**kWh**	**kWh**	**kWh**
9%	2.6	240	622	622	
61%	17.6	2,000	35,144	25,474	
15%	4.3	2,500	10,800	10,800	
6%	1.7	6,100	10,541	10,541	
9%	2.6	8,760	22,703	22,703	
Total	**28.8**		**79,810**	**70,140**	**9,670**

No adjustments are needed to electric demand since the increase in operating hours occurs during the school sessions, therefore not increasing demand.

Though adjustments are appropriate for associated fuel use, they would be trivial so are ignored.

Savings

From Equation 1, the energy savings for the first year after ECM installation are determined to be:

	Baseyear	–	Post-Retrofit	+	Adjustment	=	Savings
Electricity	70,140	–	44,340	+	9,670	=	35,470 kWh
Electric Demand	317	–	176	+	0	=	141 kW-mo
Gas	2,940,000 (83,250)	–	2,943,000 (83,340)	+	0	=	-3000 ft^3 (-84.95 m^3)

Subsequent years' savings will be computed identically, from each year's measured load on the same electrical panel.

Note that in this example the savings reported are for operations under post-retrofit period conditions. Therefore the savings can be called "avoided energy use."

Option B Example: Boiler Replacement

Situation

An office building boiler is replaced with a more efficient boiler. 95% of the load on the boiler is for building heating while 5% is for domestic water heating. There are no changes other than an improvement in boiler efficiency. No other equipment in the building uses gas.

M&V Plan

An M&V Plan was developed showing that Option B was to be used for savings determination because the boiler retrofit for energy reduction was just part of many non-energy related changes planned for the building. An outline of the Plan is shown below:

- The boundary of this ECM was drawn to include only the boiler fuel systems. This boundary excludes the electricity associated with the boiler auxiliaries of burner and blower. Though less gas may be used by the boiler, the power uses of old and new blower are expected to be very similar and their operating periods will be the same. Therefore the auxiliaries are not expected to change their electricity use significantly and can be excluded from the boundary of measurement.
- The baseyear conditions were chosen to be the load pattern of typical winter periods before ECM installation.
- The conditions of the baseyear were chosen as the common set of conditions for the energy use terms in Equation 1, since it was expected that there would be significant changes in the building's heating loads in the post-retrofit period. It is recognized that the reported savings will then be for baseyear conditions, not post-retrofit conditions.
- The baseyear energy use was $35{,}200 \times 10^3$ ft^3 ($1{,}000 \times 10^3$ m^3) of gas.
- Before retrofit, boiler efficiency was tested over three separate one week periods when average ambient temperature ranged from 20°F (– 6.7°C) to 24°F (– 4.4°C) and building occupancy was normal. A recently calibrated energy flow meter was installed on the boiler, measuring supply and return line temperature and supply water flow rate. This meter system with its data capture and processing has a manufacturer's rated accuracy of ±7% for the Btu ranges involved in this project. The utility's gas meter was used to measure gas use and is taken as the reference source, i.e. it has no error. The average efficiency readings for the three weekly intervals were 66%, 64% and 65%. An overall average efficiency of 65% was established. Outdoor temperature was measured by a sensor that was calibrated twice a year and recorded by the building control system.
- It is assumed that the percentage change in efficiency measured under typical winter conditions will prevail in all other conditions. The error in this assumption is not likely to exceed 5%.
- The savings calculation process shown below was summarized in the M&V Plan.
- Savings are to be computed annually for the subsequent year using boiler efficiency data measured each year. Data from the energy flow meter and gas meter will be stored for examination by a third party if needed.

- The cost of installing and commissioning the energy flow meter, was $7,900. The cost of each year's reading of efficiency, meter calibration and reporting is $4,000.
- Gas and energy flow meter readings will be made daily by building maintenance staff through winter months until three valid weeks have been obtained. This data will be logged in the boiler room and open for inspection at any time. Ambient temperature data will be recorded by the building automation system and logs printed for the selected valid weeks.
- Energy flow meter calibration will be done annually by xyz contractor immediately before the efficiency testing period begins. Gas meter direct readings will be corrected for pressure and temperature by the utility company's factors for the corresponding period. These factors will be provided in writing by the utility.

Baseyear Energy Use

The baseyear annual energy use for Equation 1 is 35,200 × 10^3 ft^3 (1,000 × 10^3 m^3).

Post-Retrofit Energy Use

After installation and commissioning of the ECM, three separate weekly test periods were found with an average ambient temperature between 20°F (– 6.7°C) to 24°F (– 4.4°C) and normal occupancy. The efficiency results over the three one week periods were 81%, 79% and 80%, averaging 80%.

The post-retrofit annual energy use for Equation 1 is determined from the baseyear use to be:

Baseyear Condition + Correction to Post-retrofit condition

$$= \frac{35200 \times 0.65}{0.80} + C$$

$$= (26{,}410 + C)\ 10^3\ ft^3\ ((750 + C)\ 10^3\ m^3)$$

C is an unknown quantity needed to convert baseyear projected use of the new boiler to post-retrofit conditions.

Routine Adjustments

Routine adjustments are needed to bring post-retrofit energy use to the conditions of the baseyear. This is exactly the correction amount C million ft^3 (m^3).

Savings

From Equation 1, energy savings are determined to be:

	Baseyear	–	Post-Retrofit	+	Adjustment	=	Savings
Gas	35,200	–	(26,410 + C)	+	C	=	8,790 x 10^3 ft^3 (248.9 10^3 m^3)

Note that in this example the savings reported are for operations under baseyear conditions.

Option C Example: Whole Building Multiple ECM Project

Situation

An energy efficiency project was implemented in a high school, involving six ECMs spanning lighting, HVAC, pool heating and operator training and occupant awareness campaigns. The objectives of the project were to reduce energy costs.

