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IPMVP

International Performance Measurement and Verification Protocol

Updated Version of 1996 North American Energy Measurement and Verification Protocol

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

December 1997

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ACKNOWLEDGMENTS

PARTICIPATING ORGANIZATIONS

Brazil
Institute Nacional De Eficiencia Energetica
Programa De Combate Ao Desperdicio De Energia Electrica
Ministry of Mines and Energy

Bulgaria
Bulgarian Foundation for Energy Efficiency (EnEffect)

Canada
Canadian Association of Energy Service Companies (CAESCO)
Natural Resources Canada

China
State Economic and Trade Commission
Beijing Energy Efficiency Center (BECON)
Electric Power Research Institute (EPRI)

The Czech Republic
Stredisko pro Efektivni Vyuzivani Energie (SEVEn7)

India
Tata Energy Research Institute

Japan
Ministry of International Trade and Industry (MITI)

Korea
Korea Energy Management Corporation (KEMCO)

Mexico
Comision Nacional Para El Ahorro De Energia (CONAE)
Fideicomiso De Apoyo Al Programa De Ahorro De Energia Del Sector Electrico (FIDE)

Poland
The Polish Foundation for Energy Efficiency (FEWE)

Russia
Center for Energy Efficiency (CENEf)

Sweden
Swedish National Board for Technical and Urban Development

Ukraine
Agency for Rational Energy Use and Ecology (ARENA – ECO)

United Kingdom
Association for the Conservation of Energy

United States
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
American Water Works Association (AWWA)
Building Owners and Managers Association (BOMA)
National Association of Energy Service Companies (NAESCO)
National Association of Regulatory Utility Commissioners (NARUC)
National Association of State Energy Officials (NASEO)
U.S. Department of Energy (DOE)
U.S. Environmental Protection Agency (EPA)

POLICY COMMITTEE

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National Academy of Sciences

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Iowa Dept. of Natural Resources

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Natl. Assoc. of State Energy Officials

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Charles Eley and Associates

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Measuring and Monitoring Services

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UN Development Programme

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U.S. Department of Energy

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Lawrence Berkeley Laboratory

Ronald LaCombe
Viron Energy Services

Jean Lupinacci
Environmental Protection Agency

Ajay Mathur (India)
Tata Energy Research Institute

Jaime Millan
Inter-American Development Bank

Evan Mills
Lawrence Berkeley Laboratory

John Newman (France)
International Energy Agency

Egil Ofverholm (Sweden)
Nutek

Alan Poole (Brazil)
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Nikolai Raptsoun (Ukraine)
Agency for Rational Energy Use & Ecology

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George Reeves Associates

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Schiller Associates

Terry Singer
Natl. Assoc. of Energy Service Companies

Katsunori Takahashi (Japan)
Ministry of International Trade and Industry

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Tescor Energy Services, Inc.

Andrew Warren (United Kingdom)
Association for Conservation of Energy

Dennis Whittle
The World Bank

Feng Yan (China)
State Economic & Trade Commission

Joel Zingeser
National Institute of Standards & Technology

TECHNICAL SUBCOMMITTEE

Angela Chen
Iowa Dept. of Natural Resources

David Claridge
Texas A&M University

Don Felts
Pacific Gas & Electric

Ellen Franconi
University of Colorado

Miriam Goldberg
XENERGY, Inc.

Anne Gumerlock Lee
Pacific Gas & Electric Co.

Jeff Haberl
Texas A&M University

Jim Halpern (Co-Chair)
Measuring & Monitoring Services

Kerri Herrity
Technical Writer/Editor

Oleg Komarov (Russia)
Foundation for Enterprise Restructuring

Steve Kromer
Lawrence Berkeley Laboratory

Eng Lock Lee (Singapore)
Supersymmetry Services Pvt. Ltd.

Michael Lytton (Canada)
Dept. of Education, Skills and Training

Mark Martinez
Edison Envest

Scott McGaraghan
U.S. Department of Energy

David McGeown
Energis Resources

Ricardo Valadares Pessoa (Brazil)
PROCEL

Larry Ringel
Synergistic Control Systems, Inc.

Steven Schiller (Co-Chair)
Schiller Associates

James Waltz
Energy Resource Associates

Vladimir Zhuze (Russia)
CENEf

FINANCIAL ADVISORY SUBCOMMITTEE

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Lehman Brothers

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Catalyst Financial Group

Carlton Bartels
Cantor Fitzgerald

Robert Bergstorm
Allison Williams Capital, Inc.

Brookes Browne
Environ. Enterprises Assistance Fund

Bryan Colwell
Goldman Sachs & Co.

David Carey
Fannie Mae

John Gibb
Sallie Mae

Matthew Heller
Energy Capital Partners

Pat Keogh
Bostonia, Inc.

Dave Kuncio
Citicorp

John MacLean
Energy Efficiency Capital Corp.

Mary McClellan
International Institute for Energy Conservation

Scott Mills
Lehman Brothers

Curtis Probst
Salomon Brothers, Inc.

Donald Reed
Excelsior Capital Corporation

Lisa Rogers
Goldman, Sachs & Co.

Glenn Tobias
Banque Paribas

Malcom Verdict
Alliance to Save Energy

WATER SUBCOMMITTEE

Scott Chaplin
Rocky Mountain Institute

John Flowers
U.S. Environmental Protection Agency

Patrick Higgins
P.J. Higgins & Associates

Tom Horner (Co-Chair)
Water Management Inc.

Ashley Houston
National Renewable Energy Laboratory

Gregory Kats
U.S. Department of Energy

Warren Liebold (Co-Chair)
NYC Department of Environmental Protection

Pio Lombardo
Lombardo Associates

Scott McGaraghan
U.S. Department of Energy

Joseph Pate
SweetWater Innovations, Inc.

Charlie Pike
UC Davis

Arthur Rosenfeld
U.S. Department of Energy

Steven Schiller
Schiller Associates

George Whalen
National Assoc. of Plumbing, Heating, Cooling Contractors

Phil Zacuto
ERI Services

NEW BUILDINGS SUBCOMMITTEE

Gregg Ander
Southern California Edison

Mark Bailey
U.S. Department of Energy

Ian Campbell
Turner Construction

Charles Eley
Charles Eley and Associates

Zdravko Genchev (Bulgaria)
EnEffect

Harry Gordon
Burt Hill Kosar Rittelmand and Associates

Jeff Haberl
Texas A&M University

Gunnar Hubbard
Rocky Mountain Institute

Gregory Kats
U.S. Department of Energy

Eng Lock Lee (Singapore)
Supersymmetry Services Pte Ltd.

Alisdair McGregor
Ove Arup & Partners

Alejandro Rivas (Mexico)
Naucalpan, DF

Arthur Rosenfeld
U.S. Department of Energy

Steven Schiller
Schiller Associates

Gordon Shymko (Chair, Canada)
Tescor Pacific Energy Services, Inc.

Alan Traugott
Flack and Kurtz, Consulting Engineers, LLP

Don Watson
RPI

EMISSIONS TRADING SUBCOMMITTEE

Although the emissions trading section benefited enormously from extensive review and comment by Kathleen Hogan, Jan McFarland and Rich Morgan at the U.S. Environmental Protection Agency (EPA) it does not necessarily represent the views of the U.S. EPA.

John Atcheson
US Department of Energy

Gregory Kats
US Department of Energy

Sandra Chen
New Jersey Department of Environmental Protection

Dan Lashof
Natural Resources Defense Council

Chris Cooley (Co-Chair)
Sycom Enterprises

Josh Margolis (Co-Chair)
Cantor Fitzgerald

David Festa
Climate Change Action Network

Anne Polansky
Solar Energy Industries Association

Charles Feinstein
Global Environment Facility

Kurt Zwally
US Department of Energy

Johannes Heister
The World Bank

Ed Vine
Lawrence Berkeley Laboratory

FOR ADDITIONAL INFORMATION REGARDING A SPECIFIC TOPIC

Below is a list of the authors responsible for specific sections of this Protocol. Section authors encourage readers to contact them directly for additional information on the respective topic.

Section 1.0, Purpose and Scope
Gregory Kats
U.S. Department of Energy
TEL: 202.586.1392
FAX: 202.586.9260
Email: greg.kats@hq.doe.gov

Section 2.0, Financing
Steve Kromer
Lawrence Berkeley National Lab
TEL: 510.486.6619
FAX: 510.486.5394
Email: jskromer@lbl.gov

Section 3.0, Overview of M&V
Steven Schiller
Schiller Associates
TEL: 510.444.6500
FAX: 510.444.6502
Email: steves@schiller.com

Section 4.0, M&V Options
Jeff Haberl, PhD
Texas A&M University
TEL: 409.895.6065
FAX: 409.862.2457
Email: jhaberl@.tamu.edu

Section 5.0, Other M&V Issues
Lawrence Ringel
Synergistic Control Systems, Inc.
TEL: 504.885.8180
FAX: 504.885.1180
Email: lringel@synergisticinc.com

Section 6.0, New Buildings
Gordon Shymko
Tescor Pacific Energy Services, Inc.
TEL: 604.731.4984
FAX: 604.738.4420
Email: gshymko@tescor.dwg.com

Appendix I, Emissions Trading
Chris Cooley
Sycom Enterprises
TEL: 805.682.5337
FAX: 805.682.5347
Email: crisman@west.net

Appendix II, Generic Application
Cary Bullock
Hillside Investment Associates
TEL: 617. 350.9200
FAX: 617.354.1514
Email: Cbull21415@aol.com

For Any Other Questions
Satish Kumar
Lawrence Berkeley National Lab
Tel: 202-484-7185
Fax: 202-484-0888
Email: s_kumar@lbl.gov

TO OBTAIN THE IPMVP,FEMP GUIDELINES OR INFORMATION ON ASHRAE GUIDELINE 14

To obtain the IPMVP:
As a book: call the "Efficiency and Renewable Energy Clearing House (EREC)" **1 (800) DOE-EREC** or fax your name, address & telephone number to EREC at **(703) 893-0400,** ask for the "International Performance Measurement and Verification Protocol" and include the code "IPMVP"
Electronically via E-mail: access EREC: **doe.erec@nciinc.com**
Electronically via the World Wide Web: **http://www.ipmvp.org**

To obtain the Federal Energy Management Program's Guidelines and the IPMVP together :
As a book: call EREC at **1 (800) DOE-EREC**
Electronically via E-mail: **M+V_info@lbl.gov**
Electronically via the World Wide Web: access EREN: **http://www.eren.doe.gov;** "Building Systems and Community Programs."

For information about ASHRAE Guideline 14 on M&V via the World Wide Web:
Access ASHRAE's Homepage : **http://www.ashrae.org.** ASHRAE may be posting information on Guideline 14 during the coming year.

For World Wide Web addresses of participating organizations:
See: www.ipmvp.org/organization.

NOTICE

SECTION 1.0: PURPOSE AND SCOPE OF DOCUMENT

1.1 INTRODUCTION

Investment in energy and water 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, and covers only a small fraction of the existing, financially-attractive opportunities for energy savings investments.

If all cost-effective efficiency investments were made in U.S. public and commercial buildings, 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 North American Measurement and Verification Protocol (NEMVP) was published in March of 1996. The name reflects the original scope of work, which was to create a document for use in the energy performance contracting industry in North America. That Protocol contained methodologies that were compiled by a committee of industry experts and involved hundreds of interested parties, primarily from the United States, Canada and Mexico. It was intended to provide industry consensus guidelines that would increase reliability and level of savings, cut efficiency investment costs and provide standardization required to secure lower cost financing.

Response to the 1996 document has been tremendous. North America's energy service companies have adopted the IPMVP/Protocol as the industry standard approach to measurement and verification (M&V). States ranging from Florida to New York now require use of the IPMVP in state-level energy efficiency retrofits. The U.S. Federal Government, through the Department of Energy's Federal Energy Management Program (FEMP), has built upon the Protocol to put in place an accelerated program for up to several billion dollars of energy and water retrofits in U.S. Federal buildings. A growing number of utilities and energy efficiency finance firms require the use of the Protocol. Please let us know if you are using the Protocol by filling out a one-half page form at: www.ipmvp.org/newuser.html.

Adoption now extends well beyond North America. Countries ranging from Brazil to Ukraine have begun to adopt the Protocol. Institutions such as the World Bank have found the Protocol beneficial and are incorporating it as a required part of about a half billion dollars of new energy efficiency loans. As a result of strong and widespread interest, participation in developing this second edition has expanded to include a global network of corresponding members to incorporate international expertise and to develop consensus among professionals from around the world. This version involves participating national organizations from a dozen countries and individual experts from more than 20 nations. The 1997 Protocol will be translated into Bulgarian, Chinese, Czech, Hungarian, Polish, Portuguese, Russian, Spanish, Ukrainian and perhaps other languages.

To reflect this new, larger audience and its broadening scope, the document has been renamed the "International Performance Measurement and Verification Protocol" (IPMVP). Similar in structure to the original Protocol, the contents of the IPMVP have been expanded to include efficiency opportunities for new construction projects and to cover water efficiency.

There is a consensus among climate scientists that burning fossil fuels causes global warming and that we have probably already begun to see the damaging effects of warming. Many industrialized countries have successfully applied pollution trading programs as a way to reduce the cost of cutting emissions, and this approach is being advocated by the United States and other nations as the most cost-effective way to cut greenhouse gases. Successful operation of such a trading program would require a standard international approach to measuring and verifying energy savings, and this Protocol is designed, in part, to meet this need.

The IPMVP is the result of a remarkable collaborative effort among industry, Federal and state agencies and experts in the energy, water and efficiency industries in North and South America, Europe and Asia. It has been driven largely by industry and reflects a broad industry consensus. The work was drafted by four subcommittees composed of leading international experts in their respective fields. Overall responsibility and direction is provided by the Policy Committee, composed of several dozen senior experts from a large range of fields from around the world that 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. Working groups of leading international experts in the areas of indoor air quality, renewable energy, operations and maintenance issues and insurance have provided additional expertise and have already laid the groundwork for future, major extensions of the Protocol into these new and important areas.

1.2 WHY MEASUREMENT AND VERIFICATION (M&V)?

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 that reduced reliability and performance of efficiency investments, increased project transaction costs and prevented the development of new forms of lower cost financing.

The long-term success of energy and water management projects has been 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, allow buyers, sellers and financiers of energy and water projects to quantify Energy Conservation Measure (ECM) and Water Conservation Measure (WCM) performance and savings. By using one of the different M&V options discussed in this document, readers can allocate various risks associated with achieving energy or water cost savings to either the buyer or seller of the project, facilitating financing and allowing risk reduction and better risk management.

When firms invest in energy efficiency, their executives naturally want to know how much they have saved and how long their savings will last. If the installation had been made to generate energy, then measurements would be trivial - install a meter on the generation equipment. Unlike energy generation, the determination of energy savings is a challenge, and requires both accurate measurement and repeatable methodology, known as a measurement and verification protocol.

A review of several hundred million dollars of efficiency investments in buildings in the United States demonstrates that projects with strong M&V result in a substantially higher level of savings than projects that have little or no M&V. The data indicates that building retrofits that follow strong M&V practices - like those contained in this Protocol - typically experience energy savings that are on average about 20 to 30 percent higher than buildings retrofitted with little or no M&V. The added cost of a strong M&V program is typically about five percent of the retrofit cost, but is typically paid back in months, both from substantially higher energy and water savings, as well as by lowered operations and maintenance (O&M) costs (Kats and Rosenfeld et al. 1996).

This Protocol is intended to reduce major barriers to the energy and water efficiency industries by helping to:

- increase reliability and level of savings.
- reduce transaction costs by providing an international, industry consensus approach and methodologies.
- reduce financing costs by providing project M&V standardization, thereby allowing project bundling and pooled project financing.

Our expectation is that, by providing greater and more reliable savings and a common approach to efficiency installation and measurements, widespread adoption of this Protocol will make efficiency investments more reliable and profitable, and foster the development of new types of lower cost financing. Ultimately, we hope that the standardization of M&V will lead to the development of a secondary market for efficiency investments (Kats 1995). Increased global availability of low cost and off-balance sheet financing would allow the efficiency industry to grow more rapidly, resulting in widespread benefits in the form of increased employment, greater productivity, lower energy and water bills, and reduced environmental and health damage.

1.3 SCOPE OF PROTOCOL

The Protocol provides an overview of current best practice techniques available for verifying aspects of third-party financed energy and water efficiency projects. It may also be used by building operators to assess and improve facility performance. In the interest of brevity, throughout most of this document the terms "energy" and "energy savings" represent both energy and water. Although there are several notable differences between energy efficiency programs and water-treatment/water efficiency programs, energy and water savings can typically be combined into one contract, as discussed in Section 2.0.

Energy measures covered include gas and electricity, load shifting and other measures which involve the installation of equipment and result in energy savings. Water measures covered include plumbing retrofits, building landscape irrigation measures, HVAC system upgrades and other measures which involve the installation of equipment and result in water cost savings.

This M&V Protocol is not intended to prescribe contractual terms between buyers and sellers, although it provides guidance on some of these issues. Once other contractual issues are decided, this document may be used to select the verification plan that best matches: i) project costs and savings magnitude, ii) technology-specific requirements, and iii) risk allocation between buyer and seller, i.e., which party is responsible for installed equipment performance and which party is responsible for achieving long-term energy savings.

Two basic aspects of ECM performance verification are addressed in this document:

1. Verification of: i) the accuracy of baseline conditions as specified in the contract between buyer and seller, and ii) the complete installation and proper operation of new equipment/systems specified in the contract.
2. Verification of the quantity of energy savings and/or energy cost savings that occur during the term of the contract.

The scope of this Protocol includes:

- Addressing the M&V needs of participants in energy and water efficiency projects, including financiers, sellers, buyers and technical consultants.
- Defining the role of verification in third-party financed energy and water project contracts and implementation.
- Discussing procedures, with varying levels of accuracy and cost, for verifying i) baseline and project installation conditions, and ii) long-term energy and water savings performance.
- Designing M&V procedures for a variety of facilities including residential, commercial, institutional and industrial buildings as well as for other industrial applications.
- Providing techniques for calculating "whole-facility" savings, individual technology savings and stipulated savings and that give buyers, sellers and financiers a basis to discuss key M&V project-related issues.
- Providing procedures which i) are consistently applicable to similar projects throughout all geographic regions, and ii) are internationally accepted, impartial and reliable.
- Providing procedures for the investigation and resolution of disagreements related to performance issues.
- Creating a living document that includes a set of methodologies and procedures that enable the document to evolve over time.

The target audience for this Protocol includes:

- Facility Energy Managers
- ESCOs (Energy Service Companies)
- Project Developers
- WASCOs (Water Service Companies)

- Development Banks
- Finance Firms
- Consultants
- Government Agency Employees & Contractors
- Utility Executives
- City and Municipal Managers
- Researchers

1.4 RELATIONSHIP TO OTHER PROGRAMS/DOCUMENTS

1.4.1 U.S. ASHRAE GPC 14P. The 1996 version was designed to be (and this version still is) complementary to the work of the American Society of Heating, Refrigeration andAir-Conditioning Engineers (ASHRAE) GPC 14P Committee (currently writing guidelines for the Measurement of Energy and Demand Savings), and by extension to ASHRAE sister organizations in other countries. In contrast to the ASHRAE document, which focuses on the relationship of the measurement to the equipment being verified at a very technical level, the IPMVP discusses a variety of M&V topics as they relate to actual contracts for energy services. It is advised that the reader use both documents, as well as others referenced herein, to formulate a successful M&V plan. The ASHRAE document is scheduled for completion in 1998.

1.4.2 U.S. EPA Conservation Protocol. The IPMVP has been written to be compatible with the U.S. Environmental Protection Agency's Conservation Verification Protocols which are designed to verify energy (electricity) savings from utility Demand Side Management (DSM) programs for the purpose of awarding sulfur dioxide allowances under EPA's Acid Rain Program.

Energy savings verified from performance contracting are potentially eligible for allowances under EPA's Acid Rain Program, provided the measures are paid for in part by an electric utility. IPMVP can also be used in that context to verify performance contracting energy savings, in conjunction with the EPA's Conservation Verification Protocols or other verification procedures used by state utility commissions.

Copies of EPA's Conservation Verification Protocol are available from the EPA Acid Rain Division (6204J), 401 M Street, SW, Washington, D.C. 20460.

1.4.3 Relationship to U.S. 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. Part of this assistance includes development of the first application of the IPMVP, for the U.S. Federal sector. This application is entitled "Measurement and Verification Guideline (M&V) for Federal Energy Projects." (DOE publication #DOE/GO-10096-248, February, 1996.) The FEMP Guideline is based on the IPMVP and was written to be fully consistent with it. It is intended to be used by Federal procurement teams consisting of contracting and technical specialists. The focus of FEMP Guidelines is on choosing the M&V option and method most appropriate for specific projects.

The FEMP Guideline serves as the basis for the IPMVP generic application document (Appendix II of this Protocol). The generic application provides direction and guidance on how to develop any application intended to be consistent with the Protocol. 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 1.800.DOE.EREC. An updated document is planned for early 1998.

1.4.4 Relationship to Energy and Environmental Evaluation Initiatives in U.S. Buildings.
The IPMVP is being integrated in two new major U.S. building energy and environmental evaluation efforts – the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED™) Rating system and the U.S. DOE/EPA ENERGY STAR® Building Label effort. These initiatives are being developed concurrently and are being carefully coordinated. Both seek to encourage energy savings and overall environmental awareness in both new and existing buildings. Currently, the LEED™ Rating System and the ENERGY STAR® Building Label, while maintaining their own unique identities, are scheduled to be launched jointly on Earthday 1998. For more information contact: hicks.thomas@epamail.epa.gov or denis.clough@hq.doe.gov.

A second linked U.S. building program is the USGBC-developed, comprehensive green building rating system, LEED™. In order to win a LEED™ 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 credits for achieving the ENERGY STAR® performance level. For more information, contact: www.usgbc.org - telephone: 415.543.3081.

1.5 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 discernable 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.

The various emissions trading and crediting systems allowed for under the Kyoto Protocol require internationally-accepted, cost-effective approaches to measure and verify emissions reductions from investments in greenhouse gas abatement efforts, such as energy efficiency. These emission trading systems are now in development, and continued international consensus development and adoption of the IPMVP provides project developers and the FCCC negotiators with the only internationally-developed and accepted methodology to measure and verify reductions in energy usage and, therefore, greenhouse gases. The IPMVP offers a single, consistent approach to measuring and verifying savings and associated emissions reductions in a broad range of energy sectors, including buildings, some industrial applications, and (by end of 1998) renewable energy investments. Therefore, the IPMVP is expected to be an essential tool in determining greenhouse gas reductions (from lowered energy use) and in facilitating the development of low-cost emissions trading systems for these reductions. (See Appendix I for further discussion.)

1.6 NEW TOPICS ADDRESSED IN IPMVP

This version of the Protocol addresses important new topics not covered in the 1996 version. These new areas include:

I. New Buildings (As Well As Retrofits)
II. Water Efficiency (As Well As Energy Efficiency)
III. Issues Relating To Pollution Trading Systems And How To Use The Protocol To Secure Associated Credits
IV. The Provision Of A Generic Application To Provide Guidance On How The IPMVP Can Be Applied

1.6.1 New Buildings. Construction is the single largest manufacturing activity in many countries. Industrializing countries with rapid economic growth experience high rates of new construction, offering enormous scope for adopting more efficient design. Even in an industrialized country with moderate economic growth, such as the United States, construction is the largest single manufacturing activity, accounting for about 13 percent of the gross domestic product, and providing nearly 10 million professional and trade jobs. Because of this industry's impact on national economies, even small changes in practices that promote energy and water efficiency and environmentally-sustainable design can make a significant contribution to economic prosperity and the environment.

Energy costs in commercial buildings typically represent a small portion of total business costs, so management generally pays little attention to energy efficiency opportunities. Energy performance contractors and vendors of energy efficient technologies have, until now, lacked standardized methods for measuring and verifying energy savings from these measures, and thus are hampered in selling their services and equipment. Energy and water efficient design is only slowly gaining market shares in the building design/build sector. Section 6.0 of this Protocol provides an industry consensus method for measuring and verifying those energy savings integrated into new building design, and is intended to accelerate adoption of efficiency design in new buildings.

While cost-effective retrofits can typically cut energy use in existing buildings by 30 percent, efficient design using cost-effective, existing technologies and techniques can cut energy use in new buildings by half. The advantages of incorporating efficiency into new building design include lower life-cycle costs, increased comfort, lower energy and O&M costs, better visual and audio comfort and improved indoor environmental quality (IEQ) - all factors which add value. The New Buildings Section, Section 6.0, provides methodologies to help achieve the enormous savings available through efficiency.

1.6.2 Emissions Trading - Another Opportunity For Building Managers. There is a range of pollutant trading programs that vary from country to country and region to region. These are generally market-based trading systems that reward investments which cut pollution, while allowing emission reduction objectives to be achieved at the lowest possible cost. Using these trading programs, building and industry managers in some regions have the ability to create "emissions currency" through investment in efficiency, renewable energy and other investments that reduce emissions. In addition, the ability to document reduced pollution is an important, non-financial motivating factor.

Claiming emissions credits at the project level for efficiency and renewable energy investments is a relatively new and growing phenomenon. We can expect an increase in the number of pollutants that are traded, a growing number of areas with trading regimes, and an overall maturation and ease of use of the emissions trading market. The financial value of credits resulting from emissions reductions is currently small, but is likely to become an increasingly significant source of financing for investments in energy efficiency and renewable energy. While some ESCOs have begun to claim credits directly, other firms may find it easier to work with public or private companies to aggregate and handle emissions resale, a service that can greatly simplify the process of claiming credits for project developers.

In most countries, efficiency investments offer the largest single opportunity to cut damaging pollutants in a cost- effective manner. Appendix I addresses the issue of emissions credits in some detail, providing an overview of emissions trading regimes and analysis on how to use the Protocol to secure credits for investments in efficiency and renewable energy.

For pollution trading systems to be successful in motivating increased investments in pollution-reducing technologies, they must be properly designed. Energy efficiency and renewable industry organizations have expressed concern that potential trading designs may create obstacles to expanded investment in their industries. For example, pollution trading programs that fail to provide emissions currency to investments in energy efficiency and renewable energy would prevent the successful market operation of the price signal provided by credits, and may inhibit the efficiency and renewable energy industries from meeting their potential in delivering large-scale, low-cost reductions in damaging pollutants.

1.7 FUTURE AREAS OF DEVELOPMENT

From the fall of 1997 through early 1998, the Protocol will be extended to address important new areas. These new topics include IEQ, renewable energy and O&M. The Protocol will also be extended to more fully address industrial applications, such as cogeneration.

1.7.1 Indoor Environmental Quality. The next version of the IPMVP will address IEQ which may be influenced by measures that reduce building energy use. The purpose of the IEQ section is to provide a set of best industry practices which help energy conservation professionals maintain or improve IEQ when implementing building ECMs.

On average, we spend 90 percent of our time in buildings, and the quality of the indoor environment can have a significant impact on our health and productivity. Health effects that may be influenced by the indoor environment include acute respiratory infections, allergy and asthma symptoms, and the set of building-related health symptoms referred to as sick building symptoms (e.g., irritation of eyes, nose and skin; headache). The indoor environment can also directly influence worker performance without affecting health. Although only rough estimates are available, the productivity gains from improving indoor environments and reducing these adverse health symptoms may often exceed the cost of improving indoor environment.

There are a number of topics to be addressed in relation to IEQ issues, including the following:

1. A review of the linkage(s) between specific energy conservation/savings measures and effects (either positive or negative) on the indoor environment.
2. Analysis of methods to predict what changes in IEQ might occur following changes in energy use.
3. Development of potential M&V protocols for directly assessing IEQ, similar to that being done for energy and water in this version of the IPMVP.

This brief review of IEQ issues serves as a placeholder and invitation for broad participation in extending the Protocol through the fall of 1997 and spring of 1998. Development progress will be posted on the IEQ section of the IPMVP website (http://www.ipmvp.org/committee). For information about how to participate, e-mail Bill Fisk at wjfisk@lbl.gov or Satish Kumar at s_kumar@lbl.gov.

<u>1.7.2 Renewable Energy Technologies</u>. Energy efficiency and renewable energy are generally considered separately in new construction and retrofit projects. This practice represents a significant area of lost opportunity because renewable energy technologies can have greater economic benefit in efficient buildings than in inefficient buildings. Similarly, many efficiency investments in buildings or industrial applications can include renewables as part of a financially attractive energy retrofit or design.

Building owners and industrial mangers are becoming increasingly aware of the magnitude of opportunity for integrating efficiency with renewables. Some of the more prominent renewable technologies with building and industrial applications include solar thermal, daylighting and photovoltaics. Just as with conventional energy sources, these technologies should be considered as part of a system that includes lighting, appliances and other building equipment.

Future versions of the Protocol will address renewable energy M&V issues in order to provide a common tool that can be used as a basis for performance contracting. (As with efficiency, renewable energy investments are more attractive if project performance is measured and verified.) The benefits of building integrated renewable energy projects depend in large measure on electricity or fuel costs. However, there are additional values to using renewable energy sources that include the following:

- Uninterruptible power service for core functions (lights, refrigerators and computers), which results in lower losses during business interruptions, e.g., after hurricanes
- Opportunity for avoided transmission line upgrade or line extension costs from use of renewables off-grid and some distributed applications
- Avoided transmission losses and greater grid stability provided by distributed generation
- Higher worker productivity and improved test scores by students working in buildings with increased daylighting, as documented by a growing number of studies
- Lower long-term financial risk from energy costs

- Reduced emissions from lower energy use, with resultant positive environmental and health benefits

Through early 1998, the Protocol's Renewable Energy Subcommittee will develop a new section of the IPMVP that deals specifically with M&V issues pertaining to renewable energy.

Three areas are envisaged:

I. Best Practices For Integrating Efficiency And Renewables
II. Specific Sequential Steps For Least-Cost Integrated Project Development
III. References To Best M&V and Related Practices for Renewables

This section will serve as a tool for those entering into performance contracts for renewable energy systems, and help provide a basis for contract terms. Those interested in participating in the Renewable Energy Subcommittee should contact Doug Arent at: darent@nrel.gov.

<u>1.7.3 Operations & Maintenance</u>. The 1998 Protocol will also identify issues and approaches for developing standard methodologies for measuring and verifying savings associated with improvements in O&M of commercial and institutional buildings. It will address the potential of O&M measures to save energy. Expected measures will include: improved preventive maintenance programs, commissioning, "continuous commissioning," short and long-term monitoring, surveys and out-sourcing. For information about how to participate, contact Steve Schiller at: Steve@schiller.com.

<u>1.7.4 What Next</u>? The IPMVP is revised every year and is maintained under the sponsorship of the U.S. Department of Energy by a broad coalition of facility owners/operators, financiers, contractors or ESCOs and other stakeholders. As a living document, it incorporates changes and improvements reflecting new research, improved methodologies and improved data. Extending the Protocol to address major new topics involves assembling a substantial body of leading international experts who work as volunteers to develop a recommended methodology. This involves use of the internet to maintain and provide access to evolving documents to ensure broad and open participation and review. The addition of an IEQ section to the next IPMVP version, for example, will follow a similar path, seeking the best information and a consensus among experts.

Individuals interested in reviewing this Protocol in progress or IPMVP-related documents should join us at our website: www.IPMVP.org. The website contains review drafts as they are prepared, English and other language versions of the Protocol, links to many of the organizations referenced herein, minutes of IPMVP committee meetings, and contact information for certain individuals associated with the Protocol. Individuals listed in connection with specific chapters or topic areas at the beginning of the Protocol can also be contacted directly.

SECTION 2.0: THE IMPORTANCE OF M&V IN FINANCING ENERGY AND WATER EFFICIENCY

2.1 FINANCING ENERGY AND WATER EFFICIENCY

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 or internal rate of return. 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 and is discussed in detail in this section. Most risks can be measured; it is the accuracy of the measurement 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 customer credit-worthiness. M&V, as defined in this Protocol, is primarily focused on those risks affecting the performance of energy and water efficiency measures. These risks are defined in the terms of contracts between the participants.

This Protocol provides guidance on obtaining information needed to reduce and manage performance risk in order to structure project financing contracts. The value of ECM performance data ranges 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. Different investments require different measures of performance. Accordingly, this Protocol provides four 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 retrofit. Instead, this document offers options available, provides guidance on which options to choose and helps clarify the relationship of various M&V options to the risks assumed by relevant parties.

2.2 DEFINITION AND ROLE OF PERFORMANCE CONTRACTS

When a guarantee of performance is involved in financing an energy efficiency project, it can be 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 that at some defined pricing level, energy savings will be sufficient to meet the financing payment obligations.

Energy savings is a reduction in energy use. Energy cost savings is a reduction in the cost of energy and related O&M expenses, from a base cost established through a methodology set forth in an energy savings performance contract. "Energy savings" and "energy cost savings" in a performance contract are a contractual quantity, not a measured quantity.

Performance of equipment, both before and after a retrofit, can be measured with varying degrees of accuracy. Savings, or more appropriately energy cost avoidance, are the calculated difference between the measured performance of an ECM and the amount of energy that the system/building ***would have used*** in the absence on the retrofit (see "baseline" in the Definitions Section). The baseline energy usage is created using measured equipment performance data prior to the retrofit coupled with assumptions about how that equipment would have operated in the post-installation period. Often, energy baseline 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.

Broadly speaking, ECM's have two elements, performance and operation:

The **performance** of the ECM is defined with a metric such as watts/sf or kW/ton.

The **operation** of the measure is defined as operation hours, ton hours etc.

Typically, the ESCO is responsible for the performance of any equipment or systems installed. Depending on the contract, either the ESCO or the Owner may be responsible for the operation of the equipment. In turn, changes in equipment operation may result from factors outside either party's control, such as weather. Consider three categories of variables that account for all of the changes that might affect the performance of the retrofit, and the conditions that affect energy cost avoidance:

1. ESCO-Controlled Variables - Retrofit Performance
2. Owner-Controlled Variables - Building Characteristics, Usage
3. Variables That Are Outside Of Either Party's Control - Weather, Utility Rates, Natural Disaster

It is a goal of the contract and the M&V plan that each of these categories be established before the project is implemented. The M&V process requires the skills of professionals familiar with measurement techniques, data manipulation and technology performance. In some circumstances, it may be preferable that a third party be obtained by the owner to judge whether agreements are being met. 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.

2.3 THE FINANCING RELATIONSHIP

In financing energy and water efficiency projects there are usually three primary participants: the customer (owner), the vendor (ESCO/contractor) and the financier. Relationships vary according to the structure of the transaction. In general, customers (facility-owners) want to ensure they receive value for payment. This "value" is usually in the form of reduced operating costs, improved performance and capital investments in new equipment. Vendors (ESCOs/contractors) are interested in receiving payment for products and services. Financiers want to achieve a return on invested capital.

Most types of financing share a common thread: a lender provides capital in return for a promise to repay the debt over time in the form of a contract. The financial key to the transaction is the perceived financial strength behind the promise to pay, usually referred to as the security behind the debt.

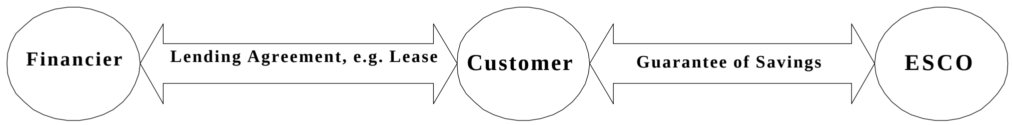
Many different forms of financing have evolved to support the funding of energy efficiency projects. By more clearly defining project M&V and providing generally-accepted M&V methods that are consistent, this Protocol may provide lending institutions confidence in the credible assessment of savings and 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.

2.3.1 The Owner. The role of the owner is to determine the project's business objectives and to understand the options available to meet those objectives. For example, some owners are interested in replacing old, inefficient equipment (capital renewal), while others may be interested in saving energy and still others in just saving money.

2.3.2 Contractor/Energy Services Company. The role of the contractor is to provide assistance in identifying and capitalizing on energy-saving opportunities and/or to implement the ECMs specified in the contract. Contractors with the resources to package engineering, financing and construction of these projects with guaranteed performance are referred to as energy service companies (ESCOs).

2.3.3 Financiers - Banks, Utilities, Etc. Funding sources to finance energy efficiency projects are maturing rapidly. A couple of years ago only a few very specialized firms provided funds for these types of deals. Today many institutions are competing for this business. There are numerous financing options in the marketplace. The optimal source of financing is dictated by the customer's financial strength and their appetite for risk.

2.3.4 ESCO/Owner/Financier Relationship. The relationship between the parties is directly related to the different contract types and who carries the risks. Three fundamental risk categories shape the relationships. For example, the risk that savings may not occur is usually allocated between the ESCO and the owner; responsibility for debt service payments to the financier will typically rest with either the owner or the ESCO.



2.4 FINANCE TYPES

2.4.1 Loans. Loans are normally the easiest financing structure to understand. A lending institution provides principal to a borrower for a specific period of time in return for a series of payments that will repay the principal plus interest. Points will be assessed at closing of the transaction and paid directly by the borrower, or added to the principal. The primary risk that a lender will consider is the borrower's ability to meet its payment obligations, its credit worthiness. These transactions in energy efficiency are readily understood as they follow similar rules to other forms of lending.

2.4.2 Leases. Leases are more complex. A lease agreement is a usage agreement between an owner, lessor and lessee (the user of the property). In return for the use of the property, in this case energy efficient systems, the lessee remits a periodic fee as compensation for the use of the property to the lessor. A lease differs from a loan in that there will be consideration of a residual value of the property at the end of the lease term. The payments will cover the difference between the predicted residual value, the principal required for the lessor to purchase the system and a return to the lessor.

Assuming that there is a residual value, payments for an equivalent system will be lower in a lease than in a loan over the same term. It is this assumption that causes most confusion in the industry. Leases are often referred to as "off balance sheet," implying that the lessor will not have to show the value of the asset (the energy efficient system) or the liability for the payment on their balance sheet. The further implication is that the payments are recorded simply as operating costs as they occur. This implication may be false. Transactions that are off balance sheet are highly structured. Since there are different methods of handling a lease for accounting and taxation purposes it is essential that professional advice is sought early on to ensure that the structure matches the business objectives of the deal.

2.4.3 Bonds. Bonds are another form of borrowing, often used in state and local government. They are effectively used to take advantage of tax-exempt status to reduce the interest charges. A bond is a loan. Unlike a classic loan where there is one lender, a bond will have many lenders - the bond holders. Proceeds from government bonds are usually for a specific purpose, perhaps in energy efficiency for infrastructure improvement. A bond certificate will state an obligation to pay back a specific amount of money, at a determined point in time, at a specific rate of interest. If the interest paid to the lender is tax-free, the lender can afford to charge a lower interest rate to make a reasonable rate of return.

2.5 Financial Risk Measurement

When creating financed energy efficiency project agreements, the parties enter into a contract where terms define and allocate risk among the parties. Generally, the lender will be looking for the most straight-forward allocation of risks. In financing efficiency projects, most risks 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 prefers to rely on one party for the performance risk, such as an ESCO.

2.5.1 Debt Service. Debt service coverage, which is the ratio of the projected savings to re-payment, 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 percent 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.

2.5.2 Construction Risks. Terms (risks) embodied in a construction contract are always present in a financed energy efficiency project. Basic risks and questions include:

- Who is responsible for the design?
- Who builds what, by when?
- Who pays whom, how much and when?

2.5.3 Performance Risks. As discussed in Section 2.2, when an energy savings performance contract is used, capturing the effect of "change" is particularly important. For example, considering which party estimated the savings and which party carries the financial impact of: i) a change in operating hours, ii) change in weather, iii) degradation in chiller efficiency, (iv) partial facility closure, and v) expansion to a third production shift, etc. is particularly important. The financial impact of these changes can be either positive or negative. For example, should an ESCO benefit from savings created by manual system manipulation, e.g., the facility-owner turns the lights off?

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 effect 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. 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 performs correctly. For this contract, Option A M&V method (as introduced in Section 3 below) is appropriate. Cost avoidance is calculated using a historical record of operation and measured change in the performance of the lighting system.

SECTION 3.0: OVERVIEW OF MEASUREMENT AND VERIFICATION

3.1 GENERAL APPROACH TO M&V

Energy savings are determined by comparing energy use associated with a facility, or certain systems within a facility, before and after ECM installation. The "before" case is called the baseline model. The "after" case is called the post-installation model. Baseline and post-installation models can be constructed using the methods associated with M&V options A, B, C and D as described in this Protocol. The challenge of M&V is to balance M&V costs, accuracy and repeatability with the value of the ECM(s) being evaluated.

In general:

ECM Energy Savings = Baseline Energy Use - Post-Installation Energy Use

Exceptions to this simple equation include the following:

1. New construction projects where baseline energy use has to be determined by methods other than pre-installation inspections or measurements (see Section 6.0).
2. Projects where the baseline is determined from other similar facilities, not from the facility where the retrofit actually occurred.

Since energy use at a facility is rarely if ever constant, another way to look at the definition of M&V is comparing post-installation energy use with what the facility would have used if the ECM had not been installed. This takes into account situations where baseline energy use must be adjusted to account for changing conditions such as: i) changes in facility operation, occupancy, or use or ii) changes in external factors such as weather.