M&V Plan

An M&V Plan was developed showing that Option C was to be used for savings determination because total facility energy cost was the focus. An outline of the Plan is shown below:

- The boundary of this savings determination was defined as:
  - The main electricity account #766A234-593 including demand
  - The auxiliary electrical account #766B122-601 serving the field house
  - The natural gas account #KHJR3333-597
- The baseyear conditions are those of the 12 months immediately preceding the decision to proceed with the project. Included in the documentation of these conditions is:
  - a lighting level survey, with a count of the number of burned out lamps in January and June;
  - a summary of typical space temperatures and humidities during occupied and unoccupied periods in each of four seasons;
  - a count of the number and size of all computers, monitors and printers, along with an estimate of the operating hours of each;
  - a record of the number of day pupils and evening courses each month of the year;
  - a record of the number of public rental hours of the gym, cafeteria and pool each month;
  - a count of the number of window air conditioning units installed;
  - the temperature setting of pool water, and domestic hot water serving the pool showers, the gym showers and the rest of the school;
  - the volume of make-up water supplied to the pool each month, as recorded by a separate uncalibrated sub-meter;
  - the cafeteria kitchen hot water temperature and the number and rating of all kitchen equipment; and
  - the open hours of the cafeteria kitchen and the value of food sales each month.
- The baseyear energy use is shown on the above utility accounts spanning the period January 1998 to December 1998.
- The baseyear energy data were analyzed as follows. Multiple linear regression was performed on monthly energy use and demand, metering period length, and degree days (DD). Degree days data were derived from mean daily dry bulb temperature published monthly by the government weather service for the city where the school is located. No significant correlation with weather was found for electric demand, summer electricity use in the field house or summer gas use. Analysis found reasonable

correlation between weather and winter gas use and the main electricity meter's winter consumption. Therefore no other independent variables were sought. The energy per DD and energy per day data shown below describe the characteristics of the straight line relationship found by the regression analyses:

		Gas	Electricity		
			Demand	**Consumption**	**Consumption**
Account Number		KHJR3333-597	766A234-593		766B122-601
Units		10^3 ft^3 (10^3 m^3)	kW-mo	kWh	kWh
Annual Total		10,238 (290)	5,782	1,243,000	62,000
Winter Regression Analysis	DD Base	15°C		16°C	20°C
	Energy/DD	2.55		39.61	18.12
	Energy/Day	9.16		2,640	20.1
	CV (RMSE)	9%		18%	5%

- Savings will be determined under post-retrofit conditions.
- The savings calculation process shown below was summarized in the M&V Plan.
- The school has provided XYZ contractor authorization to receive energy use data from the electric and gas utility companies until 2008.
- Savings are to be computed and reported monthly by XYZ contractor in a format for physical plant staff to understand and quarterly in a format for teaching staff and students to understand. This reporting is to begin immediately after ECM completion. It will continue at this rate for eight years.
- Annually the school will report any changes in the baseyear conditions listed above, within a month after the end of each school year. XYZ contractor will compute the energy impact of these changes and any others that it believes are relevant and present Non-Routine Baseline Adjustments two months before the end of the school board's fiscal year.
- This savings determination process is expected to require a data entry and utility bill analyst 10 hours each year and an engineer 5 hours to review reports for accuracy and establish suitable computations for Non-Routine Baseline Adjustments. Total cost each year is expected to be about $1,000 including reporting.

The CV (RMSE) of the baseyear models range from 5% to 18% and are far less than the expected savings of 35% for both fuel and electricity. No sampling or instrumentation error exists. Therefore the reported savings will be statistically significant, subject to any error introduced through non-routine baseline adjustments which may arise.

Baseyear Energy Use

The baseyear energy use for Equation 1 is taken directly from the utility bills without adjustment. The data were tabulated in the M&V Plan.

Post-Retrofit Energy Use

The post-retrofit energy use for Equation 1 is taken directly from the utility bills without adjustment.

Routine Adjustments

Routine adjustments are needed to bring baseyear energy use to the conditions of the post-retrofit period. For the first year after retrofit the routine adjustments are computed as follows.

Gas:

	Baseyear Energy Use		Post-Retrofit Conditions		Baseyear Energy Use Projected to Post-Retrofit Conditions				
	Consumption[a]	**Days**[b]	**Days**[c]	**DD**[d]	**Winter Base**[e]	**Winter Heating**[f]	**Summer**[g]	**Total**[h]	**Adjustment**[i]
Jan	2,239.1	29	31	742	284.0	1,892.1		2,176.1	-63.0
Feb	1,676.3	31	30	551	274.8	1,405.1		1,679.9	3.5
Mar	1,223.1	31	32	401	293.1	1,022.6		1,315.7	92.6
Apr	723.3	30	28	208	256.5	530.4		786.9	63.6
May	399.6	30	30	41	274.8	104.6		379.4	-20.3
Jun	240.1	28	30	12			257.3	257.3	17.2
Jul	201.2	31	32	0			207.7	207.7	6.5
Aug	193.6	30	30	2			193.6	193.6	0.0
Sep	288.7	30	30	20			288.7	288.7	0.0
Oct	439.1	30	31	99	284.0	252.5		536.4	97.3
Nov	1,023.6	31	30	302	274.8	770.1		1,044.9	21.3
Dec	1,591.1	33	33	521	302.3	1,328.6		1,630.8	39.7
Total	**10,238.8**	**364**	**367**					**10,497.2**	**258.4**

a. facts from the baseyear energy data
b. facts from the baseyear energy data
c. facts from the post-retrofit metering periods
d. facts from the post-retrofit metering periods
e. (c) x 9.16 for month where DD > 25
f. (d) x 2.55 for months where DD > 25
g. (a/b) x (c) for months where DD = 25 or less
h. (e) + (f) + (g)
i. (h) - (a)

Electricity Consumption:

Calculations for each of the two electricity consumption meters are performed separately in the same fashion as the gas meter above, using the relevant baseyear data, regression factors, metering periods and degree days. The net routine adjustments for each month are shown in the Savings section below.