There are two components associated with M&V of performance contract projects:

1. Verifying the ECM's potential to generate savings, also stated as confirming that: i) baseline conditions were accurately defined, and ii) the proper equipment/systems were installed, are performing to specification and have the potential to generate the predicted savings.
2. Determining actual energy savings achieved by the installed ECM(s).

Verifying baseline and post-installation conditions involves inspections (or observations), spot measurements and/or commissioning activities. Commissioning activities include:

1. Documenting ECM design assumptions.
2. Documenting ECM design intent for use by contractors, owners and operators.
3. Functional performance testing and documentation necessary to evaluate ECM acceptance.
4. Adjusting the ECM to meet actual needs within the system's capability.

For projects based on "pay for performance," each ECM or site will have a separate verification process to determine its savings. M&V activities may be conducted by the ESCO, building-owner or a third-party hired by either party. For each site or project, the baseline and post-installation energy use will be defined using a combination of metering, billing analysis and/or engineering calculations (including computer simulations). In addition, values for certain factors which affect energy use and savings, and which are beyond the ESCO's control, may be stipulated using historical data, analyses and/or the results of spot or short-term metering.

After each project is completed, the ESCO submits a report defining projected energy savings for the first year. Typically, first year payments to the ESCO are based on projected savings values submitted in the report. This post-installation report must be accepted and approved by the owner.

For the remaining contract term, the ESCO provides annual (or at some other regular interval) reports. These reports include inspections (or observations), documentation of the installed equipment/systems and, perhaps, updated savings values using data obtained and analyzed during each year of the contract. Previous payments would be reconciled, as necessary, and future year payments calculated based on report results. This report and payment reconciliation would not apply if the contract specifies fixed payments.

3.2 VERIFYING ECM POTENTIAL TO GENERATE SAVINGS

3.2.1 Baseline Verification. Baseline conditions may be defined by either the owner or the ESCO. If the baseline is defined by the owner, then the ESCO will have the opportunity to verify it. If the baseline is defined by the ESCO, then the owner will have the opportunity to verify.

Typically, projected savings from the ECM(s) are determined through an energy audit and engineering study. While this may be adequate for developing some agreements, it is typically inadequate for engineering design or M&V activities. Thus, what is called an investment grade audit is required. Baseline physical conditions (such as equipment inventory and conditions, occupancy, nameplate data, energy consumption rate, control strategies, etc.) are typically determined through well-documented audits, surveys, inspections and/or spot or short-term metering activities. The purpose of the documentation, with respect to M&V, is to: i) define the baseline for purposes of calculating savings and ii) document baseline conditions in case of future changes after ECM installation which may require baseline energy use adjustments.

3.2.2 Post-Installation Verification. One aspect of post-installation M&V is verification by both ESCO and owner that the proper equipment/systems were installed, are operating correctly and have the potential to generate predicted savings. Verification methods may include surveys, inspections and/or spot or short-term metering. System/equipment commissioning is expected to be completed by the ESCO or, in some cases, contracted out by the owner.

3.2.3 Regular Interval Post-Installation Verification. The ESCO and owner, at defined intervals during the contract term, verify that the installed equipment/systems have been properly maintained, continue to operate correctly and continue to have the potential to generate predicted savings.

3.3 DETERMINING SAVINGS

Once the ECM is installed, the ESCO and owner determine energy savings in accordance with an agreed-upon M&V approach, either continuously or at regular intervals, as defined in a site-specific M&V plan.

3.3.1 M&V Techniques. Baseline energy use, post-installation energy use and energy (and cost) savings can be determined using one or more of the following M&V techniques:

- Engineering Calculations
- Metering And Monitoring
- Utility Meter (gas or electricity) Billing Analysis
- Computer Simulations, e.g., DOE-2 Analysis
- Agreed-Upon Stipulations By The Owner And The ESCO

3.3.2 Stipulations. There are numerous factors that can affect energy savings during the term of a contract such as weather, operating hours for lighting projects, and part load performance and heat exchanger fouling for chiller replacement projects. In any savings analysis there will be some assumptions or stipulations. The number of stipulations and their importance will determine the accuracy of the savings estimate. In general, but not always, a contract objective may be to release the ESCO from responsibility for factors beyond its control such as building occupancy and weather, yet hold the ESCO responsible for controllable factors such as maintenance of equipment efficiency.

Therefore, in order to calculate energy savings the owner may, under certain circumstances, stipulate the value of factors which affect energy savings calculations. For example, for a lighting project the ESCO (or owner) measures the baseline and post-installation lighting fixture power draw and then stipulates the operating hours of the facility. For a chiller replacement project the ESCO (or owner) verifies the baseline and post-installation chiller performance factors (e.g., kW/ton, percent of rated load, parasitic load, etc.) and then stipulates the ton hours of cooling at the facility for annual energy savings calculation.

If important values are stipulated, it should be understood by both parties that the savings determination will tend to be less accurate than if measurements were used to determine the values that are stipulated. Sources of stipulations can be:

- historical data regarding equipment performance, systems or the facility as a whole.
- engineering analyses and/or computer simulations.
- spot or short-term metering that is completed for a limited period of time and then assumed to be appropriate for future years of the contract.

Stipulated values should be documented, agreed to as reasonable and then checked. A way to “check” values may be to compare total predicted savings with utility bills.

For other projects, continuous or regular interval measurements throughout the term of the contract are compared to baseline energy measurements to determine energy savings.

For example, for a "constant speed motor to variable speed drive motor" conversion, post-installation motor energy use may be continuously metered and compared to baseline measurements of motor energy use.

3.4 M&V IMPLEMENTATION PROCEDURES

M&V activities can be divided into the following tasks:

1. Define a general M&V approach for inclusion in the agreement between buyer and seller of energy services (i.e., the owner and the ESCO).
2. Define a site-specific M&V plan for the particular project being installed once the project has been fully defined, usually after the agreement is signed.
3. Define pre-installation baseline including: i) equipment/systems, ii) baseline energy use and iii) factors which influence baseline energy use - this could simply include site surveys of equipment and operating conditions; spot, short-term or long-term metering; and/or analysis of billing data.
4. Define post-installation including: i) equipment/systems, ii) post-installation energy use, and iii) factors which influence post-installation energy use - this could simply include site surveys; spot, short-term or long-term metering; and/or analysis of billing data.
5. Calculate energy savings for the first year or all of the remaining years of a contract.
6. Calculate first year payments.
7. Conduct annual M&V activities to verify operation of the installed equipment/systems and/or calculation of current year energy savings (if required in the contract).
8. Calculate annual payments.

The steps, which may be iterative, for defining an M&V plan include:

1. Identify goals and objectives.
2. Specify the characteristics of the facility and the ECM.
3. Specify the M&V Option, method and techniques to be used.
4. Specify data analyses procedures, algorithms, assumptions, data requirements and data products.
5. Specify the metering points, period of metering and analyses and metering protocols.
6. Specify accuracy and quality assurance procedures.
7. Specify how results will be reported and documented.
8. Define budget and resource requirements.

When defining an M&V plan, it is helpful to classify the project as one where baseline and post-installation energy use (or key parameters such as operating hours) are either constant during the contract term, or one (or both) vary with time, weather, occupancy or other independent variables. The following are three examples.

1. **Baseline And Post-Installation Operating Hours Are The Same During Term Of Agreement**. Example: Lighting project where lamps and ballasts in office building are changed, and the operating hours of the lights do not change during term of agreement, i.e. post-installation hours are assumed to be the same as baseline operating hours.

2. **<u>Baseline And Post-Installation Energy Use Vary During Term Of Agreement</u>**. Example: HVAC project where new chillers are installed, and building occupancy changes during agreement term.
3. **<u>Baseline Energy Use Remains Constant, And Post-Installation Energy Use Varies During Term Of Agreement.</u>** Example: Lighting controls project where occupancy sensors are installed, and the operating hours of the lights with occupancy sensors change during term of agreement.

It is important to realistically anticipate costs and effort associated with completing metering and data analysis activities. Time and budget requirements are often underestimated. It is better to complete a less accurate and less expensive M&V analysis than to have an incomplete or poorly done, yet theoretically more accurate M&V analysis that requires substantially more resources, experience and/or budget than available.

3.5 M&V Issues

<u>3.5.1 Third Party Reviewer</u>. Often the ESCO has more expertise and experience than the owner in dealing with performance contracts and ECM savings. Therefore, it is usually cost-effective and beneficial for the owner to utilize ESCOs or third-party M&V professionals to assist with defining M&V site-specific plans and analyzing the results. This helps provide a "level playing field" for negotiation and determination of savings and payments to the ESCO. M&V professionals are typically engineering consultants with experience and knowledge in verifying ECM savings, ECM technologies and performance contracting.

<u>3.5.2 Metering And Monitoring Issues Common To All Projects</u>. Metering is just one part of a successful M&V program. Other key components include:

1. Properly defining the project and critical factors which affect energy consumption in order to prepare an appropriate M&V plan. These factors may include minimum energy standards.
2. Completely defining baseline conditions such as comfort conditions, lighting intensities and hours of operation.
3. Defining analysis equations and required confidence in the savings calculations in order to determine: i) data which must be collected, ii) period of time for data collection and iii) the required accuracy of the data collection and analysis technique(s).

    - Calculate the value of the project in order to define a cost-effective level (accuracy) of M&V; address the relative value of the M&V information.
    - Use qualified staff and/or contractors to collect and analyze data.
    - Define the data reporting and archiving requirements.

<u>3.5.3 Metering and Monitoring Protocols</u>. A site-specific M&V plan should demonstrate that any metering and monitoring will be done in a consistent and logical manner, with a level of accuracy acceptable to all parties. Metering and monitoring reports should address exactly what was measured, how, with what meter, when and by whom. Calibration of sensors and meters to known standards, i.e., NIST standards, is required to ensure that data collected is valid. Project information and metered data should be maintained in usable formats. Both "raw" and "adjusted" data should be submitted to the owner through post-installation and regular interval reports.

Metering and monitoring duration should be sufficient to ensure an accurate representation of the amount of energy used by the affected equipment both before and after project installation. Measurements should be taken at typical system outputs within a specified (and representative) time period. These measurements can then be extrapolated to determine annual and time-of-use period energy consumption. The time period of measurement must be representative of the long-term, e.g. annual, performance of the ECM. For example, lighting retrofits in a 24-hour grocery store that is operated every day of the year may require only a few days of metering. However, a chiller retrofit may require metering throughout the cooling season or perhaps for one month each season of the year.

The required length of the metering period depends on the type of ECM(s). If, for instance, the project is a system that operates 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 extrapolated easily to the entire year.
However, if the project's energy use varies across both day and season, as with air-conditioning equipment, a much longer monitoring period may be required to characterize the system. In this case, long-term data is used to determine annual energy savings.

For some types of projects, metering time periods may be uncertain. For example, there is still controversy over how long lighting operating hours must be measured in office buildings to determine a representative indication of annual operating hours. For these situations, an agreement is required between project parties to determine the appropriate measurement period and accuracy level for the ECM(s) under consideration.

If energy consumption varies by more than ten percent from one month to the next, sufficient measurements should be taken to document these variances. In addition, changes that will effect the base year energy consumption adjustment by more than ten percent should also be documented and explained. Any major energy consumption variance due to seasonal activity increases or periodic fluctuations should also be monitored. If these variances cannot be monitored for whatever reason, they must be included in the annual energy consumption figure through a mathematical adjustment agreeable to both parties.

Energy use can be normalized as a function of some independent parameter such as temperature, humidity, product type or production quantity. Once the relationship between equipment energy consumption and parameter(s) is established, values of independent parameters measured during the post-installation period can be used to drive the baseline model. Extrapolation can be accomplished by extending the relationship over a one-year period. Therefore, a site-specific M&V plan should identify critical variables, explain how they will be measured or documented and discuss how they will be used in the empirical model. As well, assumptions and mathematical formulas used in the M&V plan must be clearly stated.

Additionally, any auxiliary energy-consuming equipment must be metered or modeled if its energy consumption changes as a result of project installation.

3.5.4 Energy Costs. For some projects, contract payments will be based on energy or demand savings, e.g., kWh, kW, therms, etc. For other projects, payments will be based on energy *cost* savings. When required, energy cost savings may be calculated using energy savings and the appropriate cost of energy. In most cases, the cost of energy will be based on the servicing utility's energy rate schedules (typically the rate schedules current at the time an agreement is executed). The cost of energy used in calculating energy cost savings should be defined in sufficient detail in the contract to allow accurate calculation using each of the factors which affect cost savings. These factors include items such as $/kWh saved, $/kW saved, power factor, kW ratchets, energy rate tiers, etc.

3.5.5 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 projected energy usage of the new equipment compared to minimum standard equipment. In these situations, baseline energy and demand consumption may be determined to be equal to or less than any applicable minimum energy standards.

3.5.6 Interactive Effects. It is commonly understood that various ECMs interact with each other. Reduced lighting loads, for example, can reduce air-conditioning energy consumption, but increase heating consumption. In cases where interactive effects are to be measured, M&V plans for electricity use, cooling and heating end use will need to be developed. However, the detailed relationship between most dissimilar, interactive ECMs is generally not known, and the methods for measuring interactive effects are not cost-effective for most applications. For these reasons, payments for ECM projects with interactive effects will typically:

- be made on savings directly related to the ECM being evaluated.
- include some stipulated interactive factors.
- be calculated based on Option C or D type analyses.

3.5.7 Baseline Adjustments. Baseline adjustments which may be required into the service phase of a contract are a common area of contention in performance contracts. Thus, even if utility bill analysis is used to determine energy savings, a complete and detailed audit (e.g. investment grade audit) is required. Examples of situations where the baseline needs to be adjusted are: i) changes in the amount of space being air conditioned, ii) changes in auxiliary systems (towers, pumps, etc.) and iii) changes in occupancy or schedule. If the baseline conditions for these factors are not well documented it becomes difficult, if not impossible, to properly adjust them when they change and require changes to payment calculations. For example, if a chiller retrofit takes place in a building with 100,000 square feet of conditioned space, and later (during the service phase) the building's conditioned space is reduced to 75,000 square feet, post-installation energy use would be lower and calculated savings would be higher, perhaps inappropriately higher, depending on the terms of the contract. However, if there were no records of how much space was originally conditioned, the baseline could not be adjusted to properly reflect "true" savings and ESCO payment.

Additionally:

1. Baseline adjustments for issues such as changes in number of production shifts, facility closures, adding new wings or loads (e.g. computers) require a conceptual approach/agreement in a contract versus a method to cover each eventuality.

    - Clearly predictable annual variations are usually handled through established procedures for each identified factor in the savings formulas.

- Changes which are considered permanent, such as changes in square footage, are handled through either agreement clauses which allow expected or predictable changes and/or through the use of a "re-open" clause, which allows either party to re-negotiate the baseline energy model.

2. Using Option A (options defined at the end of this Section 3.0), M&V techniques involving significant stipulations for the baseline adjustments are less likely to be required as many of the factors are stipulated, such as cooling load. This is one reason why Option A can be less accurate, but easier and less expensive to implement.

3. Option B involves metering techniques. Baseline capacity data is not changed (e.g., lighting wattages, chiller kW/ton and motor kW), but baseline "operating values" can be changed by use of post-installation monitoring data (e.g., operating hours and ton-hours). (See Section 4.0 for methods.)

4. For Option C billing analysis, time series comparisons or regression analyses of either typical values or post-installation values are defined for baseline and post-installation independent variables which influence energy use (e.g., weather and occupancy). It is important to agree in advance on those variables to be used.

5. For Option D calibrated simulation, it is important to agree in advance how the model will be calibrated and what changes will require a new simulation run. For typical retrofit and new construction projects, baseline and post-installation models are calibrated and then run with typical data (e.g., weather data). Thereafter they are not modified unless major changes occur in the building. Annual verifications are expected, however, under normal circumstances the models do not need to be run again.

3.6 WATER ISSUES AND M&V

Water efficiency performance contracts share many common aspects with energy performance contracts. This section outlines water efficiency in general, and discusses some M&V issues particular to water.

3.6.1 Water Projects In General. Providing clean, adequate water supplies and safe, efficient sewage treatment while controlling rising costs is a tremendous challenge. This challenge can in large part be met by retrofitting and upgrading aging, water-consuming equipment and plumbing systems in buildings. Building owners, residents, and local water and sewer authorities each benefit from efficiency investments.

Water resource efficiency has become one of the most successful tools that water and sewer providers are using to limit and manage the increasing costs of providing water and treating wastewater. Along with a cost reduction in overall water and sewer expense, building owners will realize a reduction in the energy used to heat water.

A partial list of water conservation measures that Water Service Companies (WASCOs)/ESCOs might consider includes:

- Replacing components of older plumbing systems with water-saving equipment such as Ultra Low Flow Toilets (ULFTs), high efficiency showerheads, aerators and self-closing valves.
- Eliminating continuously flowing urinals, lab drains, drinking fountains and other devices.
- Replacing once-through cooling devices for space cooling, icemaking and other purposes with closed loop or air cooled systems.
- Improving technologies and management techniques for boilers, dish washing, laundry and other special purposes.
- Identifying and repairing all leaks promptly.
- Maintaining proper pressure through use of Pressure Regulating Valves (PRVs).
- Decreasing use of water for landscaping purposes by implementing xeriscaping and more efficient irrigation systems and practices.
- Installing graywater, rainwater and reclaimed water recycling technology for flushing and/or irrigation which, in most utility jurisdictions, results in reduced wastewater charges.
- Installing meter monitoring equipment and sub-meters as needed so that increases in consumption over time can be quickly rectified.

The IPMVP Water Group has estimated that the savings potential from water efficiency projects is similar to that associated with energy. Table 1 below shows a rough approximation of the U.S. potential for bill savings from energy and water efficiency, assuming 25 percent reduction in water and energy consumption, and assuming that half of water savings will be heated water. As illustrated in Table 1, the economic, energy and water/wastewater benefits of water conservation activities are significant and generally should reflect savings greater than 60 percent of the potential residential energy savings. Energy savings associated with hot water reduction represents greater than 13 percent of the total potential level of cost-effective energy savings. Coupling water and energy performance measures is generally economically beneficial.

Table 1: Residential Annual Energy and Indoor Water Consumption/Potential Savings

	Primary Energy Consumption (quads)	Cost (billions)	Assumed Savings (percent)	Potential Level of Cost- Effective Savings (billions)
Total Household Energy (all uses)	18.5	$120	25%	$30
Indoor Water (supply and sewage)		$50	25%	$12
Total		*$170*	*25%*	*$42*
Total Energy Minus Hot Water	16.0	$104	25%	$26
Hot Water	2.5	$16	25%	$4
Hot Water & Indoor Water		$66	25%	$16

Combining water and energy savings into one contract can be both simple and beneficial. M&V techniques for these water-efficiency measures are generally the same M&V techniques used for energy conservation measures. In some cases, water sub-metering may be necessary to improve accuracy or project viability.

3.6.2 Initial Considerations. The most comprehensive approach to M&V for water is the whole-building or main-meter approach whereby all aspects of water usage are combined into a single program. Other M&V options have been used on water-efficiency programs worldwide, and these have been proven successful for specific facilities and/or owners.

As with other performance contracting projects, to begin the process an itemized water audit and cost analysis is completed by the WASCO/ESCO. A detailed measure implementation plan is developed. Based on consumption levels and water rates, the plan is designed to accomplish all water system upgrades comprehensively. The WASCO/ESCO must be responsible for actual water and sewer consumption, as measured by the water/sewer authority, in order for the main-meter approach to be successful.

Other M&V options are needed for large facilities with distinct water use areas that can be accurately metered and monitored. Examples include individual buildings on military bases, cooling towers, laundry facilities or graywater systems. As with all types of measures, savings estimates can be used by the owner and contractor if agreed to contractually.

To establish a baseline figure on which all savings calculations are based, the generally agreed-upon method is to average the previous 1-3 years of consumption (directly from past water/sewer bills) and convert this number into daily usage. This calculation typically is in gallons, but can also be in cubic feet or cubic meters. The baseline figure is in units of water/sewer use - Average Daily Consumption (ADC), not a monetary amount. During the term of the performance contract, this baseline figure will be converted into a monetary amount using the current water/sewer rate in that community. If a building owner wishes only to achieve savings on a discrete portion of a building, sub-meter monitoring equipment should be installed so that baseline consumption in that portion of the building can be established.

3.6.3 Use of Sub-meters and Data Loggers. Water sub-metering should be considered for facilities with significant single process use or outdoor water use. One benefit of sub-metering is that it provides continuous information on system efficiency, which can provide early warnings of system problems and may prove helpful if trouble-shooting is required. For example, a leak that could easily nullify all water savings resulting from a water measure can be more easily identified and repaired by regular reading of sub-meters. Sub-metering in multi-family residences can also lead to further savings, as it makes each unit financially accountable for water use.

Sophisticated water meter data loggers have been developed that can greatly assist in the M&V of water measures. The use of data loggers can often help identify actual savings when a facility faces considerable and/or uncontrollable changes in factors that affect water use, i.e., occupancy, weather, etc. Such changing factors can often be too expensive and nearly impossible to measure. With data loggers, water savings per occurrence of fixture use can be measured rather than relying on the measurement of overall water use reduction.

3.6.4 Water Rates. Water and sewer rates vary tremendously throughout the world. Many locations do not charge based on consumption and/or do not meter the service. Other jurisdictions charge only for water consumption and issue a flat bill for sewer services. Most areas bill for water and sewer service from meter readings, and a large percentage of charges are consumption based. These are the areas where performance contracting can be most successful for all parties involved.

3.6.5 Meter Accuracy. Water meter accuracy varies. Depending on the type of meter, size and age, a "properties reported consumption level" could be substantially lower than actual flow. With right-sizing and repair of meters by water authorities becoming more prevalent, agreed-upon baseline consumption figures (that reflect pre-program consumption) would be too low and/or too risky for a performance contract.

The quality of sub-meters must be addressed if these will be used to verify savings. Degradation of low quality meters can result in artificially low flow readings. WASCOs should not be rewarded for apparent savings that do not materialize on the main billing meter. All meters installed to verify savings should comply with the American Water Works Association (AWWA) or international accuracy standards.

3.6.6 Use of Nameplate Data. WASCOs and building owners/managers should not rely on nameplate data for M&V calculations of baseline water use or savings. The water consumed by most water fixtures can be easily adjusted to go well above or below nameplate specification. Actual use for existing fixtures should be determined by short-term metering or other techniques. All newly installed equipment should be tested and adjusted as needed.

3.6.7 Sanitary Considerations. Most domestic water use is for cleaning and transporting waste. These are sanitary functions which use equipment and systems designed to comply with carefully crafted sanitary codes and standards. Saving water through the use of methods which compromise system performance is unacceptable.

3.6.8 Long-Term Savings Considerations. The quality of the water and treatment chemicals used must be known so that premature degradation of elastomers in the plumbing system are anticipated and accounted for. Swelling and warping of rubber and vinyl compounds is well documented when the local water authority uses specific treatment chemicals and additives. Repair and replacement of washers, o-rings, restrictors, seals and flapper valves must be included for a long-term program to succeed.

The practice of using metal water piping to ground electrical systems should be avoided as it leads to a premature failure of components of the water delivery system and to possible deterioration in water quality. This improper grounding causes an electrolytic reaction that leads to a type of point scale corrosion, greatly accelerating the leaching of metal pipe and solder into the water. As this process continues, pipes will develop pin-hole leaks which can cause property damage.

In addition to the proper grounding of the electrical system using specialized grounding rods, installation of dielectric couplings should be installed on water pipes leading to water heaters and boilers to further isolate this equipment from stray electrical currents. This ties in with the energy management program because it helps ensure that major mechanical equipment has a prolonged life span.

M&V of specific water sub-meters must be continuous during the life of the contract. After establishing post-installation consumption patterns, leaks that can affect total savings over time will be identified and rectified.

3.7 CREDIT FOR OFF-SITE (WATER PUMPING AND TREATMENT) ENERGY SAVINGS

Although this approach has not yet been used in any practical projects, WASCOs/ESCOs or building owners may be able to obtain incentives for water measures from energy utilities based on anticipated long-term off-site energy savings associated with water and wastewater treatment and pumping. Use of this Protocol may lend credibility to such efforts and provide the basis for claiming any credits or incentives.

Electric utilities could provide such incentives directly to building owners and WASCOs/ESCOs after they come to an agreement with the local water and wastewater utilities on the amount of energy savings that result from decreased water demand. Such a calculation needs to be revisited as treatment and delivery technologies change. In the future, such incentives for water measures could also be given for off-site pollution and storm water problem abatement. Electric utilities in communities where water utilities rely on deep or long-distance pumping, or energy intensive treatment such as reverse osmosis are likely candidates for such arrangements.

3.7.1 Energy Use. As shown in Table 2, 91 percent of the energy associated with municipal water consumption is used on-site, primarily to heat water in homes and buildings, while nine percent of it is consumed off-site for pumping and treatment. Many water measures lead to significant energy savings by reducing such needs. This table should not be used as the basis for engineering calculations. The actual breakdown will vary greatly from one utility service area to another depending on the relative use of electric versus gas water heaters and on treatment and distribution needs.

Table 2: Relative Magnitude of Energy Requirements for U.S. Residential Water Use

Purpose*	Percentage of Total*	Annual Nationwide Cost†
Water Transportation (Off-Site)	3%	$0.5 billion
Water Treatment (Off-Site)	2%	$0.33 billion
Treated Water Distribution (Off-Site)	2%	$0.33 billion
Wastewater Treatment (Off-Site)	2%	$0.33 billion
Sub Total of Off-Site Energy Use	9%	$1.6 billion
Water Heating (On-Site)	91%	$16 billion
Total	100%	$17.6 billion

**Source: American Water Works Association, 1987; †From Table 1*

Off-Site Savings. Energy requirements for water transportation, treatment, delivery and wastewater treatment vary from one community to the next due to differences in the distance (or depth) to supplies, water quality, terrain, climate, population density and other factors. Often 30 to 50 percent of the electrical demand at water treatment plants can be saved by upgrading pumps, aeration systems and reducing friction losses, and additional energy can be saved by reducing the demand for water or wastewater treatment. It is these latter savings that could be of interest to some ESCOs.

WASCOs/ESCOs should be aware that a given percentage reduction in water use will not necessarily lead to an equal reduction in off-site energy use. The actual ratio will depend greatly on service area- specific criteria. One study of wastewater treatment plants, for example, indicates an average reduction in energy demand of only 1.4 percent resulting from every three percent decrease in sewage flow.

The figures in this section are included solely to indicate the magnitude of the off-site energy/water relationship. WASCOs/ESCOs should work with local water and energy utilities to obtain service area-specific information.

3.8 ENERGY SAVINGS RESULTING FROM WATER MEASURES

3.8.1 On-Site Savings. On-site energy savings, or savings that accrue directly to a building owner/tenant, are usually the result of lowered water heating needs, but in some cases may also include lowered on-site pumping and treatment needs. This is often true for water measures involving high-rise apartment and office buildings that use pumps to boost water pressure or facilities that utilize pumps to irrigate with groundwater. In some cases, WASCOs/ESCOs should consider sub-metering such pumps.

BOX 1: ENERGY SAVINGS FROM WATER PROJECTS

This example has been adapted from actual project data provided by Pio Lombardo of Lombardo Associates, Boston, MA, on a water efficiency project carried out in an apartment building in the Northeastern United States. The details on how the project was carried out have been altered slightly to highlight certain steps in the process of determining water savings achieved from a water efficiency project. Rather than focusing on M&V methodologies, this example provides the order of magnitude of potential savings from a real-life project. The project involved repairing leaks and replacing toilets, showerheads and faucets in a 1,000-person apartment building. The project cost was $210,000 with a payback period of 32 months. It did not address outdoor water use.

Table B1: Building Water Consumption (1,000 residents)

	Number	Measured Pre-Project Flow	Measured Post-Project Flow
Units	325		
Toilets	325	5.0 gpf*	1.6 gpf
Kitchen faucets	325	4.8 gpm†	2.2 gpm
Bathroom faucets	325	2.64 gpm	2.0 gpm
Shower heads	325	5.28 gpm	2.5 gpm

*gpf = gallons per flush
†gpm = gallons per minute

Table B2: Annual Savings

	Pre-Project	Post-Project
Annual Water Use	34,637,000 gallons (131,000 m^3)	17,941,000 gallons/yr (68,000 m^3)
Water & Sewer Rate	$3.50/1000 gallons ($0.924/m^3)	$3.50/1000 gallons ($0.924/m^3)
Annual Water Cost	$120,000	$63,000
Water Savings		**$57,000**
Heated Water Percentage	59%	63%
Annual Heated Water Use	20,436,000 gallons (77,000 m^3)	11,303,000 gallons (43,000 m^3)
Water Heating Rate‡	$2/1000 gallons ($0.529/m^3)	$2/1000 gallons ($0.529/m^3)
Annual Water Heating Cost	$41,000	$22,000
Energy Savings		**$19,000**

‡This cost is based on a gas cost of $0.439/therm ($0.155/m3) combined with assumptions about water heater efficiency and occupant usage for different types of fixtures. If the WASCO will be getting credit for energy savings, it may be worthwhile to invest more to improve this estimate by:

- metering a sample of fixtures to determine the actual amount of hot water heated.
- metering water flowing into water heater.
- metering throughout the year to determine the seasonal variation.

As noted above, most energy savings resulting from water measures are due to lowered hot water needs and are the result of replacing faucets, showers, washing machines and dishwashers. Some studies have shown that replacing showerheads and faucets in a typical household can reduce water use by up to 15,000 gallons per year and cut annual energy costs by $140 in homes with electric water heaters. Actual savings may vary greatly based on the type of water heater, efficiency, usage patterns and other variables, and will likely be much greater for high-use fixtures in commercial buildings.

WASCOs/ESCOs need to be aware, however, that in some warm, humid climates hot water is also used to temper cold water in toilet and urinal cisterns in order to prevent condensation problems. In addition, in some very cold climates hot water is bled into cisterns and cold water pipes to prevent freezing problems. While fixture retrofits may greatly reduce hot water needs for these purposes, it is generally preferable to retrofit the fixtures and to reduce or eliminate the need for hot water by using strategies such as insulating cisterns, insulating pipes, passive heating of cold water pipes and other techniques.

Finally, certain water measures may actually lead to increases in on-site energy use. Switching from a once-through cooling system to a closed-loop or air-cooled system can greatly reduce water usage, but requires fans or pumps and can lower cooling efficiency, depending on the temperature of incoming water. WASCOs/ESCOs should take such increases in energy demand into account when determining overall energy savings accruing to a specific site.

3.8.2 M&V of On-Site Energy Savings. For projects involving significant hot water savings from water measures in large facilities as well as other measures, a separate water meter for hot water demand can help distinguish the source of energy savings. In some such cases, extrapolation of energy savings based on a pre-agreed factor of assumed heating system efficiency is sufficient (a variation of M&V Option A), while in other cases, installation of gas and/or electric sub-meters may also be warranted (a variation of M&V Option B).

Water sub-metering should also be considered for facilities with significant single-process use or outdoor water use. Water and electrical sub-metering should be considered in cases where there is significant electrical demand for groundwater pumping or pressure boosters.

One benefit of sub-metering both energy and water in these situations is that it provides continuous information on the efficiency of the systems in terms of energy consumption per unit of water consumed, which can provide ESCOs and building owners/managers with early warnings of system problems and may prove helpful if trouble-shooting is required.

M&V Option C is appropriate to measure water savings for situations where there is no significant hot water, outdoor, pressure-booster or single-process use. An office building where water demand is primarily for toilet flushing is one example.

For some facilities, WASCOs/ESCOs should collect additional data that correlate with energy and water use for some processes, such as weather data and cooling or landscape water use, or correlate water use and the number of process cycles, car washes, laundry loads, etc. As with sub-metering of water and energy, such data can assist WASCOs/ESCOs and building owners/managers in diagnosing inefficient or faulty systems.

3.9 DEFINING THE APPROPRIATE LEVEL OF M&V

The level of certainty required for verifying ECM energy-saving potential and actual savings will vary from project to project. The confidence which is appropriate for establishing savings is a function of project value and the cost-effectiveness of increasing or decreasing confidence in savings. Factors which will affect effort level and cost are:

- Value of ECM in terms of projected savings
- Complexity of ECM
- Number of ECMs at a single facility and the degree to which savings are interrelated
- Number of interrelated ECMs
- Uncertainty of savings
- Risk allocation between ESCO and owner for achieving savings
- Other uses for M&V data and systems

With respect to ECM value, suppose a project has an expected savings of $100,000 per year, and that it was believed that this estimate had a resolution of plus or minus 25 percent (±25%) or $25,000 per year. Thus, it may be reasonable to spend $5,000 per year on M&V to bring the actual determination of savings to within an accuracy of plus or minus ten percent (±10%). However, it would not be appropriate to spend $30,000 per year on M&V as the value of the information (resulting in changes in payment and/or savings realized) would not be worth the price paid.

Factors which typically affect M&V accuracy and costs are (some of these are inter-related):

- Level of detail and effort associated with verifying baseline and post-installation surveys
- Sample sizes (number of data points) used for metering representative equipment
- Duration and accuracy of metering activities
- Number and complexity of dependent and independent variables which are metered or accounted for in analyses
- Contract term
- Confidence and precision levels specified for energy savings analyses

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. For certain types of projects, a statistical definition of accuracy could be included in a contract. For other types of projects, it may be only possible to define a subjective accuracy range or percent of payment budget for M&V.

3.9.1 Value Of ECM In Terms Of Projected Savings. Scale of a project, energy rates, term of contract, comprehensives of ECMs, benefit sharing arrangement and magnitude of savings can all affect the value of the project. The M&V effort should be scaled to the value of the project's savings so that the value of information provided by M&V activity is appropriate to project value. "Rule of thumb" estimates put M&V costs at 1-10 percent of typical project construction cost, with a maximum of 20 percent.

3.9.2 Complexity of ECM. More complex ECM projects may require more complex and expensive M&V methods to determine energy savings. However, this is not always the case. In general, the complexity involved in isolating savings is the critical factor. A complicated HVAC measure may not be difficult to assess if there is a utility meter dedicated to the HVAC system, or if savings are large enough to measure with the whole-building meter.

When defining the appropriate M&V requirements for a given project it is helpful to place projects in one of the following categories (listed in order of increasing M&V complexity):

1. Constant Load, Constant Operating Hours
2. Constant Load, Variable Operating Hours
   - Variable Hours With A Fixed Pattern
   - Variable Hours Without A Fixed Pattern, i.e., Weather Dependent
3. Variable Load, Variable Operating Hours
   - Variable Hours Or Load With A Fixed Pattern
   - Variable Hours Or Load Without A Fixed Pattern, i.e., Weather Dependent

3.9.3 Number Of ECMs At A Single Facility And The Degree To Which Their Savings Are Interrelated. If there are multiple ECMs being installed at a single site, savings from each measure may be, to some degree, related to the savings of other measure(s) or other non-ECM activities at the facility, e.g., interactive effects between lighting and HVAC measures, or HVAC control measures and a chiller replacement. In these situations it will probably not be possible to isolate and measure one system in order to determine savings. Thus, for multiple, interrelated measures, Options C or D are almost always required.

3.9.4 Uncertainty Of Savings. The importance of M&V is often tied to the uncertainty associated with estimated energy or cost savings. ECMs with which the facility staff are familiar may require less M&V than other, uncommon ECMs. In addition, if a given ECM project is similar to other projects which have documented savings, M&V results may be applied from the other project.

3.9.5 Risk Allocation Between The ESCO And Owner. If an ESCO's payments are not tied to actual savings, M&V is not typically required (but still may be desired by the owner). Conversely, if an ESCO is not held responsible for certain aspects of project performance, these aspects may not have to be measured or verified. The contract should specify how payments will be determined and exactly what needs to be verified. For example, variations in facility operating hours during the contract term may be a savings risk the owner takes. Consequently, operating hours need not be continuously measured for purposes of payment. In this example, the Option A approach may be appropriate.

3.9.6 Other Uses for M&V Data and Systems. Often the array of instrumentation installed and measurements collected during M&V can be used for other purposes. These include commissioning, system optimization and fine tuning, diagnostics, alarms and control. Such uses can be more cost-effective if combined with the objectives of M&V activities. In addition, there is possible interest in quantifying savings beyond performance contract requirements. Information may be desired for cost-allocation between facility tenants for future projects or research purposes.

3.10 MEASUREMENT AND VERIFICATION OPTIONS

Each of the four M&V options defined in this Protocol is applicable to different types of performance contracts, project values and risk sharing between the ESCO and the owner. The purpose of defining several M&V options is to allow for variations in the cost and methods for assessing savings. Consequently, the M&V options described within this Protocol vary in accuracy, cost of implementation, strengths and limitations.

Both parties should select an M&V option and method for each project and then prepare a site-specific M&V plan that incorporates project-specific details. The M&V options have been defined to help organize selection; Table 3 below provides a quick overview of the options. The options have several similarities and are defined by their differences. Option A emphasizes verification of performance factors and involves determining long-term savings through the liberal use of stipulations for operational factors. Options B and C involve use of long-term metering data; Option B involves end-use data analyses and Option C involves whole-building data analyses. Option D is calibrated simulation and can involve a combination of Option A stipulations and Options B or C, end-use or whole-building data analyses.

It is important to note that all methods of defining savings are estimates. ***Performance can be measured, savings cannot be measured.*** The options described in this document are created to meet the needs of a wide range of contracts that use savings to determine financial payments. It is vital to understand the limitations as well as the strengths of each method presented.

M&V costs depend on many factors such as the:

- M&V option method selected.
- complexity of the ECM.
- number of exterior factors affecting its performance.
- number of similar ECMs in a single project or program.
- accuracy requirements.
- duration of contract.
- reporting requirements.
- experience and professional qualifications of the people conducting M&V.

As a general rule, M&V costs should fall within the ranges listed in Table 3 below. Percentages listed are representative of a percentage of construction costs for the project.

Table 3: Overview of M&V Options

M&V Option	**How Savings Are Calculated**	**Cost**
Option A: Focuses on physical assessment of equipment changes to ensure the installation is to specification. Key performance factors (e.g., lighting wattage or chiller efficiency) are determined with spot or short-term measurements and operational factors (e.g., lighting operating hours or cooling ton-hours) are stipulated based on analysis of historical data or spot/short-term measurements. Performance factors and proper operation are measured or checked annually.	Engineering calculations using spot or short-term measurements, computer simulations, and/or historical data.	Dependent on no. of measurement points. Approx. 1-5% of project construction cost.
Option B: Savings are determined after project completion by short-term or continuous measurements taken throughout the term of the contract at the device or system level. Both performance and operations factors are monitored.	Engineering calculations using metered data.	Dependent on no. and type of systems measured and the term of analysis/metering. Typically 3-10% of project construction cost.
Option C: After project completion, savings are determined at the "whole-building" or facility level using current year and historical utility meter (gas or electricity) or sub-meter data.	Analysis of utility meter (or sub-meter) data using techniques from simple comparison to multivariate (hourly or monthly) regression analysis.	Dependent on no. and complexity of parameters in analysis. Typically 1-10% of project construction cost.
Option D: Savings are determined through simulation of facility components and/or the whole facility.	Calibrated energy simulation/modeling; calibrated with hourly or monthly utility billing data and/or end-use metering.	Dependent on no. and complexity of systems evaluated. Typically 3-10% of project construction cost.

3.10.1 Option A. The verification techniques for Option A determine savings by measuring the capacity or efficiency of a system before and after a retrofit, and multiplying the difference by an agreed-upon or "stipulated" factor, such as hours of operation or load on the system. Option A is best applied to individual loads or systems within a building, such as a lighting system or chiller. This method is appropriate for projects where both parties will agree to a payment stream that is not subject to fluctuation due to changes in the operation of the equipment. Payments could be subject to change based on periodic measurements of system performance.

Option A is an approach designed for projects where the potential to generate savings needs to be verified, but actual savings can be stipulated based on the results of the "potential to generate savings" verification and engineering calculations (and possibly short-term data collection). Post-installation energy use is not measured throughout the term of the contract.

Post-installation and perhaps baseline energy use is predicted using engineering or statistical analysis of information that does not involve long-term measurements. Data from the estimates may come from historical data, information from other similar projects and/or spot or short-term metering before and after ECM installation during the first year of operation. Stipulation is the easiest and least expensive method of determining savings. It can also be the least accurate and is typically the method with the greatest uncertainty of savings. Option A includes procedures for verifying that:

- baseline conditions have been properly defined.
- the equipment and/or systems contracted to be installed have been installed.
- the installed equipment/systems meet contract specifications in terms of quantity, quality and rating.
- the installed equipment is operating and performing in accordance with contract specifications and is meeting all functional tests.
- the installed equipment/systems continue, during the term of the contract, to meet contract specifications in terms of quantity, quality and rating, operation and functional performance.

This level of verification is all that is contractually required for certain types of performance contracts. Baseline and post-installation conditions (e.g., equipment quantities and ratings such as lamp wattages, chiller kW/ton or motor kW) represent a significant portion of the uncertainty associated with many projects.