Electric Demand:

No routine adjustments are made since no correlation was found with weather.

Non-Routine Adjustments

During the first post retrofit period extra computer equipment was added, partially replacing older computers. The following monthly energy and demand estimates were made from nameplate ratings, typical loading and operating hours for the ten months when school is in session:

	Computer	Monitor	Printer	Total
Net Number Added	23	23	5	
Nameplate Watts	150	120	175	
Average Watts	70	110	50	
Hours Use/month	150	150	120	
kWh/month	242	380	30	652 kWh
Demand diversity	90%	90%	70%	
kW demand	1.45	2.28	0.23	3.96 kW

Though there may be a 50% error in these estimates, their impact is small relative to the savings report.

Savings

From Equation 1, the energy savings for the first year after ECM installation are determined for each account to be:

1 Gas Account #KHJR3333-597 Thousand ft^3 or Thousand m^3

	Baseyear Energy Use	–	Post-Retrofit	+	Adjustment	=	Savings
Jan	2,239.1	–	1,839.1	+	-63.0	=	337.0 (9.54)
Feb	1,676.3	–	1,233.6	+	3.5	=	446.3 (12.64)
Mar	1,223.1	–	932.1	+	92.6	=	383.6 (10.86)
Apr	723.3	–	621.1	+	63.6	=	165.8 (4.69)
May	399.6	–	301.0	+	-20.3	=	78.4 (2.22)
Jun	240.1	–	160.2	+	17.2	=	97.1 (2.75)
Jul	201.2	–	120.1	+	6.5	=	87.6 (2.48)
Aug	193.6	–	150.9	+	0.0	=	42.7 (1.21)
Sep	288.7	–	202.3	+	0.0	=	86.4 (2.45)
Oct	439.1	–	339.1	+	97.3	=	197.3 (5.59)
Nov	1,023.6	–	678.4	+	21.3	=	366.5 (10.38)
Dec	1,591.1	–	1,123.2	+	39.7	=	507.6 (14.27)
Total	**10,238.8**	**–**	**7,701.1**	**+**	**258.4**	**=**	**2,796.1 (79.16)**

2 Electricity Account #766A234-593 Consumption (kWh)

	Baseyear Energy Use	–	Post-Retrofit	+	Routine Adjustment	+	Non-Routine Adjustment	=	Savings
Jan	122,400	–	81,200	+	3,740	+	652	=	45,592
Feb	118,600	–	76,200	+	2,780	+	652	=	45,832
Mar	132,200	–	83,200	+	-1,220	+	652	=	48,432
Apr	110,800	–	77,600	+	1,890	+	652	=	35,742
May	106,000	–	65,400	+	2,120	+	652	=	43,372
Jun	101,200	–	61,200	+	120	+	652	=	40,772
Jul	30,200	–	20,800	+	-3,600	+	0	=	5,800
Aug	36,200	–	23,800	+	2,480	+	0	=	14,880
Sep	105,200	–	66,800	+	2,260	+	652	=	41,312
Oct	110,200	–	70,600	+	200	+	652	=	40,452
Nov	126,600	–	83,200	+	5,320	+	652	=	49,372
Dec	128,400	–	81,000	+	-2,240	+	652	=	45,812
Total	**1,228,000**	**–**	**791,000**	**+**	**13,850**	**+**	**6,520**	**=**	**457,370**

3 Electricity Account #766A234-593 Demand (kW)

	Baseyear Energy Use	–	Post-Retrofit	+	Routine Adjustment	+	Non-Routine Adjustment	=	Savings
Jan	561	–	402	+	0	+	4	=	163
Feb	521	–	381	+	0	+	4	=	144
Mar	502	–	352	+	0	+	4	=	154
Apr	490	–	328	+	0	+	4	=	166
May	472	–	330	+	0	+	4	=	146
Jun	470	–	336	+	0	+	4	=	138
Jul	300	–	222	+	0	+	0	=	78
Aug	470	–	324	+	0	+	0	=	146
Sep	476	–	336	+	0	+	4	=	144
Oct	480	–	350	+	0	+	4	=	134
Nov	500	–	362	+	0	+	4	=	142
Dec	540	–	390	+	0	+	4	=	154
Total	**5,782**	**–**	**4,113**	**+**	**0**	**+**	**40**	**=**	**1,709**

4 Electricity Account #766B122-601 Consumption (kWh)

	Baseyear Energy Use	–	Post-Retrofit	+	Adjustment	=	Savings
Jan	12,200	–	10,200	+	-1,200	=	800
Feb	9,600	–	11,200	+	2,320	=	720
Mar	8,800	–	7,800	+	-200	=	800
Apr	4,400	–	4,800	+	1,280	=	880
May	3,800	–	5,100	+	2,120	=	820
Jun	1,200	–	500	+	120	=	820
Jul	800	–	400	+	23	=	423
Aug	600	–	300	+	-48	=	252
Sep	1,200	–	400	+	41	=	841
Oct	4,400	–	3,800	+	140	=	740
Nov	6,600	–	5,400	+	-290	=	910
Dec	8,400	–	9,000	+	1,400	=	800
Total	**62,000**	**–**	**58,900**	**+**	**5,706**	**=**	**8,806**

Note that in this example the savings reported are for operations under post-retrofit period conditions. Therefore the savings can be called "avoided energy use."