All end-use technologies can be verified using Option A. However, the accuracy of this option is generally inversely proportional to the complexity of the measure. Thus, the savings from a simple lighting retrofit will typically be more accurately estimated with Option A than the savings from a chiller retrofit. If greater accuracy is required, Options B, C or D may be more appropriate.

Within Option A various methods and levels of accuracy in verifying performance are available. The level of accuracy depends on the quality of assumptions made, and can depend on whether just an inventory method is used for ensuring nameplate data and quantity of installed equipment, or whether short-term measurements are used for verifying equipment ratings, capacity, operating hours and/or efficiency. The potential to generate savings may be verified through observation, inspections and/or spot/short-term metering conducted immediately before and/or immediately after project installation. Annual (or some other regular interval) inspections may also be conducted to verify an ECM's continued potential to generate savings.

Savings potential can be quantified using any number of methods, each depending on contract accuracy requirements. Equipment performance can be obtained either directly (through actual measurement) or indirectly (through the use of manufacturer data). There may be sizable differences between published information and actual operating data. Where discrepancies exist, or at least are believed to exist, field operating data should be obtained. This could include spot measurement for a constant load application. Short-term M&V can be used if the application is not proven to be a constant load. Baseline and post-installation equipment should be verified with the same level of detail. Either formally or informally, all equipment baselines should be verified for accuracy and for concurrence with stated operating conditions. Actual field audits will almost always be required.

3.10.2 Option B. Verification techniques for Option B are designed for projects where long-term continuous measurement of performance is desired. Under Option B, individual loads are continuously monitored to determine performance, and this measured performance is compared with a baseline to determine savings. Option B M&V techniques provide long-term persistence data on ECM operation and performance. This 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. Option B also relies on the direct measurement of affected end uses.

Option B is for projects where: i) the potential to generate savings needs to be verified, and ii) actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A plus determining energy savings during the contract term through the use of end-use metering. Option B:

- confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings.
- determines an energy (and cost) savings value using measured data taken throughout the contract term.

All end-use technologies can be verified with Option B. However, the degree of difficulty and costs associated with verification increases proportionately as metering complexity increases. Energy savings accuracy is defined by the owner or negotiated with the ESCO. The task of measuring or determining energy savings using Option B can be more difficult and costly than Option A. Results, however, will typically be more precise.

Option B methods involve the use of post-installation measurement of one or more variables. The use of periodic or long-term measurement accounts for operating variations and will more closely approximate actual energy savings than the use of stipulations as defined for Option A. However in instances such as constant load retrofits, there may be no inherent increase in accuracy. Measurement of all end-use operating systems may not be required through the use of statistically valid sampling. Examples of this include measurement of operating hours for a selected group of lighting fixtures or power draw of certain constant load motors which have been pre-determined to operate in a similar manner.

3.10.3 Option C. Verification techniques for Option C determine savings by studying overall energy use in a facility and identifying the effects of energy projects from changes in overall energy use patterns. Option C methods are required when measuring interactions between energy systems is desired, and when determining the impact of projects that cannot be measured directly, such as insulation or other envelope measures, is necessary.

Option C may be applied to projects where: i) the potential to generate savings needs to be verified, and ii) actual energy use during the contract term needs to be measured for comparison with the baseline model for calculating savings. Option C involves procedures for verifying the same items as Option A plus determining energy savings during the contract term through the use of whole-building metering data. Option C:

- confirms that the proper equipment/systems were installed and that they have the potential to generate predicted savings.
- determines an energy savings value using measured utility meter data taken throughout the contract term.

All end-use technologies can be verified with Option C providing the reduction in consumption is larger than the associated modeling error. This option may be used in cases where there is a high degree of interaction between installed energy conservation systems and/or the measurement of individual component savings is difficult. Accounting for changes (other than those caused by the ECMs) is the major challenge associated with Option C - particularly for long-term contracts.

The following points should be considered when conducting utility billing analysis for M&V:

1. All explanatory variables that affect energy consumption as well as possible interactive terms (i.e., combination of variables) need to be specified, whether or not they are accounted for in the model. Critical variables can include weather, occupancy patterns, set points and operating schedules.
2. Independent variable data needs to correspond to the time periods of the billing meter reading dates and intervals.
3. If the energy savings model discussed above incorporates weather in the form of heating degree days and cooling degree days, the following issues should be considered:

   - Use of the building “temperature balance point” for defining degree days versus an arbitrary degree day temperature base.
   - The relationship between temperature and energy use that tends to vary depending upon the time of year. For example, an ambient temperature of 55°F in January has a different implication for energy usage than the same temperature in August. Thus, seasons should be addressed in the model.
   - The non-linear response to weather. For example, a 10°F change in temperature results in a very different energy use impact if that change is from 75°F to 85°F rather than 35°F to 45°F.
   - Matching degree day data with billing start and end dates.

4. The criteria used for identifying and eliminating outliers needs to be documented. Outliers are data beyond the expected range of values (or two-to-three standard deviations away from the average of the data). Outliers should be defined using common sense as well as common statistical practice.

5. Statistical validity of the final regression model needs to be demonstrated. Validation steps include checks to make sure:

- the model makes intuitive sense, e.g., the explanatory variables are reasonable and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- modeled data is representative of the population.
- model form conforms to standard statistical practice.
- the number of coefficients is appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations).
- all model data is thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.

Option C usually requires at least 9 to 12 months of continuous data before a retrofit and continuous data after the retrofit, where the data can be hourly or monthly whole-building data.

3.10.4 Option D. Option D is intended for energy retrofits where calibrated simulation of baseline energy use and calibrated simulations of post-installation energy consumption are used to measure savings from the retrofit. Option D can involve measurements of energy use both before and after the retrofit for specific equipment/systems or whole-building data for calibrating the simulation(s).

Option D may be applied to projects where: i) the potential to generate savings needs to be verified, and ii) actual energy use during the contract term needs to be analyzed for comparison with the baseline model for savings calculation. Option D involves procedures for verifying the same items as Option A plus determining energy savings during the contract term through the use of calibrated building simulation. Option D:

- confirms that the proper equipment/systems were installed and that they have the potential to generate the predicted savings.
- determines an energy savings value using measured utility meter data taken throughout the term of the performance contract and/or computer simulation documentation.

All end-use technologies can be verified with Option D providing the size of the drop in consumption is larger than the associated modeling error. This option may be used in cases where there is a high degree of interaction between installed energy conservation systems and/or where measurement of individual component savings is difficult. Accurate modeling and calibration is the major challenge associated with Option D.

The building simulation model may involve elaborate models (such as DOE-2), spreadsheets, vendor (e.g., VSD) estimating programs, etc. Calibration is accomplished by linking simulation inputs to actual operating conditions and comparing simulation results with end-use or whole-building data. The simulation may be of a whole facility or just the effected ECM end-use.

The following points should be considered when completing simulations for M&V:

1. Simulation analysis needs to be conducted by trained and experienced personnel who are familiar with the software used.

2. Input data should represent the best available information including, if possible, the same or similar data and precautions described above for billings analysis.
3. The simulation needs to be calibrated by its ability to track with real utility billing data and/or sub-metering data within acceptable tolerances.
4. Simulation analyses need to be well documented with hard copy and electronic copies of input and output "decks" as well as the survey and metering/monitoring data used to define and calibrate the model.

3.11 SPECIFICATION OF THE IPMVP FOR PROJECTS

Only "specifying" use of the IPMVP is not an adequate definition of how M&V will be conducted for a specific project or program. Since the IPMVP contains a wide range of different M&V options and methods, an ESCO could claim compliance while conducting M&V with any of the numerous methods described, with an unspecified level of accuracy and without assurance of repeatable of results. At this time there is no formal or informal group that checks compliance with the Protocol.

The proper use of the IPMVP and the specification of a M&V method require, at least the following:

- State the document to be referenced, e.g. the IPMVP.
- State which option and method from the document will be used, e.g. Option B with post-installation metering of operating hours.
- Indicate who will conduct the M&V.
- Define the details of how calculations will be made.
- Specify metering to be conducted including information on the equipment, calibration, location of measurements, metering period, etc.
- Define key assumptions to be made about significant variables or unknowns.
- Define the level of accuracy to be achieved, if not for the entire analysis, at least for key components.
- Indicate how quality assurance will be maintained and repeatability confirmed.
- Indicate reports to be prepared, their contents and when they are to be provided.

SECTION 4.0: DESCRIPTION OF M&V OPTIONS, WITH EXAMPLES

4.0.1 DOCUMENTING BASELINE/INSTALLED EQUIPMENT

Energy consuming equipment to be replaced or modified as part of an energy conservation project requires a thorough documentation of the installed equipment operating during the baseline and post-installation periods. The following are general sources of additional information: ASHRAE (1995), Dukelow (1991), Dyer and Maples (1981), Dubin and Long (1978), Dubin et al. (1976), Dutt and Harrje (1988a; 1988b), DOE (1980), EPA (1993), Fracastoro and Lyberg (1983), Haberl et al. (1990; 1992a; 1992b), Haberl and Komor (1989), Harrje (1982), Harrje (1986), IES (1987), Jilar (1990), Lyberg (1987), MacDonald et al. (1989), SMACNA (1985), Stein and Reynolds (1992), Ternes (1987), Turner (1993) and Witte et al. (1988).

PROCEDURES

At a minimum, the following procedures are recommended to characterize and document installed equipment during the baseline and post-installation periods:

- Record the location and count of equipment to be retrofitted so that it can easily be located on a set of plans. Indicate the facility, room and location of the equipment within the room.
- Photograph and/or videotape the equipment to accurately document its condition. Each piece of equipment, or equipment lots, should have the manufacturer's model number, serial number and nameplate information recorded. This information is usually necessary when contacting the manufacturer to obtain equipment performance specifications.
- If a lighting retrofit is being considered, measure baseline and post-installation lighting illuminance levels using standard Illuminating Engineering Society (IES) measurements. Determine lighting fixture operating schedules including: general, task, hallway and exterior lighting.
- If a heating/cooling equipment retrofit is being considered, determine system setpoints and operating schedules including: thermostat setpoints; system temperature settings, i.e., cold deck temperature, boiler temperature/pressure; on/off schedules for air-handler units, pumps, air conditioners, chillers, boilers, etc. 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.

4.1 OPTION A: END-USE RETROFITS - MEASURED CAPACITY, STIPULATED CONSUMPTION APPROACH

Option A, the first approach to M&V presented in this protocol, is intended for retrofits where end use capacity, demand or power level can be measured or stipulated with manufacturer's measurements, and energy consumption or operating hours are known in advance, stipulated or agreed upon by both parties. Option A usually involves a one-time measurement of the instantaneous baseline energy use, and a one-time measurement of the instantaneous post-installation energy use. In certain circumstances, representative measurements can be made in place of in-situ measurements where multiples of identical units are being installed. Periodic equipment inspections may also be warranted. Estimated or stipulated energy consumption is calculated by multiplying the measured end use capacity (i.e., the kW, Btu/hr or kJ/hr) by the stipulated hours of operation for each characteristic mode of operation (i.e., weekday/weekend hourly profiles).

4.1.1 Confirming Installed Equipment Performance. Option A performance verification is estimated or stipulated by multiplying the representative energy capacity by the stipulated hours of operation. The capacity, demand or power level (i.e., kW, Btu/hr or kJ/hr) needs to be stipulated or measured using one-time, in-situ end-use measurements. The capacity may be estimated with representative sample measurements, representative manufacturer's measurements or representative baseline power levels. The hours of operation are either known in advance, stipulated or agreed upon by both parties. Each of these methods is described below.

One-Time, In-Situ End-Use Measurement METHOD. One-time, in-situ end-use measurements are measurements taken at the site using calibrated instrumentation. Information regarding calibration and instrumentation can be found in Section 5.0 of this document. Such measurements are appropriate for energy consuming equipment that does not vary significantly in load, i.e., by more than plus or minus five percent (±5%) of the reading.

For electrical loads, this type of measurement usually requires isolating the device to be measured and measuring the electrical power (RMS Wattage) that the device draws on all phases. Thermal energy use measurements are measurements taken after the energy fuel (electricity, natural gas) has been converted into thermal energy (steam, hot or chilled water). Thermal energy use measurements of chilled water or hot water usually require a volumetric flow rate per unit time which is then converted to a mass flow rate (m), a specific heat value (cp) and a temperature difference (delta-T). Steam measurements require a steam mass flow rate (m), temperature (T) and pressure (P) of the steam, and temperature of the boiler feedwater. Thermal fuel energy use measurements are measurements of the weight, mass or quantity of fuel being consumed by the energy conversion device including: electricity, coal, wood, biomass, natural gas, oil and/or various forms of liquid petroleum. The energy content of the fuel is also needed to convert the fuel to units of energy.

Representative Sample Measurement METHOD. Representative sample measurements are measurements taken with calibrated instrumentation on a representative sample of equipment being installed. Representative sample measurements are appropriate for energy consuming equipment that does not vary significantly in load and must be taken on similar equipment model types. Estimates using representative sample measurements and stipulated consumption may be adversely affected by inaccurate one-time, in-situ measurements if proper care is not exercised.

Representative Manufacturer's Measurement METHOD. Representative manufacturer's measurements are measurements published by the manufacturer of the equipment. In order for such measurements to be valid, they should be taken with calibrated instruments on a representative sample of equipment being installed. Representative manufacturer's measurements are appropriate for energy consuming equipment that does not vary significantly in load and must be taken on similar equipment model types. Estimates using manufacturer's sample measurements and stipulated consumption may be adversely affected by the same factors as one-time, in-situ measurements.

Representative Baseline Power Level Profile METHOD. Representative baseline power level profiles are either hourly or 15-minute measurements taken at the site usually at the whole-facility level or sub-panel level using portable monitoring equipment. These measurements represent an aggregate end-use load, e.g., all motors or lighting loads in a facility. Representative baseline power level profiles capture the in-situ 24-hour profiles of a group of equipment operating during weekday or weekend modes. Such measurements are appropriate for non-weather-dependent energy consuming equipment loads that vary within a 24-hour period, but do not vary daily by more than plus or minus ten percent (±10%). Examples include: weekday/weekend whole-facility lighting and motor control center loads that include only constant load motors. In general, representative baseline power level profiles can be used to measure weather-independent loads. Representative baseline power level profiles for weather-dependent loads should include measurements taken over a long enough period to adequately characterize the schedule (i.e., weekday/weekend and weather-dependent characteristics of the end use load). Examples of day-type profiling can be found in Katipamula and Haberl (1991), Akbari et al. (1988), Hadley and Tomich (1988), Bou Saada and Haberl (1995a, 1996) and Bou Saada et al. (1996).

4.1.2 Examples. Both owner and contractor/ESCO should understand that each of the options and examples presented in this section contain some uncertainties. Any of these measurement approaches may be applied to the example projects providing both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies them. In all cases, existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

Option A: Lighting Efficiency and/or Controls Project. Lighting projects require that capacity, demand or power level (kW) be measured using one-time, in-situ end-use measurements, representative sample measurements, representative manufacturer's measurements or representative baseline power levels (i.e., one of the “METHODS” mentioned above). Operating hours are known in advance, stipulated or agreed upon by both parties.

> *Calculating Electricity Savings*. First, measure the baseline capacity of the facility's lighting load using one of the METHODS listed above. Second, stipulate energy savings by multiplying the difference between baseline and post-installation measurements by the stipulated hours-of-use or hourly profiles.
>
> *Calculating Peak Electric Demand Reductions*. First, develop a baseline demand measurement using the METHODS previously described. Second, calculate retrofit electric demand savings for the appropriate demand period by comparing baseline demand to measured post-installation demand, where the demand is measured using one of the METHODS listed above.
>
> *Limitations Of Calculating Retrofit Savings From Lighting and/or Lighting Controls Projects Using Option A.* Savings resulting from lighting efficiency and/or lighting

controls projects that are calculated using Option A can be adversely affected by the following factors. Savings stipulations:

1. may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.
2. may vary if operating settings that affect facility system performance are changed after measurements are taken.
3. may vary if there is a significant number of lamp outages, or if the actual operating schedule varies significantly from the stipulated operating schedule.
4. do not measure cooling interaction or increases in heating load due to reductions in internal heating caused by improved lighting system efficiency.
5. may vary when manufacturer's wattage is used if in-situ lamp-ballast-fixture temperature is significantly different than ANSI conditions that manufacturer's use for published fixture wattage.

Option A: Constant Load Motor Replacement Project. Constant load motor replacement projects require the capacity, demand or power level (kW) be measured using one-time, in-situ end-use measurements, or can be estimated with representative sample measurements, representative manufacturer's measurements or representative baseline power levels. Operating hours are known in advance, stipulated or agreed upon by both parties.

Calculating Electricity Savings. First, measure the baseline capacity of the motor(s) to be replaced using one of the METHODS described above. Second, estimate energy savings by multiplying the difference between baseline and post-installation capacity measurements by the stipulated hours-of-use or hourly profiles.

Calculating Peak Electric Demand Reductions. Electric demand reductions resulting from a constant load motor replacement can be stipulated by using the same METHOD described for lighting projects in this Section.

Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Option A. Savings calculated using Option A can be adversely affected by the following. Savings stipulations:

1. may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.
2. may vary if operating settings that affect facility system performance are changed after measurements are taken.
3. may vary if there is a change in the load placed on the motor, e.g., if there is a significant increase in the pressure drop across the motor due to a valve closure in the piping system.
4. do not measure cooling/heating savings due to downsizing in the pump that may be delivering thermal energy to a facility.

Option A: Variable Speed Drive (VSD) Motor Project. The uncertainty of VSD motor retrofit savings using Option A can be greater than the savings if there is variation in the post-installation loading of the VSD motors that is not measured. As is the case with HVAC/EMCS projects, chiller and boiler projects, owners and contractors/ESCOs need to take responsibility for greater risk if Option A is chosen to measure these types of retrofits.

Option A: HVAC and/or EMCS Project. The uncertainty of HVAC and/or EMCS project savings using Option A can be larger than the savings due to a number of circumstances including: variations in schedules, system setpoints and weather conditions.

Option A: Chiller Project. The accuracy of chiller retrofit savings using Option A can be highly uncertain due to a number of circumstances including: variations in post-installation chilled water temperature and condenser water temperature, loading of the chillers, system setpoints and weather conditions.

Option A: Boiler Project. The accuracy of boiler retrofit project savings using Option A can be highly uncertain due to variations in boiler loading, boiler setpoints and weather conditions.

4.1.3 Expected Accuracy. Option A is meant to serve as a contractual substitute for measuring post-installation savings. Option A substitutes baseline and sometimes, post-installation measured capacity multiplied by a stipulated hours-of-use number, for actual measured energy retrofit savings. Accuracy of expected savings is dependent on the accuracy of the one-time baseline and post-installation in-situ measurements and the stipulated hours-of-use or baseline and post-installation consumption estimates. If significant attention is paid to measurement accuracy, and if the estimates of run-time or load profiles are collaborated with in-situ measurements, the accuracy of such tests can be plus or minus twenty percent (±20%) of the actual performance. However, any inaccuracies in estimated annual run-time profiles can severely affect savings estimates. In the worst case, errors of 100-200 percent have been observed.

4.1.4 Expected Cost. Option A costs will generally fall between one and five percent of retrofit construction costs. This includes any periodic reports made over the payback period of the retrofit. For example, if a $100,000 retrofit was installed, roughly between $1,000 and $5,000 should be allocated to estimate savings and produce the appropriate reports throughout the expected payback period.

4.2 OPTION B: END-USE RETROFITS - MEASURED CAPACITY, MEASURED CONSUMPTION APPROACH

Option B is intended for retrofits where the end use capacity, demand or power level can be measured baseline, and the energy consumption of the equipment or sub-system can be measured post-installation over time. Option B can involve a continuous measurement of energy use both before and after the retrofit for the specific equipment or energy end use affected by the retrofit or measurements for a limited period of time necessary to determine retrofit savings. Periodic inspections of the equipment may also be warranted. Energy consumption is calculated by developing statistically representative models of the energy end use capacity (i.e., the kW or Btu/hr) and consumption (i.e., the kWh or Btu). Additional information about the development of calibrated models in contained in Section 4.4.

4.2.1 Confirming Installed Equipment Performance. The primary difference between Options A and B is that Option A uses *one-time* baseline and post-installation "snap-shot" capacity, power measurements, or stipulated energy use, whereas Option B involves portable monitoring equipment installed in a facility for a *period of time or continuously* to measure the in-situ, baseline and post-installation performance of the specific equipment being replaced. Time allotted for installing portable metering devices during the baseline and post-installation periods depends on the type of equipment being measured. For example, the in-situ measurement of constant load motor replacements may take only a few hours or days baseline, and some period of post-installation. Measurement of the 24-hour profile of whole-facility lighting loads may take several weeks to one month to determine average weekday and weekend use (baseline and post-installation). Option B may not include measurement of whole-facility heating or cooling loads which would be necessary to calculate heating-cooling interaction of a lighting retrofit.

4.2.2 Examples.

Option B: Lighting Efficiency and/or Controls Project. The capacity, demand or power level (i.e., kW, Btu/hr or kJ/hr) and consumption are measured during the baseline period using portable hourly or 15-minute monitoring equipment for a period deemed sufficient to characterize lighting system performance during all operational periods, i.e., weekday, weekend, etc. Post-installation, the measurements are repeated to develop similar 24-hour profiles of lighting system energy consumption. Continuous post-installation measurements can also be taken.

> *Calculating Electricity Savings*. Electricity savings due to reduced lighting energy consumption are calculated by analyzing the difference between measured 24-hour consumption profiles for the baseline and post-installation periods, and then projecting these savings to an annual calculated savings. Care should be taken to adequately capture the correct number of day-type profiles to accurately represent the facility's baseline electricity use during weekday, weekend and holiday periods. In some cases, additional profiles may be needed to capture lighting energy use during secondary schedules. For example, educational facility loads often vary between school year and summer vacation periods. In some instances baseline, weekday/weekend profile measurements may be necessary during both of these times. Electric demand reductions can also be analyzed provided representative baseline and post-installation demand measurements have been taken. Post-installation measurements can either be taken continuously throughout the payback period or for a representative sample period. Savings can be projected with the appropriate statistical method.
>
> *Calculating Peak Electric Demand Reductions*. First, develop an hourly baseline demand measurement profile using the Option B METHODS previously described. Second, calculate retrofit electric demand savings for the appropriate demand period by comparing baseline demand to measured post-installation demand.
>
> *Limitations Of Calculating Retrofit Savings From Lighting And/Or Lighting Controls Projects Using Option B.* Savings estimates using the Option B METHOD are intended to be estimates of electricity savings which utilize representative one-time samples of baseline electricity use and either continuous or representative samples of post-installation electricity use. Therefore, measurement accuracy is completely dependent on how well representative profiles match actual baseline and/or post-installation lighting profiles in the facility. Additionally, savings resulting from lighting efficiency and/or lighting controls

projects that are calculated using Option B can be adversely affected by the same four factors which affect lighting projects listed in Section 4.1.2.

Option B: Constant Load Motor Replacement Project. Baseline capacity, demand or power level (i.e., kW, Btu/hr or kJ/hr) needs to be measured using short-term, in-situ end-use measurements (Biesemeyer and Jowett 1994; Brandemuel et al. 1996). These measurements are then repeated post-installation to determine any change in the energy use of the motor. Depending upon the type of system or load, these measurements can either be representative measurements (for constant speed, constant load systems) or continuous measurements (for constant speed, varying load systems). If the motors being replaced are used to deliver chilled or hot water, downsizing the motor may reduce thermal flows to the facility, which may cause cooling or heating reductions. Savings due to any cooling or heating load reductions are not included in Option B estimates and will need to either be stipulated or measured using other methods.

Calculating Electricity Savings. First, measure the baseline capacity of the motor(s) to be replaced using short-term, in-situ measurements during the baseline period. Next, either repeat the measurements one time or continuously during post-installation. Calculate energy savings by analyzing the difference between baseline and post-installation measured electricity use. When sample measurements are used to calculate savings, statistical models of electricity use will need to be created, and energy use projected using the appropriate statistical load profiles.

Calculating Peak Electric Demand Reductions. First, develop a baseline demand measurement for the electric load of the motor(s) to be replaced. Second, calculate the retrofit electric demand savings by comparing baseline demand to the measured post-installation demand for the appropriate demand period.

Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Option B. Savings measured using Option B are intended to be estimates of electricity savings which utilize representative baseline and post-installation, one-time measurements or short-term measurements of the installed electric motors. Therefore, the accuracy of the measurements is completely dependent on how well representative measurements match actual motor electricity consumption over an annual period. Additionally, savings resulting from a constant load motor retrofit calculated using the Option B approach can be adversely affected by the same four factors which affect constant load motor replacement projects listed in Section 4.1.2.

Option B: Variable Load Motor Replacement Project. Baseline capacity, demand or power level (i.e., kW) needs to be measured using short-term, in-situ end-use measurements. Short-term measurements are then repeated post-installation to adequately characterize the motor's variable electricity use. Continuous measurements are taken in cases where it is not possible to predict the varying loads on the motor.

Calculating Electricity Savings. First, measure the baseline electricity use of the motor(s) to be replaced using short-term, in-situ measurements in the baseline period. These measurements should adequately characterize the 24-hour, seven-day-per-week electricity use. Second, post-installation, take either continuous measurements or short-term measurements to characterize the variable electricity use. In cases where short-term measurements are used, electricity use variability in the post-retrofit period should be analyzed and correlated to a predictor variable (such as ambient temperature), so that an hourly statistical model can be developed to predict electricity use for an entire year under all conditions. When continuous measurements are used, only the baseline period calculation requires a statistical model be developed for predicting constant speed energy use.

Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by calculations of the R^2, RMSE and CV(RMSE). Equations for determining model error are included in Section 5. Uncertainty equations for measuring in-situ performance can be found in Brandemuel et al., (1996).

Calculating Peak Electric Demand Reductions. Electric demand reductions from a constant load motor replacement project can be estimated by comparing measured peak hourly baseline electricity use with peak hourly electricity use measured in the post-installation period or peak electricity use predicted by the post-installation statistical model.

Limitations Of Calculating Retrofit Savings From Variable-Speed Motor Retrofits Using Option B. Savings resulting from variable speed motor retrofits calculated using the Option B approach can be adversely affected by the same issues which may affect constant load motor replacement projects, with the exception of the following:

1. Option B savings estimates of variable speed motor retrofits are dependent on the accuracy of baseline constant-speed measurements and either continuous post-installation electricity use or the post-installation statistical model. Therefore, care should be taken to develop a model(s) that accurately characterizes performance in both the baseline and post-installation periods.
2. Savings due to any cooling or heating load reductions are not included in Option B.

Option B: HVAC and/or EMCS Project. Savings resulting from HVAC systems and/or Energy Management Control System (EMCS) projects can be analyzed providing a calibrated engineering model is developed for each HVAC system to adequately assess performance in the baseline period, and either continuous measurements are made in the post-installation period or a calibrated model is developed in the post-installation period from short-term measurements (Knebel 1983, Katipamula and Claridge 1992, Liu and Claridge 1995). Additional information on calibrated simulation models is provided in Option D. Annual savings are calculated by comparing energy use predicted by the baseline and/or post-retrofit model(s) for the agreed-upon standard operating schedule and ambient conditions. Such models are capable of determining electricity and thermal savings, as well as hourly electric demand reductions.

Calculating Electricity Savings. Electricity savings resulting from HVAC and/or EMCS retrofits can be calculated using calibrated baseline and post-installation engineering models of the HVAC system. To develop such models, each major HVAC system in the facility must be inspected and analyzed, and a separate baseline psychometric model developed to predict existing system energy use. This normally includes short-term measurements of in-situ performance of the HVAC system (Brandemuel et al. 1996, Balcomb et al. 1993, Liu et al. 1994, Katipamula and Claridge 1992). In the post-installation period, either continuous energy use is measured or post-installation HVAC system models are developed from short-term measurements that reflect post-installation operational changes.

Savings are determined to be significant if the difference between the model-predicted baseline and post-installation energy use is greater than model error as determined by the RMSE of the model against the measured data for the system.

Calculating Peak Electric Demand Reductions. Electric demand reductions can be calculated by comparing the difference between projected baseline electricity use and electricity use predicted by the post-installation model for the appropriate demand period. Care should be taken to ascertain the appropriate demand billing intervals that agree with those charged by the local utility.

Calculating Heating/Cooling Savings. Heating and cooling energy savings can be calculated if calibrated baseline and post-installation HVAC simulation models are used. Additional discussion of calibrated simulation models is provided in Option D. Savings are estimated by comparing post-installation projections of the baseline HVAC cooling use to HVAC cooling use predicted by the post-installation model. Appropriate calculations need to be made to determine the effect of the primary cooling and/or heating system efficiency (i.e., kW/ton of the chillers and efficiency of the boilers) for varying loads.

Limitations Of Calculating Retrofit Savings From HVAC And EMCS Retrofits Using Option B. Estimated savings from HVAC and/or EMCS projects calculated using Option B can be adversely affected by the following factors:

1. HVAC or EMCS retrofit savings measured using the Option B approach are intended to be estimates of electricity savings which utilize representative baseline and post-installation, one-time measurements or short-term measurements of the installed HVAC electricity and thermal performance. Therefore, the accuracy of the measurements is completely dependent on how well representative measurements predict actual HVAC electricity and thermal consumption over an annual period.
2. Estimated savings using Option B may be affected if HVAC system operating characteristics do not represent schedules used to drive the models.
3. Estimated savings from Option B may be affected if EMCS programming is significantly different than the representative schedule used to drive the models (i.e., setpoint temperatures, schedules, etc.).
4. Changes in heating or cooling savings may be affected by procedures used to operate the primary heating-cooling systems. For example, the average chiller kW/ton ratio is affected by the rate of the cooling load on a particular chiller. Certain types of chillers that are loaded below 50 percent of their capacity tend to have significantly higher kW/ton ratios which can increase overall electricity consumption and thus reduce total savings from the retrofit. Boilers or furnaces run at low loads can cycle excessively,

which decreases fuel conversion efficiency and thus reduces total savings from the retrofit.

Option B: Chiller Project. Savings resulting from chiller retrofit projects can be estimated if calibrated baseline and post-installation chiller models are developed (Brandemuel et al. 1996, Gordon and Ng 1994, Anderson and Breene 1995). Additional information on calibrated component models is provided in Option D. Such models are primarily sensitive to differences in chilled water supply temperatures, condenser water return temperatures (or refrigerant return temperatures for air condensers) and chiller loads. To calibrate such models, chiller thermal output, chiller electricity use, chilled water supply temperature and condenser water return temperatures need to be measured over the expected range of operation. Measurements are repeated post-installation. Annual savings are then calculated by driving the chiller models with an agreed-upon schedule of hourly chiller loads, chilled water supply temperatures and condenser temperatures, and comparing the differences between the predictions from the two models.

Limitations Of Calculating Retrofit Savings From Chiller Retrofits Using Option B. Estimated chiller retrofit savings calculated using Option B can be adversely affected by factors 1 and 2 listed above for HVAC and/or EMCS projects.

Option B: Boiler Project. Boiler retrofit savings can be estimated if input-output boiler efficiency tests, or combustion efficiency tests, are taken before and after the retrofit (Dukelow 1991, Dyer 1981, Babcock and Wilcox 1992). In smaller boilers, other test methods can be used, (i.e., the "time to make steam" test [Center for Energy and Environment, CEE]). In order to be effective, these boiler efficiency tests should be taken under varying operating conditions in order to capture boiler efficiency over its expected operating range, temperature and pressure. The results of these tests should yield a set of performance curves that can then be applied to an agreed-upon histogram of annual operating hours to establish annual boiler performance. Retrofit savings are then calculated by comparing differences between baseline annual boiler performance and post-installation annual boiler performance. Continuous post-installation measurements can also be taken and used to establish the annual histogram. Savings may be calculated by comparing these measurements to the baseline measurements.

Limitations Of Calculating Retrofit Savings From Boiler Retrofits Using Option B. Boiler retrofit savings calculated using the Option B approach can be adversely affected by factors 1 and 2 listed above for HVAC or EMCS projects.

4.2.3 Expected Accuracy. If significant attention is paid to measurement accuracy, and continuous post-installation measurements are taken, the accuracy of such tests can be plus or minus ten to twenty percent (±10-20%) of actual performance. However, any inaccuracies in the estimated annual run-time profiles can severely affect savings estimates. In the worst case, errors of 100-200 percent have been observed.

4.2.4 Expected Cost. The expected cost of Option B should be three to ten percent of the installed retrofit cost. For example, if a $100,000 retrofit was installed, roughly $3,000 to $10,000 should be allocated for estimating savings and producing the necessary reports. If continuous post-installation monitoring is planned, savings recording and reporting for the second and subsequent years should not exceed one percent of the cost of the retrofit each year.

The use of continuous post-installation monitoring may help identify O&M problems in a facility and will significantly reduce the analysis uncertainty. Results from several studies have shown that O&M savings as high as five to fifteen percent of annual energy costs can be identified using continuous data from hourly data loggers (Claridge et al. 1994, 1996; Haberl et al. 1995a).

4.3 OPTION C: WHOLE -FACILITY OR MAIN METER MEASUREMENT APPROACH

Option C encompasses whole-facility or main-meter verification procedures that provide retrofit performance verification for those projects where whole-facility baseline and post-installation data is available to measure savings. Option C usually involves a continuous measurement of whole-facility baseline energy use and electric demand, and a continuous measurement of the whole-facility energy use and demand post-installation. Periodic inspections of the equipment may also be warranted. Energy consumption under Option C is calculated by developing statistically representative models of whole-facility energy consumption (i.e., kWh, Btu or kJ), or electric demand (i.e., kW).

Developing A Baseline Energy Use Using An Inverse (Regression) Model. Option C requires an analysis be conducted on the empirical behavior of the facility as it relates to one or more driving forces or parameters. This approach is referred to as "a system identification, parameter identification or inverse modeling approach." Using the inverse statistical modeling approach, certain characteristics of the facility or system being studied are assumed, and the most important parameters are identified through the use of statistical analysis (Rabl 1988, Rabl and Rialhe 1992, ASHRAE 1997). The simplest form of an inverse model is a steady-state regression model of a facility's energy use versus one or more important parameters. The simplest steady-state inverse model can be calculated by statistically regressing monthly utility consumption data against average billing period temperatures.

Although simple in concept, the most appropriate methods use change-point statistical procedures that simultaneously solve for several parameters including a weather-independent base-level parameter, one or more weather-dependent parameters and the change-point or change-points at which the model switches from weather-dependent to non-weather-dependent behavior (ASHRAE 1997). In its simplest form, the 65^{o}F (18.3^{o}C) degree day model is a change-point model that has a fixed change point at 65^{o}F. A variable-based degree day model is similar to a three-parameter change point model for either heating or cooling.

Figure 1 illustrates steady-state, single variable models appropriate for commercial facility energy use as follows: (a) One-Parameter Weather Independent Model, (b) Two-Parameter Cooling Model, (c) Three-Parameter Heating Model, (d) Three-Parameter Cooling Model, (e) Four-Parameter Heating Model, (f) Four-Parameter Cooling Model and (g) Five-Parameter Heating And Cooling Energy Use Model (i.e., with Distinct Heating And Cooling Modes and a Weather Independent Base Level). Additional information about steady-state, single variable inverse models can be found in the 1997 ASHRAE Handbook of Fundamentals. The basic equations for the models are listed below.

Eperiod (one parameter) = B_0 ....(4.3.1)
E_{period} (two parameter) = $B_0 + B_1(T)$...(4.3.2)

E_{period} (three parameter heating) = $B_0 + B_1(B_2 - T)^+$ ....(4.3.3)
E_{period} (three parameter cooling) = $B_0 + B_1(T - B_2)^+$ ....(4.3.4)
E_{period} (four parameter heating) = $B_0 + B_1(B_3 - T)^+ - B_2 (T - B_3)^+$ ....(4.3.5)
E_{period} (four parameter cooling) = $B_0 - B_1 (B_3 - T)^+ + B_2(T - B_3)^+$ ....(4.3.6)
E_{period} (five parameter heat & cool) = $B_0 + B_1 (B_3 - T)^+ + B_2 (T - B_4)^+$ ....(4.3.7)

There are several advantages to these steady-state linear and change-point, linear inverse models, including:

- The application can be automated and applied to large numbers of facilities where monthly utility billing data and average daily temperatures are available.
- It has been shown that linear and change point linear models have physical significance to the actual heat loss/gain mechanisms that govern the energy use in most facilities (Fels 1986, Ruch and Claridge 1991, Rabl and Riahle 1992, Claridge et al. 1994, Rabl 1988).
- These results from the application of the models are highly repeatable from one analyst to another if both use the same input data and make the same assumptions.

Disadvantages of the steady-state, change-point, linear inverse models include:

- Insensitivity to dynamic effects, e.g., thermal mass.
- Insensitivity to variables other than temperature, e.g., humidity, solar, or occupancy.
- Inappropriateness for certain facility types, e.g., facilities that have strong on/off schedule dependent loads, or facilities that display multiple change points. In such cases, alternative models need to be developed.

Selecting The Best Regression Model. Ideally, model selection procedures should be simple to apply and produce consistent, repeatable results. Several selection procedures have been recommended to select the best regression model. In general, these procedures calculate savings using several regression models and select the best model depending on the best fit evaluation, such as the R^2, coefficient of variation of the normalized annual consumption (i.e., CV(NAC)), or coefficient of variation of the RMSE (i.e., CV(RMSE)). Additional information concerning these selection procedures can be found in Reynolds and Fels (1986), Kissock (1994), Kissock et al. (1992) and in the ASHRAE Handbook of Fundamentals (1997). Well documented software related to these selection procedures can be obtained from Princeton University (Fels et al. 1995), and from Texas A&M University (Kissock et al. 1994). Spreadsheet procedures have also been developed (Landman and Haberl 1996a, 1996b), and proprietary versions of the above models also exist. 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).

Calculating Energy Savings By Forecasting With The Baseline Model. Once the appropriate baseline model has been determined for the facility, energy savings are calculated by comparing energy use predicted by the baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. In general the following steps are used to calculate the savings:

1. Develop the appropriate baseline model for the baseline period that represents normal operations.
2. Project the baseline energy use into the post-installation period by driving the baseline model with the post-installation weather and operating parameters.
3. Calculate savings by comparing the difference between energy use predicted by the baseline model and actual energy use during the post-installation period. Equation 4.3.8 is the basic equation used in this analysis.

$E_{(save,i)} = E_{(baseline,i)} - E_{(post,i)}$ ....(4.3.8)

where

$E_{(save,i)}$ = energy savings from the energy conservation retrofit during period (i).

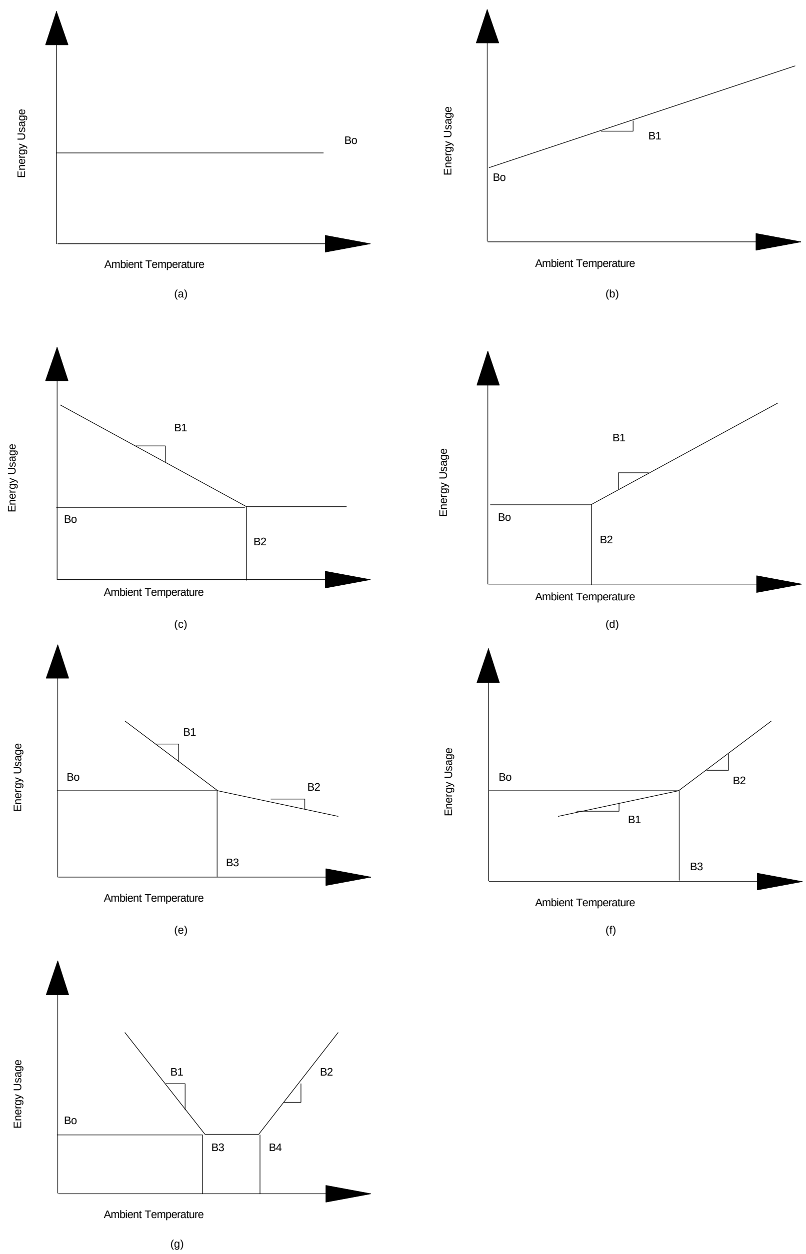


Figure 1: Several types of steady-state, single variable inverse models.