Option D Example: Calibrated Simulation Multiple ECM Project

Situation

An energy efficiency project was implemented in a university library building, involving four ECMs spanning lighting, HVAC, operator training and occupant awareness campaigns. The building is part of a multiple building campus without individual building meters. As part of the energy management program steam, electricity and electric demand meters were installed on the main supply lines to the library. The objectives of the project were to reduce energy costs in the library.

M&V Plan

An M&V Plan was developed showing that Option D was to be used for savings determination because baseyear data did not exist for the library on its own. An outline of the Plan is shown below:

- The boundary of this project was defined as the total energy use of the library as it affects the main campus energy and demand purchases, assuming:
  - a pound of steam at the library requires 1.5 ft^3 (0.04 m^3) of natural gas at the campus heating plant's gas meter,
  - a kWh of electricity at the library requires 1.03 kWh of electricity at the campus electricity meter, and
  - a kW of demand at the library is coincident with 1.03 kW of electric demand at the campus electric demand meter.
- The baseyear conditions are those of the 12 months immediately preceding the decision to proceed with the project, 1999. Light levels were surveyed during this period and recorded. However the library use and occupancy is assumed to be the same in the baseyear and post-retrofit periods.
- No baseyear energy data exist so it will be simulated using DOE-2 software, version 2.1 calibrated against actual meter data from the first year of post-retrofit operations.
- The common set of conditions selected for use in the energy use terms in Equation 1 consists of the library use and occupancy in the first year of the post-retrofit period, and the weather conditions of a 'normal' year for the city, as published by the National Renewable Energy Lab in 1989.
- Recordings were made of the following load and operating conditions during the post-retrofit period:
  - turnstile data, producing hourly occupancy data for each hour of the year, averaging a peak daily occupancy of 300 persons;
  - a library open hours: 8:00 AM to midnight, seven days a week, except for statutory holidays when it is closed;
  - operating staff measurements of space temperature and humidity at twenty five locations, mid morning and mid afternoon on the first day of each of the 12 months; and
  - continuous power draw on the 120 volt circuits supplying library equipment, for five typical days and a statutory holiday. A total of 801 kWh/occupied day was recorded and an hourly profile was developed for typical occupied and unoccupied days.

- the input file of data including assumptions and the above measured data were printed and saved electronically for use by any other person.
- ABC consulting engineering firm designated J. Smith as the professional engineer to conduct the simulation and calibration because of his experience in this field.
- The intended savings calculation process shown below was summarized in the M&V Plan.
- Savings are to be computed after the end of the first post-retrofit year. To ensure that savings remain in place the building operating staff will regularly report the status of the key operating parameters which were used in the calibrated simulation model. If operating conditions change, the savings will not be adjusted since they are computed at a fixed set of conditions.
  - Savings are to be determined using the following marginal prices derived from the respective energy supply contracts:
    electricity consumption = $.0791/kWh
    electric demand = $9.93/kW-month
    steam = $14.23/$10^3$ lbs ($31.34/$10^3$ kg)
- This savings determination process is expected to require a consulting professional engineer one month to set up and calibrate an appropriate simulation model, costing about $20,000. A review of the work by DEF consultant is planned and may cost a further $8,000.

Baseyear Energy Use

The following steps were followed to compute baseyear energy use after the first post-retrofit year:

1 The newly installed meters were calibrated before installation. Operating staff read the meters monthly and recorded monthly total steam and electricity use, as well as monthly demand, for each of 12 months throughout the post-retrofit year.

2 A model was developed of the building with the ECM's installed. This model used actual weather of the post-retrofit period and the operating profiles recorded in the same period. The modeled space temperatures and humidities were examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days. Initially the model did not model energy use well, so further site investigations were undertaken. During these investigations it was found that during unoccupied night periods, there was no effective indoor temperature change, so the thermal mass characteristics of the model were adjusted. With this correction the model was determined to adequately match the calibration data. The modeled results compared to the monthly data as follows

	MBE	CV (RMSE)
Electricity Consumption	8%	10%
Electric Demand	12%	15%
Steam	5%	8%

3 This accuracy of calibration is good enough to allow reasonable confidence in the relative results of two runs if the model. However the model should not be used to compare simulated results to actual data.

4 The calibrated model was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

5 The calibrated model was then adjusted to remove the ECMs, and the weather data file was changed to correspond to the actual weather of the baseyear, 1999. The modeled space temperatures and humidities were again examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days. This baseyear model was archived, with both printed and electronic copy of input data, diagnostic reports and output data. The energy consumption of this model was:

Baseyear Energy Data

Electricity use	=	2,971,000 kWh
Electric Demand	=	6,132 kW-months
Steam	=	10.67×10^6 lbs (4.84×10^6 kg)

Post-Retrofit Energy Use

The calibrated model showed the following energy use with the ECMs in place:

Post Retrofit Energy Data

Electricity use	=	1,711,000 kWh
Electric Demand	=	5,050 kW-months
Steam	=	6.26×10^6 lbs (2.84×10^6 kg)

Routine Adjustments

Routine adjustments are needed to bring baseyear and post-retrofit energy use to the agreed standard set of conditions: post-retrofit operations and weather of a 'normal' year. The following steps were followed:

1 The calibrated model was re-run with the 'normal' weather data. The modeled space temperatures and humidities were again examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days.

2 This calibrated model with 'normal' weather was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

3 The difference between the two versions of the calibrated model were computed as the Adjustment term, and is shown below.

4 The baseyear model was re-run with the 'normal' weather data. The modeled space temperatures and humidities were again examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days.