> $E_{(baseline,i)}$ = the baseline or baseline energy use projected into the post-installation period by multiplying the baseline model parameters by weather and operating parameters from the post-installation period (i).
>
> $E_{(post,i)}$ = the actual post-installation energy use during period (i).

In situations where significant data is missing from the post-installation period, a post-installation model can be created to fill in missing data. Energy savings are then calculated by comparing the energy use predicted by the baseline model to energy use predicted by the post-installation model. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the baseline model's RMSE. If the savings are less than the RMSE, this is an indication that the uncertainty of the model is high and that this method may not be useful for determining reliable savings.

4.3.1 Monthly Utility Billing METHODS. Monthly utility billing methods calculate the savings from energy conservation retrofits by establishing a baseline or baseline model using 12 or more months of whole-facility utility billing data and average daily billing period weather data. In general, this type of savings calculation procedure is intended for projects where savings are expected to be 20 percent or more of the monthly utility bill, and where the size of the project or metering budget is too small to justify installing an hourly data logger. Utility billing analysis methods can also be used in conjunction with Options A, B and D to cross-check savings calculations.

Data Requirements. Normally, 9 to 12 months or more of monthly baseline data is required to establish baseline energy consumption (Fels 1986). This includes the following information: i) meter reading dates, ii) daily average temperature data from a nearby airport or NWS weather station, and iii) the amount of energy consumed during each utility billing period. For each billing period, the average temperature should be calculated from daily data. The appropriate statistical model is determined by regressing billed utility data against average billing period temperature. If several different meters are read on separate days, then each meter having a unique billing period should be separately analyzed. The results should then be combined after each individual analysis.

Differences in the lengths of baseline and post-installation billing periods can be accounted for by calculating average daily energy use in the billing period. A small amount of error, i.e., about five percent, may occur due to differences between the number of weekdays and weekends in the baseline and post-installation periods, and/or differences in holiday schedules.

4.3.2 Examples. The example projects that follow can be analyzed with monthly utility billing data provided that the change in post-installation energy use due to the retrofit is larger than the inherent uncertainty in the statistical model as calculated by the RMSE. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1. For those retrofits where the change in post-installation consumption is *less* than the uncertainty in the statistical model, alternative methods of measuring retrofit savings should be considered (Options A, B or D).

***Option C (Monthly): Lighting Efficiency and/or Controls Project*.** If electricity savings and electric demand are being evaluated, a separate demand analysis can be performed that compares demand for a given month with the demand for that same month in the year prior to the retrofit. Electricity savings due to reduced lighting electricity use can be calculated by analyzing whole-facility electricity use. Electricity savings resulting from the reduced cooling load (from reduced internal heat from reduced lighting loads) can also be determined through the selection of the appropriate baseline and post-installation modeling strategy if chiller or air conditioning equipment energy use is included in the whole-facility utility meter. Negative savings which account for increased heating due to reduced internal heating loads from the removal or replacement of lights can also be determined if data regarding heating system energy use is included in the whole-facility utility meter.

> *Calculating Electricity Savings*. First, develop a baseline model using the monthly Option C METHODS previously described. Second, calculate the retrofit electricity savings by comparing electricity use predicted by the baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. In situations where significant data are missing in the post-installation period, a post-installation model can be created to fill in information. Energy savings are then calculated by comparing energy use predicted by the baseline model to measured energy use or energy use predicted by the post-installation model.
>
> *Calculating Peak Electric Demand Reductions*. First, develop a baseline demand model using the monthly Option C METHODS previously described. Second, calculate the retrofit electric demand savings for a given month by comparing monthly demand with the demand for that same month in the year prior to the retrofit. In some cases it may be possible to create a model of the facility's monthly electricity demand which can be used to calculate demand savings.
>
> *Calculating Interactive Cooling Savings.* In most lighting retrofits there will be a significant reduction in the energy required to cool the space due to internal heat reduction. The amount of cooling savings will vary by facility depending on the size of the internal load relative to the envelope loads, the type of cooling system, cost of the energy used by the cooling system and whether or not economizer or free cooling is utilized. Cooling savings can be determined from monthly data if: i) separate metering data for cooling system energy use is available, or ii) the cooling energy use is part of the main meter.
>
> If separate metering data are available for the cooling system, cooling savings can be determined by developing a baseline cooling model using the monthly Option C METHODS previously described. Cooling energy savings are calculated by comparing the electricity use predicted by baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. In situations where significant data are missing in the post-installation period, a post-installation model can be created to fill in missing data.
>
> If cooling energy use is part of the main meter, cooling savings are combined with the electricity reduction (due to lighting fixture retrofits) in the whole-facility data. A combined electricity and cooling reduction calculation can be determined by developing a

baseline model using the monthly Option C METHODS previously described. Electricity savings plus cooling savings are calculated by comparing the electricity use predicted by baseline parameters (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. In situations where significant data are missing in the post-installation period, a post-installation model can be created to fill in missing data. Electricity plus cooling energy savings are then calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model.

Calculating Interactive Heating Savings. In most lighting retrofits additional heating will be necessary to make up for internal heating loss due to the removal or replacement of inefficient lighting fixtures. The amount of additional heating required will vary depending on the relative proportions of the internal loads versus the envelope loads, the type and operation of the heating system and the cost of heating fuel. The additional heating energy required can be determined from monthly data if: 1) separate metering data for the energy use of the heating system is available, or 2) the heating energy use is part of the main meter.

If separate metering data is available for the heating system, the heating reduction can be determined by developing a baseline heating model using the monthly Option C METHODS previously described. Additional heating energy is then calculated by comparing energy use predicted by the baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. Missing data in the post-retrofit period can be filled in with a post-retrofit model.

If the heating energy use is part of the main electric meter, the additional heating will be combined with the electricity reduction (due to lighting fixture retrofits) in the whole-facility data. An evaluation of reduced lighting electricity and increased heating electricity can be determined by developing a baseline model using one of the monthly Option C METHODS previously described. Electricity savings plus additional heating are then calculated by comparing the electricity use predicted by the baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data.

Limitations Of Calculating Retrofit Savings From Lighting And/Or Lighting Controls Projects Using Monthly Utility Billing Data. Lighting efficiency and/or lighting controls project savings calculated using the Option C monthly METHODS should be greater than the uncertainty as calculated by the baseline model's RMSE. These savings can be adversely affected by the following factors:

1. Option C monthly savings evaluated with whole-facility electricity consumption can be affected by changes in electric receptacle loads. In previously reported cases, increases in receptacle loads have been in the 5 to 8 percent per year range (Bou Saada et al. 1996). If such creep is experienced in the post-retrofit data the baseline model may need to be adjusted to account for the increased loads.

2. Option C monthly savings in the reduction of whole-facility peak electric demand can be affected by additions or subtractions of major electric consuming sub-systems.
3. Changes in the interactive cooling savings measured with whole-facility data may be affected by procedures used to operate the cooling systems. In particular, the average chiller kW/ton ratio is affected by the rate of the cooling load on a particular chiller. Chillers that are loaded below fifty percent (50%) of their capacity tend to have significantly higher kW/ton ratios which can increase the electricity consumption used for cooling. In buildings where the lighting loads represents a significant portion of the total electricity use the loading on the chiller should be examined.
4. Changes in heating savings using whole-facility data may be affected by procedures used to operate the heating systems. Boilers or furnaces run at low loads can cycle excessively, which decreases fuel conversion efficiency.

Option C (Monthly): Constant Load Motor Replacement Projects. When measuring constant load motor replacement projects, care should be taken to note pressure rises across pumps or blowers because the electric demand of a pump or blower is dependent on the pressure it exerts on the fluid stream passing through the pump or blower. For such retrofits where variations are significant and unpredictable, hourly measurements of baseline and post-installation energy use and/or in-situ component efficiency measurements are usually required. For constant load motor replacement projects, obtaining utility billing data for 12 months prior to the retrofit is recommended. If electricity savings and electric demand are being evaluated, a separate demand analysis needs to be performed that compares demand for a given month with demand in the same month of the year prior to the retrofit.

Calculating Electricity Savings. First, develop a baseline model using the monthly Option C METHODS previously described. Second, calculate the retrofit electricity savings by comparing the electricity use predicted by the baseline model to measured post-installation data. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the baseline model's RMSE.

Calculating Peak Electric Demand Reductions. First, develop a baseline demand model using the Option C methods previously described. Second, calculate the retrofit electric demand savings by comparing the monthly demand predicted by the baseline model to measured post-installation demand data for the appropriate demand period. Demand savings are determined to be significant if the difference between baseline and post-installation electric demand are greater than model error as determined by the baseline model's RMSE.

Limitations Of Calculating Savings From A Constant Load Motor Retrofit Using Utility Billing Data. Constant load motor retrofit savings measured using the Option C approach can be adversely affected by the following factors:

1. Option C monthly savings in electricity consumption can be affected when the motor being replaced no longer operates in a constant load. For example, if the pressure drop changes across a pump, the electricity use of the pump will also drop a corresponding amount as determined by the appropriate pump curve.

2. Option C monthly savings in electric demand can be affected by additions or subtractions of major electric consuming sub-systems when the motor being replaced no longer operates in a constant load. For example, if the pressure drop changes across a pump, the electricity use of the pump will also drop a corresponding amount as determined by the appropriate pump curve for that specific pump.

Option C (Monthly): Variable Speed Drive (VSD) Motor Project. VSD motor retrofit savings are not easily analyzed using the Option C monthly approach. For such retrofits, hourly measurements of baseline and post-installation energy use and/or in-situ component efficiency measurements are usually required.

Option C (Monthly): HVAC and/or EMCS Project. Obtaining utility billing data for 12 months prior to the retrofit is recommended when using Option C to measure HVAC and/or EMCS projects. If electricity savings and electric demand are being evaluated, a separate demand analysis needs to be performed that compares the demand for a given month to the demand in the same month of the year prior to the retrofit. Electricity savings due to the reduction in the HVAC energy use are calculated by analyzing whole-facility electricity use. Electric demand reductions can also be analyzed using monthly utility billing data. Retrofits to HVAC and/or EMCS systems can also affect the cooling and heating energy use in a facility. Such interactions can be evaluated with utility billing data in facilities with large envelope-driven loads. Buildings with large internal loads, significant schedule changes and/or simultaneous heating and cooling may require hourly baseline and post-installation measured data.

Calculating Electricity Savings. Use the same Option C monthly METHOD as described above for constant load motor projects.

Calculating Peak Electric Demand Reductions. Use the same Option C monthly demand savings calculation METHOD as described above for constant load motor projects.

Calculating The Heating/Cooling Savings. In most HVAC or EMCS projects there may be significant reductions in the energy required to heat or cool the space due to improved HVAC system efficiency. The amount of heating or cooling savings may vary by facility depending on the relative proportions of internal loads versus the envelope loads, the type of heating/cooling system, cost of the energy used by the cooling system and whether or not economizer or free cooling is utilized. Heating/cooling energy savings from an HVAC retrofit can be determined from monthly data if: 1) separate metering data for the energy use of the heating and cooling system are available, or 2) the heating and cooling energy use is part of the main meter.

In either case, cooling reductions can be determined by developing a baseline cooling model using the methods previously described. Cooling energy savings are calculated by comparing the electricity use predicted by the baseline model to measured post-installation data. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the RMSE.

Limitations Of Calculating Retrofit Savings From HVAC Or EMCS Retrofits Using Monthly Utility Billing Data. Savings from HVAC or EMCS retrofits that are calculated with monthly baseline and post-installation utility billing data should be greater than the uncertainty as calculated by the RMSE. These savings can be adversely affected by the following factors:

1. In facilities where simultaneous heating/cooling occurs during a significant portion of the year, savings due to HVAC system modifications may require an hourly baseline model and hourly post-installation measurements or in-situ hourly efficiency measurements of the HVAC system.
2. Monthly savings in whole-facility electricity consumption can be affected by changes in the electric receptacle loads, and/or other significant internal loads.
3. Monthly savings in whole-facility demand can be affected by additions or subtractions of major electric consuming sub-systems.
4. Monthly whole-facility cooling savings can be affected by procedures used to operate the cooling systems (i.e., chiller loading).
5. Monthly whole-facility heating savings may be affected by procedures used to operate the heating systems (i.e., boiler loading).

Option C (Monthly): Chiller Project. When using Option C to measure chiller projects care should be taken to note the loading of the chiller, chilled water supply temperatures, condenser return temperatures and flow rates through the chiller. This documentation is important because the efficiency of the chiller , i.e., kW/ton or COP, is dependent on the percent load on the chiller, temperature of the chilled water supply, condenser return temperature and flow rates through the chiller (Gordon and Ng 1994; Brandemuehl et al. 1996). For those retrofits where such parameters are uncertain or cannot be ascertained, it may be necessary to measure the baseline and post-installation, in-situ chiller efficiency as outlined in the section that describes Option B. In such cases hourly baseline and post-installation measurements should be used if the loading and temperature have remained relatively constant, and if the chiller output and electricity input are being measured.

For chiller replacement projects that have constant baseline and post-installation loading conditions and operating temperatures, obtaining utility billing data for 12 months prior to the retrofit is recommended. If electricity savings and electric demand are being evaluated, a separate demand analysis needs to be performed that compares the demand for a given month with the demand in the same month of the year prior to the retrofit.

Calculating Electricity Savings. Use the same Option C monthly METHOD as described above for constant load motor projects.

Calculating Peak Electric Demand Reductions. Use the same Option C monthly demand savings calculation METHOD as described above for constant load motor projects.

Limitations Of Calculating Savings From A Chiller Retrofit Using Utility Billing Data. In many cases it may not be possible to accurately assess chiller retrofit savings by comparing monthly utility billing data. This is due to the fact that most chiller retrofits are usually accompanied by changes to the chilled water pumping systems, chilled water setpoints, downsizing of the chillers or staging of the chillers, etc. Therefore, most chiller retrofits require baseline and post-installation efficiency measurements and load profiles be developed using hourly data. Even in such cases where all of these variables have been held constant, savings from a chiller retrofit project can still be adversely affected by the following:

1. Savings in electricity consumption can be affected when the chiller operates at different baseline and post-installation chilled water setpoint conditions or condenser temperatures because of additional work which is required to produce colder evaporator temperatures, or shed heat in the condenser at higher temperatures.
2. Savings in electricity consumption can be affected if the baseline and post-installation loading on the chiller are substantially different. This is due to the fact that chillers tend to have a non-linear increase in kW/ton ratios as the loading drops below approximately 50 percent.
3. Option C monthly savings in electricity consumption can also be affected by varying flow rates through the chiller evaporator and/or condenser. Fortunately, most chillers utilize constant flow rates through the evaporator and/or condenser.

Option C (Monthly): Boiler Project. When using Option C monthly METHOD to measure boiler projects care should be taken to note boiler loading, setpoint temperatures and general condition because the efficiency of the boiler is primarily dependent upon the loading and setpoint temperatures. Useful information regarding boiler efficiency can be found in Dyer and Maples (1981), Dukelow (1991) and Babcock and Wilcox (1992). For those retrofits where such parameters are uncertain or cannot be ascertained, it may be necessary to measure the baseline and post-installation, in-situ boiler efficiency as outlined in the section that discusses Option B. Hourly baseline and post-installation measurements can also be used for such retrofits if the hourly or daily loading and temperature remain relatively constant, and if the boiler fuel input and thermal output are being measured.

For boiler replacement projects that have similar baseline and post-installation loading conditions and operating temperatures, obtaining utility billing data for 12 months prior to the retrofit is recommended. If electricity savings and electric demand are being evaluated, a separate demand analysis should be performed that compares the demand for a given month with the demand for that same month of the year prior to the retrofit.

Calculating Energy Savings. Use the same Option C monthly METHOD as described above for constant load motor projects.

Calculating Peak Electric Demand Reductions. Use the same Option C monthly METHOD as described above for constant load motor projects.

Limitations Of Calculating Savings From A Boiler Retrofit Using Utility Billing Data. Boiler retrofit savings calculated with Option C monthly METHOD can be adversely affected by the following:

1. Savings in energy consumption can be affected when the boiler operates at different baseline and post-installation setpoint conditions. This is due to the additional fuel required to produce higher temperatures.

2. Savings in energy consumption can be affected if the baseline and post-installation loading on the boiler are substantially different. This can be a significant problem if the new boiler is oversized and must operate at low loads which cause in-efficient on/off cycling conditions.
3. Option C monthly savings in energy consumption can also be affected by combustion settings, changes in the environment surrounding the boiler and changes in the boiler operating schedule.

4.3.3 Whole-Facility Or Main Meter Hourly Before/After Analysis METHOD. For projects where hourly monitoring equipment has been installed at least 9-12 months prior to the retrofit, the following procedures can be used to document savings. In order for the measurements to be valid, monitoring equipment should be installed to economically capture a significant portion of the energy use of the equipment to be replaced and/or upgraded (Claridge et al. 1991).

The equipment, where feasible, should also be installed to minimize irrelevant data that might be introduced by other (non-retrofitted) equipment. For example, if a lighting retrofit is being analyzed with a derived whole-facility "lights and receptacles" measurement, care should be taken to document the electric receptacle loads so that changes can be noted and adjustments made should there be significant change in the electric receptacle loads that might affect savings measurements, e.g.., the purchase and installation of extensive 120 VAC office computer equipment.

Data Requirements for Hourly or Daily Models. In many cases whole-facility, or main-meter hourly baseline and post-installation measurements can utilize the same revenue meters that the local utility uses to bill the owner. Such meters must be equipped or modified to provide a digital pulse that can be recorded by the monitoring equipment. Each recorded pulse then represents a specific unit of consumption over a given time period, i.e., kWh/hour or CCF/hour. Such equipment may also be modified to provide a 4-20 mA signal that can be recorded as an accumulated analog signal by the monitoring equipment.

Action should be taken to accurately calibrate the "kWh/pulse" constant against a known reference, or to determine the scale and offset values to be entered into the data logger to convert the 4-20 mA signal into engineering units. Often, this can be accomplished by comparing acquired, recorded data values against similar data recorded by the utility revenue meter, provided the revenue meter has been recently calibrated according to National Institute of Standards and Technology (NIST) traceable standards. Additional material concerning calibration may be found in Section 5.0.

EMCSs can be used to record energy use using the "trend" capability. However, most EMCSs use Change of Value (COV) data that is not immediately useful for calculating energy savings because of varying time intervals for the individual records. Such data will need to be converted to interval data before it is useful for energy savings calculations (Claridge et al. 1993, Heinemeier 1993).

Hourly measurements are often adequate to characterize energy and demand profiles of most equipment to be retrofitted. However, where changes to electric demand represent a significant amount of the calculated energy savings, the minimum time step for recording data should match the utility demand time interval. For example, if the local utility is calculating peak demand using a 15-minute fixed window, then the loggers should be set to record data every 15 minutes. In some cases, utilities use "sliding windows" to record electric demand data. This type of demand measurement requires a special data recorder that has sliding window recording capabilities. This can also be accomplished by setting the data acquisition system to the one-minute level, recording one-minute data and then recreating the sliding 15-minute window using post-processing software. Most often 15-minute fixed 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 are indeed generating high one-minute peak loads which may show up in a sliding window interval and not in a fixed interval 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.

In most facilities, hourly baseline and post-installation whole-facility electricity, cooling, heating and motor-control center measurements are usually sufficient to capture lighting retrofits, HVAC system retrofits and facility envelope modifications. Such data needs to be recorded for 9-12 months prior to the retrofit to adequately ensure that sufficient data is recorded to adjust for weather normalization measure (Fels 1986, Haberl et al. 1996, Reddy et al. 1994). Other data required includes average hourly dry bulb temperatures and, in some special cases, humidity data which can be recorded on-site or obtained from a nearby National Weather Service station.