5 This baseyear model with 'normal' weather was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

6 The difference between the two versions of the baseyear model were computed as the Adjustment term, and is shown below.

	Baseyear Model Adjustment	**Calibrated Post-Retrofit Model Adjustment**	**Total Adjustment**
Electricity consumption (kWh)	122,000	50,000	172,000
Electric Demand (kW-months)	200	100	300
Steam (10^3 lbs) or (10^3 kg)	-521 (-236.3)	1,096 (497.1)	575 (260.8)

Savings

From Equation 1, the energy savings at the standard set of conditions are:

	Baseyear	**–**	**Post-Retrofit**	**+**	**Adjustment**	**=**	**Savings**
Electricity	2,971,000	–	1,711,000	+	172,000	=	1,432,000 kWh
Electric Demand	6,132	–	5,050	+	300	=	1,382 kW-mo
Steam (10^3 lbs or 10^3 kg)	10,673 (4,841)	–	6,261 (2,840)	+	575 (261)	=	4,987 (2,262)

The value of these energy/demand savings are computed from the marginal prices as:

electricity consumption	=	$113,300
electric demand	=	$13,700
steam	=	$70,970
Total	=	$197,970

Appendix B Uncertainty

Note: Use of statistical techniques such as sampling in determining energy savings is relatively unsophisticated compared to the exact science of statistics. Nonetheless, relatively simple statistical methods are helpful in explaining the results of an energy saving program and securing confidence and financing. The MVP uses the language of statistics, such as confidence levels and sampling, in a way that reflects best industry practices, and not as prescribed in statistics textbooks. These methods may not be statistically rigorous, but do provide sufficient confidence to complete and finance projects.

Introduction

Instrumentation Error —The magnitude of instrumentation errors is given by manufacturer's specifications. Typically instrumentation errors are small, and are not the major source of error in estimating savings.

Modeling Error —Modeling error refers to errors in the models used to estimate parameters of interest from the data collection. Biases in these models arise from model miss-specification. Miss-specification errors include:

- omitting important terms from the model.
- assigning incorrect values for "known" factors.
- extrapolation of the model results outside their range of validity.

Non systematic errors are the random effects of factors not accounted for by the model variables.

The most common models are linear regressions of the form

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_p x_p + e \qquad \textbf{Eq. 2}$$

where:

y and $x_{k,}$ k = 1, 2, 3,..., p	observed variables
b_k, k = 0, 1, 2,..., p	coefficients estimated by the regression
e	residual error not accounted for by the regression equation

Models of this type can be used in two ways:

1. To estimate the value of y for a given set of x values. An important example of this application is the use of a model estimated from data for a particular year or portion of a year to estimate consumption for a normal year.
2. To estimate one or more of the individual coefficients b_k.

In the first case, where the model is used to predict the value of y given the values of the x_k s, the accuracy of the estimate is measured by the *root mean squared error* (RMSE) of the predicted mean. This accuracy measure is provided by most standard regression packages. The MSE of prediction is the expected value of:

$$(y|_x - \hat{y}|_x)^2 \quad \textbf{Eq. 3}$$

where $y|_x$ is the true mean value of y at the given value of x, and $\hat{y}|_x$ is the value estimated by the fitted regression line. The RMSE of prediction is the square root of the MSE.

In the second case, where the model is used to estimate a particular coefficient b_k, the accuracy of the estimate is measured by the standard error of the estimated coefficient. This standard error is also provided by standard regression packages. The variance of the estimate $\hat{b}$ is the expected value of:

$$(b - \hat{b})^2 \quad \textbf{Eq. 4}$$

where b is the true value of the coefficient, and $\hat{b}$ is the value estimated by the regression. The standard error is the square root of the variance.

Whether the quantity of interest is the predicted value of y or a particular coefficient b_k, the accuracy measures provided by the standard statistical formulas are valid characterizations of the uncertainty of the estimate only if there are no important biases in the regression model.

Three statistical indices that can be used to evaluate regression models are defined below (SAS 1990):

1. The Coefficient of Determination, R^2 (%):

$$R^2 = \left(1 - \frac{\sum_{i=1}^{n}(y_{pred,i} - y_{data,i})^2}{\sum_{i=1}^{n}(\bar{y}_{data} - y_{data,i})^2}\right) \times 100 \quad \textbf{Eq. 5}$$

2. The Coefficient of Variation CV (%):

$$CV = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}(y_{pred,i} - y_{data,i})^2}{n-p}}}{\bar{y}_{data}} \times 100 \quad \textbf{Eq. 6}$$

3. The Mean Bias Error, MBE (%):

$$MBE = \frac{\dfrac{\sum_{i=1}^{n}(y_{pred,i} - y_{data,i})}{n-p}}{\bar{y}_{data}} \times 100 \quad \textbf{Eq. 7}$$

where:

$y_{data, i}$	data value of the dependent variable corresponding to a particular set of the independent variables,
$y_{pred, i}$	predicted dependent variable value for the same set of independent variables above,
$\bar{y}_{data}$	mean value of the dependent variable of the data set,
n	number of data points in the data set.
p	total number of regression parameters in the model.

Sampling Error —Sampling error refers to errors resulting from the fact that a sample of units were observed rather than observing the entire set of units under study. The simplest sampling situation is that of a simple random sample. With this type of sample, a fixed number n of units is selected at random from a total population of N units. Each unit has the same probability n/N of being included in the sample. In this case, the standard error of the estimated mean is given by:

$$SE(y) = \sqrt{\left(1 - \frac{n}{N}\right)\left(\left[\sum_{i=1}^{n} \frac{(y_i - \bar{y})^2}{(n-1)}\right] / n\right)} \quad \textbf{Eq. 8}$$

For more complicated random samples, more complex formulas apply for the standard error. In general, however, the standard error is proportional to $1/(\sqrt{n})$. 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 $\sqrt{f}$.

Combining Components of Uncertainty

If the savings (S) estimate is a sum of several independently estimated components (C), then

$$S = C_1 + C_2 + C_3 + \ldots + C_p \quad \textbf{Eq. 9}$$

the standard error of the estimate is given by

$$SE(S) = \sqrt{[SE(C_1)^2 + (C_2)^2 + (C_3)^2 + \ldots + (C_p)^2]} \quad \textbf{Eq. 10}$$

If the savings (S) estimate is a product of several independently estimated components (C), then

$$S = C_1 \times C_2 \times C_3 \times \ldots \times C_p \quad \textbf{Eq. 11}$$

the relative standard error of the estimate is given approximately by

$$\frac{SE(S)}{S} \approx \sqrt{\left[\left(\frac{SE(C_1)}{(C_1)}\right)^2 + \left(\frac{SE(C_2)}{(C_2)}\right)^2 + \left(\frac{SE(C_3)}{(C_3)}\right)^2 + \ldots + \left(\frac{SE(C_p)}{(C_p)}\right)^2\right]} \quad \textbf{Eq. 12}$$

The requirement that the components be independently estimated is critical to the validity of these formulas. Independence means that whatever random errors affect one of the components are unrelated to errors affecting the other components. In particular, different components would not be estimated by the same regression fit, or from the same sample of observations.

The above formulae for combining error estimates from different components can serve as the basis for a Propagation of Error analysis. This type of analysis is used to estimate how errors in one component will affect the accuracy of the overall estimate. Monitoring resources can then be designed cost-effectively to reduce error in the final savings estimate. This assessment takes into account:

- the effect on savings estimate accuracy of an improvement in the accuracy of each component.
- the cost of improving the accuracy of each component.

This procedure is described in general terms in ASHRAE 1991 and EPRI 1993. Applications of this method have indicated that, in many cases, the greatest contribution to savings estimate uncertainty is the uncertainty in baseyear conditions. The second greatest source of error tends to be the level of use, typically measured by hours (Violette et al. 1993). Goldberg (1996a) describes how to balance sampling errors against errors in estimates for individual units in this type of analysis.

Establishing a Level of Quantifiable Uncertainty

Determining savings means estimating a difference in level rather than measuring the level of consumption itself. In general, calculating a difference with a given relative precision requires greater absolute precision, therefore a larger sample size than measuring a level with the same relative precision. For example, suppose the average load is around 500 kW, and the anticipated savings is around 100 kW. A 10% error with 90% confidence (90/10) criterion applied to the load would require absolute precision of 50 kW at 90 percent confidence. The 90/10 criterion applied to the savings would require absolute precision of 10 kW at the same confidence level.

In M&V, the precision criterion may be applied not only to demand or energy savings, but also to parameters that determine savings. For example, suppose the savings amount is the product of number (N) of units, hours (H) of operation and change (C) in watts:

$$S = N \times H \times C \qquad \textbf{Eq. 13}$$

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. On the other hand, if 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.

In the M&V context, the precision standard could be imposed at various levels. The choice of level of disaggregation dramatically affects the sample size requirements and associated monitoring costs. Possible choices include the following:

- For individual sites, where sampling is conducted within each site
- For all savings associated with a particular type of technology, across several sites for a given project, where both sites and units within sites may be sampled

- For all savings associated with a particular type of technology in a particular type of usage, across several sites for a project
- For all savings associated with all technologies and sites for a given ESCO

In general, the finer the level at which the precision criterion is imposed, the greater the data collection requirement. If the primary goal is to ensure savings accuracy for a project or group of projects as a whole, it is not necessary to impose the same precision requirement on each subset. In fact, a uniform relative precision target for each subset is in conflict with the goal of obtaining the best precision possible for the project as a whole.

Appendix C Measurement Techniques

Electricity

The most common way of sensing alternating electrical current (AC) for energy efficiency and savings applications is with a current transformer or current transducer (CT). CTs are placed on wires connected to specific loads such as motors, pumps or lights and then connected to an ammeter or power meter. CTs are available in split core and solid torroid configuration. Torroids are usually more economical than split-core CTs, but require a load to be disconnected for a short period while they are installed. Split-core CTs allow installation without disconnecting the load. Both types of CTs are typically offered with accuracies better than one percent.

Voltage is sensed by a direct connection to the power source. Some voltmeters and power measuring equipment directly connect voltage leads, while others utilize an intermediate device, a potential transducer (PT), to lower the voltage to safer levels at the meter.

Though electrical load is the product of voltage and current, separate voltage and current measurements should not be used for inductive loads such as motors or magnetic ballasts. True RMS power digital sampling meters should be used. Such meters are particularly important if variable frequency drives or other harmonic-producing devices are on the same circuit, resulting in the likelihood of harmonic voltages at the motor terminals. True RMS power and energy metering technology, based on digital sampling principles, is recommended due to its ability to accurately measure distorted waveforms and properly record load shapes.

It is recommended that power measurement equipment meeting the IEEE Standard 519-1992 sampling rate of 3 kHz be selected where harmonic issues are present. Most metering equipment has adequate sampling strategies to address this issue. Users should, however, request documentation from meter manufacturers to ascertain that the equipment is accurately measuring electricity use under waveform distortion.

Power can be measured directly using watt transducers. Watt-hour energy transducers that integrate power over time eliminate the error inherent in assuming or ignoring variations in load over time. Watt-hour transducer pulses are typically recorded by a pulse-counting data logger for storage and subsequent retrieval and analysis. An alternate technology involves combining metering and data logging functions into a single piece of hardware.

Hand-held wattmeters, rather than ammeters, should be used for spot measurements of watts, volts, amps, power factor or waveforms.

Regardless of the type of solid-state electrical metering device used, it is recommended that the device meet the minimum performance requirements for accuracy of the American National Standards Institute standard for solid state electricity meters, ANSI C12.16-1991, published by the Institute of Electrical and Electronics Engineers. This standard applies to solid-state electricity meters that are primarily used as watt-hour meters, typically requiring accuracies of one to two percent based on variations of load, power factor and voltage.

Runtime

Determination of energy savings may involve measuring the time that a piece of equipment is on, and then multiplying it by a short term power measurement. Constant load motors and lights are examples of equipment that may not be continuously metered with recording watt-hour meters to establish energy consumption. Self-contained battery-powered monitoring devices are available to record equipment runtime and, in some cases, time-of-use information. This equipment provides a reasonably priced, simple to install approach for energy savings calculations.

Temperature

The most commonly used computerized temperature measurements devices are resistance temperature detectors (RTDs), thermocouples, thermistors, and integrated circuit (IC) temperature sensors.

Resistance Temperature Detectors or RTDs — These are common equipment for measuring air and water temperature in the energy management field. They are among the most accurate, reproducible, stable and sensitive thermal elements available. An RTD measures the change in electrical resistance in special materials.

RTD's are economical and readily available in configuration packages to measure indoor and outdoor air temperatures as well as fluid temperatures in chilled water or heating systems. Considering overall performance, the most popular RTDs are 100 and 1,000 Ohm platinum devices in various packaging including ceramic chips, flexible strips and thermowell installations.

Depending on application, two, three and four-wire RTDs are available. Required accuracy, distance, and routing between the RTD and the data logging device can determine the specific type of RTD for a project. Four-wire RTDs offer a level of precision seldom required in the energy savings determination, and are most commonly found in high precision services or in the laboratory. Three-wire RTDs compensate for applications where an RTD requires a long wire lead, exposed to varying ambient conditions. The wires of identical length and material exhibit similar resistance-temperature characteristics and can be used to cancel the effect of the long leads in an appropriately designed bridge circuit. Two-wire RTDs must be field-calibrated to compensate for lead length and should not have lead wires exposed to conditions that vary significantly from those being measured.

Installation of RTDs is relatively simple with the advantage that conventional copper lead wire can be used as opposed to the more expensive thermocouple wire. Most metering equipment allows for direct connection of RTDs by providing internal signal conditioning and the ability to establish offsets and calibration coefficients.

Thermocouples — They measure temperature using two dissimilar metals, joined together at one end, which produce a small unique voltage at a given temperature that is measured and interpreted by a thermocouple thermometer. Thermocouples are available in different combinations of metals, each with a different temperature range. Apart from temperature range, consider chemical abrasion and vibration resistance and installation requirements while selecting a thermocouple.

In general, thermocouples are used when reasonably accurate temperature data are required. The main disadvantage of thermocouples is their weak output signal, making them sensitive to electrical noise and always requiring amplifiers. Few energy savings determination situations, except for thermal energy metering, warrant the accuracy and complexity of thermocouple technology.

Thermistors — These are semiconductor temperature sensors usually consisting of an oxide of manganese, nickel, cobalt or one of several other types of materials. One of the primary differences between thermistors and RTDs is that thermistors have a large resistance change with temperature. Thermistors are not interchangeable, and their temperature-resistance relationship is non-linear. They are fragile devices and require the use of shielded power lines, filters or DC voltage. Like thermocouples, these devices are infrequently used in savings determination.

Integrated Circuit Temperature Sensors — Certain semiconductor diodes and transistors also exhibit reproducible temperature sensitivities. Such devices are usually ready-made Integrated Circuit (IC) sensors and can come in various shapes and sizes. These devices are occasionally found in HVAC applications where low cost and a strong linear output are required. IC sensors have a fairly good absolute error, but they require an external power source, are fragile and are subject to errors due to self-heating.

Humidity

Accurate, affordable and reliable humidity measurement has always been a difficult and time-consuming task. Equipment to measure relative humidity is available from several vendors, and installation is relatively straightforward. However, calibration of humidity sensors continues to be a major concern (see Chapter 5.4) and should be carefully described in the M&V Plan and documented in savings reports.

Flow

Different types of flow measurement may be used for quantities such as natural gas, oil, steam, condensate, water, or compressed air. This section discusses the most common liquid flow measurement devices. In general, flow sensors can be grouped into two different types of meters:

1 Intrusive Flow Meters (Differential Pressure and Obstruction)

2 Non-Intrusive Flow Meters (Ultrasonic and Magnetic)

Choosing a flow meter for a particular application requires knowing the type of fluid being measured, how dirty or clean it is, the highest and lowest expected flow velocities, and the budget.

Differential Pressure Flow Meters — The calculation of fluid flow rate by measuring the pressure loss across a pipe restriction is perhaps the most commonly used flow measurement technique in building and industrial applications. The pressure drops generated by a wide variety of geometrical restrictions have been well characterized over the years, and, these primary or "head" flow elements come in a wide variety of configurations, each with specific application strengths and weaknesses. Examples of flow meters utilizing the concept of differential pressure flow measurement include Orifice Plate meter, Venturimeter, and Pitot Tube meter. Accuracy of differential pressure flow meters is typically in the vicinity of 1-5% of the maximum flow for which each meter is calibrated.

Obstruction Flow Meters — Several types of obstruction flow meters have been developed that are capable of providing a linear output signal over a wide range of flow rates, often without the severe pressure loss penalty incurred with an orifice plate or venturi meters. In general, these meters place a small target, weight or spinning wheel in the flow stream that allows fluid velocity to be determined by the rotational speed of the meter (turbine) or by the force on the meter body (vortex).

Turbine meters — They measure fluid flow by counting the rotations of a rotor that is placed in a flow stream. Turbine meters can be an axial-type or insertion-type. Axial turbine meters usually have an axial rotor and a housing that is sized for an appropriate installation. An insertion turbine meter allows the axial turbine to be inserted into the fluid stream and uses existing pipe as the meter body. Because the insertion turbine meter only measures fluid velocity at a single point on the cross-sectional area of the pipe, total volumetric flow rate for the pipe can only be accurately inferred if the meter is installed according to manufacturer's specifications. Most important with insertion turbine meters is installation in straight sections of pipe removed from internal flow turbulence. This type of meter can inserted without having to shut down the system. Insertion meters can be used on pipelines in excess of four inches with very low pressure loss. Turbine meters provide an output that is linear with flow rate. Care must be taken when using turbines as they can be damaged by debris and are subject to corrosion. Insertion meters can be damaged during insertion and withdrawal.

Vortex meters — They utilize the same basic principle that makes telephone wires oscillate in the wind between telephone poles. This effect is due to oscillating instabilities in a low pressure field after it splits into two flow streams around a blunt object. Vortex meters require minimal maintenance and have high accuracy and long-term repeatability. Vortex meters provide a linear output signal that can be captured by meter/monitoring equipment.

Non-Interfering Flow Meters — They are well suited to applications where the pressure drop of an intrusive flow meter is of critical concern, or the fluid is dirty, such as sewage, slurries, crude oils, chemicals, some acids, process water, etc.

Ultrasonic flow meters — They measure clean fluid velocities by detecting small differences in the transit time of sound waves that are shot at an angle across a fluid stream. Accurate clamp-on ultrasonic flow meters facilitate rapid measurement of fluid velocities in pipes of varying sizes. An accuracy rate from 1% of actual flow to 2% of full scale are now possible, although this technology is still quite expensive. Recently, an ultrasound meter that uses the Doppler principle in place of transit time has been developed. In such a meter a certain amount of particles and air are necessary in order for the signal to bounce-off and be detected by the receiver. Doppler-effect meters are available with an accuracy between 2% and 5% of full scale and command prices somewhat less than the standard transit time-effect ultrasonic devices. Meter cost is independent of pipe size. Ultrasonic meters can have low installation costs since they do not require shutting down systems to cut pipes for installation.

Magnetic flow meters – They measure the disturbance that a moving liquid causes in a strong magnetic field. Magnetic flow meters are usually more expensive than other types of meters. They have advantages of high accuracy and no moving parts. Accuracy of magnetic flow meters are in the 1-2% range of actual flow.

Pressure

Mechanical methods of measuring pressure have been known for a very long time. U-tube manometers were among the first pressure indicators. But manometers are large, cumbersome, and not well suited for integration into automatic control loops. Therefore, manometers are usually found in the laboratory or used as local indicators. Depending on the reference pressure used, they can indicate absolute, gauge, or differential pressure. Things to keep in mind while selecting pressure measurement devices are: accuracy, pressure range, temperature effects, outputs (millivolt, voltage or current signal) and application environment

Modern pressure transmitters have come from the differential pressure transducers used in flow meters. They are used in building energy management systems and are capable of measuring pressures with the necessary accuracy for proper building pressurization and air flow control.

Thermal Energy

The measurement of thermal energy flow requires the measurement of flow and some temperature difference. For example, the cooling provided by a chiller is recorded in Btu and is a calculated value determined by measuring chilled water flow and the temperature difference between the chilled water supply and return lines. An energy flow meter performs an internal Btu calculation in real time based on input from a flow meter and temperature sensors. It also uses software constants for the specific heat of the fluid to be measured. These electronic energy flow meters offer an accuracy better than 1%. They also provide other useful data on flow rate and temperature (both supply and return).

When a heating or cooling plant is under light load relative to its capacity there may be as little as a 5˚F difference between the two flowing streams. To avoid significant error in the thermal energy measurement the two temperature sensors should be matched or calibrated to the tightest tolerance possible. It is more important that the sensors be matched, or calibrated with respect to each another, than for their calibration to be traceable to a standard. Suppliers of RTDs can provide sets of matched devices when ordered for this purpose. Typical purchasing specifications are for a matched set of RTD assemblies (each consisting of an RTD probe, holder, connection head with terminal strip and a stainless steel thermowell), calibrated to indicate the same temperature, for example within a tolerance of 0.1˚F over the range of 25˚F to 75˚F. A calibration data sheet is normally provided with each set.

The design and installation of the temperature sensors used for thermal energy measurements should consider the error caused by: sensor placement in the pipe, conduction of the thermowell, and any transmitter, power supply or analog to digital converter. Complete error analysis through the measurement system is suggested, in recognition of the difficulty of making accurate thermal measurements.

Thermal energy measurements for steam can require steam flow measurements (e.g., steam flow or condensate flow), steam pressure, temperature and feedwater temperature where the energy content of the steam is then calculated using steam tables. In instances where steam production is constant, this can be reduced to measurement of steam flow or condensate flow (i.e., assumes a constant steam temperature-pressure and feedwater temperature-pressure) along with either temperature or pressure of steam or condensate flow.

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This protocol serves as a framework to determine energy and water savings resulting from the implementation of an energy efficiency program. It is also intended to help monitor the performance of renewable energy systems and to enhance indoor environmental quality in buildings.

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