Developing A Baseline Energy Use Using An Hourly Or Daily Inverse (Regression) Model. Inverse or regression models of a facility's hourly or daily baseline energy use are developed in the same fashion as those developed using monthly data, except hourly or daily models must often incorporate a switching variable to account for differences in facility operation. At the monthly level, switching variables are usually not used because the data has been aggregated to the monthly level. However, in daily and hourly inverse models, data scatter makes the fit of the regression line less accurate. Reasons for scatter in hourly data include:

- on/off switching of HVAC systems.
- schedule variations.
- dynamic effects of thermal mass, etc.
- solar effects in buildings with significant amounts of glazing.
- latent cooling loads due to dehumidification of moist air during the cooling season when ambient conditions exceed 50-55^{o}F dewpoint temperature.

In many facilities, data scatter can be reduced without losing significant accuracy by aggregating the data to the daily level prior to analysis (Katipamula et al. 1996, Kissock et al. 1992). In daily data a fair amount of scatter can be accounted for by using the appropriate weekday/weekend model. To accomplish this, the analyst should first sort the daily data into weekday and weekend groups, perform the appropriate analysis on the separate groups and then create a combined model that automatically switches between weekday and weekend (or holiday) modes, depending on the day of the week in the post-installation period. Such daily models have been shown to be capable of accounting for 90 to 95 percent of the variation in a facility's weather-dependent energy use (Reddy et al. 1994, Kissock et al. 1992). Appropriate models for the analysis of daily energy use include the previously described 1-, 2-, 3-, 4- and 5-parameter models using a single influencing variable and, in some cases, multi-parameter models.

Hourly models tend to be significantly more complex. In general, such models must account for hourly scheduling differences and often need to account for additional parameters such as solar and humidity, and dynamic parameters such as thermal mass. Models that have been shown to be effective in hourly applications include: simple 1-, 2-, 3-, 4-, and 5-parameter models, inverse bin models (Kissock et al. 1992, Thamilseran and Haberl 1994, 1995) and more advanced models such as neural network models (Kreider and Haberl 1994, Haberl and Thamilseran 1996, 1997).

Selecting The Best Hourly Or Daily Regression Model. The best hourly or daily regression model is selected in the same fashion as monthly models. Several regression models are calculated, and the best model is selected based on the best statistical match to the measured data as measured by the R^2, coefficient of variation of the normalized annual consumption, i.e., CV(NAC)), or coefficient of variation of the root mean squared error (CV(RMSE)). Additional information on such indices can be found in Section 5.0 and in standard statistical references such as Draper and Smith (1981).

4.3.4 Examples. The following example projects can be analyzed using baseline and post-installation hourly measurements provided the savings are greater than the uncertainty of the regression model. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

Option C (Hourly): Lighting Efficiency and/or Controls Project. Hourly measurements for at least 12 months should be taken to adequately characterize cooling and heating season performance. In some cases, nine months of data can adequately characterize performance if the period under analysis reflects all normal environmental and schedule conditions. If electricity savings and electric demand are being evaluated, a separate demand analysis will need to be performed that compares the peak demand for a given month to that of the same month of the year prior to the retrofit. Total measured energy savings should consider electricity savings from the reduced lighting load, cooling savings from reduced internal heating and increased heating to make up for internal heating reductions caused by lighting retrofits.

Calculating Electricity Savings. The analysis method used to determine hourly electricity savings from a lighting retrofit depends on facility loads being monitored by the hourly data acquisition system. To achieve the highest level of accuracy, it is best to monitor the retrofit at the end use level. However, this is not usually economically feasible. In most facilities, electricity savings from a lighting retrofit can be monitored adequately with hourly data if the following loads can be monitored: i) whole-facility electricity, ii) motor control center electricity, iii) electricity used for powering chillers (and electric heating), and iv) other electric loads that are easily identified as "non-lighting" such as exterior security lighting and electric slab heaters. Assuming such channels can be monitored, a proxy lighting channel can be created by subtracting the sum of the motor control center (plus cooling, heating and other loads), from the whole-facility electric as indicated in equation 4.3.9 below.

$$E_{(lights,\ proxy)} = E_{(whole\text{-}facility)} - [\,E_{(motor\ control\ center)} + E_{(chiller)} + E_{(boiler)} + E_{(other,\ non\text{-}lighting)}\,] \quad (4.3.9)$$

where

$E_{(lights,\ proxy)}$ =	the hourly (or 15-minute) electricity use of the derived lights and receptacles load.
$E_{(whole\text{-}facility)}$ =	the hourly (or 15-minute) electricity use of the whole-facility.
$E_{(motor\ control\ center)}$ =	the hourly (or 15-minute) electricity use of all motors in the facility.
$E_{(chiller)}$ =	the hourly (or 15-minute) electricity use of all chillers or large cooling equipment and associated equipment.
$E_{(boiler)}$ =	the hourly (or 15-minute) electricity use of all heating equipment and associated equipment.
$E_{(other,\ non\text{-}lighting)}$ =	the hourly (or 15-minute) electricity use of all other significant non-lighting loads.

Once such measurements have been obtained, electricity savings from a lighting retrofit can be determined in the following fashion. First, develop a baseline model using the regression (or inverse) METHODS previously described for each of the channels being monitored. Second, calculate electricity savings by comparing electricity use predicted by baseline parameters (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. In situations where significant data are missing in the post-installation period, a post-installation model can be created to fill in missing data. Electricity savings are then calculated by comparing the energy use predicted by the baseline model to the energy use predicted by the post-installation model. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the baseline model's RMSE.

In cases where only whole-facility electricity is available on a 15-minute or hourly basis, savings can be calculated if at least 12 months of data are available, and the data can be statistically separated into heating season, cooling season and non-heating/non-cooling season data. Several methods have been developed for accomplishing this separation, including weather day-types (Bou Saada and Haberl 1995a) and calibrated simulations (Katipamula 1996, Bou Saada and Haberl 1995b, Akbari et al. 1988, BPA 1993). In general, these techniques synthesize end use loads by breaking down 8,760 hours of use into average profiles for weekday and weekend loads that represent non-cooling/non-heating loads. Retrofit savings are calculated by comparing average profiles for baseline and post-installation, non-cooling/non-heating loads.

Calculating Peak Electric Demand Reductions. If end use lighting loads are being monitored or if proxy lighting loads are being measured, peak electric demand reductions can be determined if the measurements are taken at the same demand time interval used for utility billing purposes. Savings can be determined by comparing the baseline and post-installation maximum values for the appropriate demand interval. Several calculations may be required for more complex utility rate structures that can include on-peak, off-peak summer and/or winter electric demand rates.

Calculating Interactive Heating/Cooling Savings. Interactive heating/cooling savings can be measured using hourly data if the boiler and/or chillers are being measured directly, or statistically if only whole-facility electric data are available, which includes heating, cooling and all other electrical uses. If separate metering data are available for the heating and cooling system, cooling reductions can be determined by developing a baseline heating and cooling model using methods previously described. Heating and cooling energy savings are calculated by comparing predicted energy use to measured post-installation data. In situations where significant data is missing in the post-installation period, a post-installation model can be created to fill in missing data. Energy savings are then calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model.

If heating and/or cooling energy use is part of the main meter, savings will be combined with electricity reduction (due to lighting fixture retrofits) in the whole-facility statistical model. Combined reductions can be determined by developing a baseline model using METHODS previously described. Savings are then calculated in the same fashion as the Option C hourly METHODS described in the preceding paragraph.

Limitations Of Calculating Retrofit Savings From Lighting And/Or Lighting Controls Projects Using Hourly Whole-Facility, Before/After Data. Savings calculated with hourly whole-facility, baseline and post-installation utility billing data should be greater than the uncertainty as calculated by the CV(RMSE) and/or R^2. These savings can be adversely affected by the following factors:

1. Savings measured with end use lighting measurements are most accurate, but can be affected by fixture outages and/or changes in lighting system operational patterns.
2. Savings that utilize proxy lighting measurements can also be accurate. In addition to being affected by fixture outages and changes in operational patterns, such savings can also be affected by significant additions to the plug (or receptacle loads).
3. Changes in hourly whole-facility interactive cooling savings can be affected by procedures used to operate the systems. In particular, the average chiller kW/ton ratio is affected by the rate of the cooling load on a particular chiller. Chillers that are loaded below 50 percent of their capacity tend to have higher kW/ton ratios, which can create a flat consumption profile at reduced cooling loads.
4. Changes in the hourly whole-facility interactive heating savings may be affected by heating system operating procedures. Boilers or furnaces running at low loads can cycle excessively, which decreases fuel conversion efficiency.

Option C (Hourly): Constant Load Motor Replacement Project. Hourly measurements should be obtained for several months to adequately characterize baseline motor performance. Often, 12 months of data may be needed to characterize performance if the facility has several occupancy schedules throughout the year that affect the motor load. If electricity savings and electric demand are being evaluated, a separate demand analysis will need to be performed that compares demand for a given month with that of the same month in the year prior to the retrofit. Total measured energy savings should include end use electricity savings from reduced motor load where possible. In special cases where the motor is being used to deliver heating and/or cooling loads, an additional analysis may need to be performed to evaluate the impact of reduced heating and/or cooling requirements due to the change in the motor used to run the pump.

Calculating Electricity Savings. The analysis method used to determine electricity savings from a constant load motor replacement project depends on facility loads being monitored by the hourly data acquisition system. To achieve the highest level of accuracy, it is best to monitor the retrofit at the end use level. However, in most situations this is not economically feasible. In some facilities, electricity savings from a constant load motor retrofit can be adequately monitored with hourly whole-facility electricity data if the change in baseline and post-installation electricity use is greater than the uncertainty in the whole-facility baseline model, and there are no substantial changes to other electric consuming sub-systems. Caution must be taken to identify any significant additions or deletions to the whole-facility electricity use.

Retrofit savings using whole-facility hourly measurements can be determined in the same fashion described for calculating electricity savings using the Option C hourly METHOD in the previous section. In those cases where end use hourly electricity measurements are available, electricity savings are calculated by comparing end use electricity use predicted by the baseline model, to energy use predicted by the post-installation model.

Calculating Peak Electric Demand Reductions. If end use motor loads are being monitored, electric demand reductions and savings can be determined in the same fashion described for calculating peak electric demand reductions in the previous section using the Option C hourly METHODS.

Calculating Cooling Or Heating Savings. If the motor to be retrofitted is being used to deliver heating/cooling energy to the facility from a mechanical room or central plant, there may be changes to overall heating and/or cooling energy use due to changes in motor operation. Savings can be measured using hourly data if cooling or heating equipment is being measured directly, or statistically if only whole-facility electric data is available. If separate metering data is available for the system, reductions can be determined by developing a baseline model using methods previously described.

Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Hourly Before/After Data. Constant load motor retrofit savings using hourly utility billing data can be adversely affected by additions or deletions to electric consuming equipment in the facility. Care should be taken to document major equipment in the facility. Electricity use at the whole-facility level can also be affected by operational changes in the equipment schedules.

Option C (Hourly): Variable Speed Drive Motor Project. Follow the same initial Option C hourly procedures described above for constant load motor replacement projects.

Calculating Electricity Savings. The analysis method used to determine electricity savings from a VSD project is the same Option C hourly METHOD used to calculate a constant speed motor retrofit using hourly data.

Calculating Peak Electric Demand Reductions. If end use motor loads are being monitored, electric demand reductions and savings can be determined using the same Option C hourly METHOD described for calculating peak electric demand reductions in the previous section.

Calculating Cooling Or Heating Savings. If the motor is being used to deliver heating and/or cooling energy to the facility from a mechanical room or central plant, there may be changes to the overall heating and/or cooling energy use due to changes in motor operation. Savings can be measured using the same method outlined for measuring constant load motor retrofits with hourly data.

Limitations Of Calculating Retrofit Savings From Variable Speed Drive Motor Retrofits Using Hourly Before/After Data. Savings from a VSD load motor retrofit using hourly before/after data can be adversely affected by additions or deletions to electric consuming equipment in the facility. Care should be taken to document major equipment in the facility. Electricity use at the whole-facility level can also be affected by operational changes in equipment schedules. In certain cases, special monitoring equipment may be required to analyze VSD electricity use to check for power factor changes and adverse harmonics caused by an improperly installed VSD.

Option C (Hourly): HVAC and/or EMCS Project. Hourly measurements should be taken for at least 12 months to adequately characterize cooling and heating season performance. In some cases, nine months of data can adequately characterize performance if the period under analysis reflects all normal environmental and schedule conditions (Fels 1986, Katipamula et al. 1994, 1995). If electricity savings and electric demand are being evaluated, a separate demand analysis should be performed that, at a minimum, compares the demand for a given month with that of the same month in the year prior to the retrofit. Total measured energy savings should include electricity savings from reduced motor loads, as well as cooling and heating savings.

Calculating Electricity Savings. The general analysis method used to determine electricity savings from HVAC and EMCS retrofits is the same as the Option C method used for lighting projects.

Calculating Peak Electric Demand Reductions. If end use loads are being monitored, electric demand reductions from an HVAC/EMCS retrofit can be determined using the Option C method previously described for lighting projects. Demand savings can also be calculated from whole-facility measurements. However, caution should be taken to verify that reductions are caused by the HVAC/EMCS retrofit, not from an unknown cause.

Calculating Interactive Heating/Cooling Savings. Heating/cooling savings can be measured using the Option C method previously described for lighting projects.

Limitations Of Calculating Retrofit Savings From HVAC Or EMCS Projects Using Hourly Whole-Facility, Before/After Data. These savings can be adversely affected by changes to operational parameters. Changes in hourly whole-facility heating/cooling savings can be affected by heating/cooling system operating changes. In particular, the average chiller kW/ton ratio is affected by the rate of the cooling load on a particular chiller, the chilled water supply temperature and the condenser water return temperature. Boilers or furnaces that run at low loads can cycle excessively, which decreases fuel conversion efficiency.

Option C (Hourly): Chiller Project. Hourly measurements during the previous cooling season should be taken to adequately characterize cooling season performance. If electric demand savings are being evaluated, a separate demand analysis should be performed that, at a minimum, compares the demand for a given month with the demand for that same month in the year prior to the retrofit. Total measured energy savings from a chiller retrofit should include electricity savings from reduced chiller load and associated loads such as pumps, etc., that accompany the chiller where possible.

Calculating Electricity Savings. The most accurate analysis method used to determine electricity savings from chiller retrofits is the method developed by ASHRAE RP 827 (Brandemuehl et al. 1996) which involves a calibrated thermodynamic model of the chiller similar to the models described by Gordon and Ng (1994) and Anderson and Breene (1995). The RP827 model captures part load performance at varying chilled water and condenser temperatures, and only requires hourly baseline and post-installation measurement of chiller electricity use, chiller thermal output, chilled water supply temperature and condenser water return temperature (or refrigerant return temperature in cases where air-cooled condensers are in use). Chiller savings can also be measured with fewer channels if operating conditions in post-installation periods are exactly the same as operating conditions in the baseline period. In instances where the baseline and post-installation chilled water supply temperature is constant, and the baseline and post-installation condenser return temperature is constant, savings can be measured using hourly chiller thermal output and electric input measurements. In instances where temperature and chiller loading are constant, only chiller electric measurements need be obtained.

Once such measurements have been obtained, electricity savings from a chiller retrofit can be determined in the following fashion. First, develop a baseline model for the chiller using the in-situ chiller performance techniques described in ASHRAE RP827. Second, develop a post-retrofit chiller model for the new chiller. Third, calculate electricity savings by comparing electricity use predicted by baseline model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation chiller data. In situations where significant data are missing in the post-installation period, a post-installation chiller model can be created to fill in missing data. Electricity savings are then calculated by comparing the energy use predicted by the baseline model to the energy use predicted by the post-installation model. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the baseline model's RMSE.

Calculating Peak Electric Demand Reductions. If end use loads are being monitored, electric demand reductions from a chiller retrofit can be determined by comparing peak electric demand predicted by the baseline chiller model against either measured peak chiller demand in the post-retrofit period or peak demand predicted by the post-retrofit model. However, caution should be taken to ascertain that reductions could only have been caused by the chiller retrofit, not by an unknown cause.

Limitations Of Calculating Retrofit Savings From Chiller Projects Using Hourly Whole-Facility, Before/After Data. These savings can be adversely affected by the following factors:

1. Savings measured with hourly chiller electricity measurements only can be adversely affected by chiller loading, chilled water supply temperature, condenser water return temperature and other changes to operational settings that affect chiller efficiency, i.e., chilled water flow rate through the chiller.
2. Option C hourly savings measured with only chiller thermal output measurements can be adversely affected by chilled water supply temperature, condenser water return temperature and other changes to operational settings that affect chiller efficiency.

Option C (Hourly): Boiler Project. During the previous heating season, hourly measurements should be taken to adequately characterize heating season boiler performance. As well, measurements for the non-heating season may be required to measure standby losses and/or non-heating season use, i.e., domestic water heating supplied by the boiler, etc. If electric demand savings are being evaluated, a separate demand analysis will need to be performed, at a minimum, that compares the demand for a given month with that of the same month in the year prior to the retrofit. Total measured energy savings from a boiler retrofit should include electricity and thermal savings resulting from boiler replacement, as well as associated loads such as pumps, blowers, etc. that accompany the new boiler package.

Calculating Energy Savings. In a similar fashion to chillers, boiler efficiency is affected by boiler loading, control settings for combustion, fuel energy content and surrounding environmental conditions. Therefore, is it important to record enough baseline data to develop an adequate baseline model which captures the "part-load" performance at various boiler loads as well as surrounding environmental conditions. Useful information regarding boilers can be found in Dukelow (1991), Babcock and Wilcox (1992) and Dyer and Maples (1981). In cases where boiler load is the same for both the baseline and post-installation periods, energy savings can be calculated using hourly measurements of fuel input to the boiler only. However, the analyst should be sure to note both baseline and post-installation operating conditions affecting boiler operation. Savings can be calculated by developing a baseline model using methods previously described.

For cases where the post-installation boiler load, or operating characteristics are different than the baseline boiler load or conditions, boiler fuel input and thermal output should be measured, as well as pertinent operating characteristics, so that a baseline input/output model can be developed which can then be used to forecast the baseline use into the post-installation period.

Once such measurements have been obtained, energy savings from a boiler retrofit can be determined in the following fashion. First, develop a baseline model for the boiler using the in-situ boiler performance measurements. Second, develop a post-retrofit boiler model for the new boiler. Third, calculate energy savings by comparing the energy use predicted by baseline boiler model (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation boiler data. In situations where significant data are missing in the post-installation period, a post-installation boiler model can be created to fill in missing data. Energy savings are then calculated by comparing the energy use predicted by the baseline model to the energy use predicted by the post-installation model. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the baseline model's RMSE.

Calculating Peak Electric Demand Reductions. If end use loads are being monitored, electric demand reductions can be determined using the Option C method previously described for lighting projects.

Limitations Of Calculating Retrofit Savings From Boiler Retrofits Using Hourly Whole-Facility, Before/After Data. These savings can be adversely affected by boiler loading, boiler supply temperature, combustion settings and other changes to operational settings affecting boiler efficiency. Option C hourly savings calculated with boiler thermal and fuel input measurements can be adversely affected by differences in the baseline and post-retrofit boiler operating settings.

4.3.5 Expected Accuracy. Calculating energy savings using a monthly baseline regression model is expected to be accurate plus or minus twenty percent (±20%) for those facilities that do not have significant schedule changes during the course of one year. Energy savings calculated using a daily or hourly baseline and post-installation, whole-facility models should be accurate to plus or minus five to ten percent (±5-10%) for facilities that do not have significant schedule changes during the course of one year.

4.3.6 Expected Cost. The expected cost of Option C should be one to ten percent (1-10%) of the installed retrofit cost depending on whether utility billing methods or hourly data is used. If monthly utility billing methods are used, the expected cost should be approximately one to three percent (1-3%) of the installed retrofit cost. If hourly monitoring equipment is installed in a facility, costs can vary from three to ten percent (3-10%) depending on the amount of instrumentation and end-use measurements being recorded. If continuous hourly post-installation monitoring is planned, savings recording and reporting for the second and subsequent years should not exceed one to three percent (1-3%) of the retrofit cost.

Installing and maintaining a data logger, as well as collecting and archiving data over the life of the retrofit significantly increases the accuracy of daily and hourly models (Claridge et al. 1994). For most applications, whole-facility data loggers can be installed for the first year for five percent of the retrofit cost. Recording and reporting during the second and subsequent years should cost approximately one to three percent (1-3%) of the cost of the retrofit each year.

EMCSs can be used to collect trend data which is used in the before-after analysis. However, great care should be exercised to control access and/or changes to the EMCS trend log from which the savings analysis is extracted. Also, post-processing routines will need to created for changing the EMCS COV data into time series data for performing an analysis, especially if the analysis depends on NWS hourly time series data. EMCS manufacturers should also provide the facility manager with NIST traceable calibrations of all sensors to be used in the project upon request. EMCS manufacturer's should also provide a facility manager with evidence that their 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).

4.4 OPTION D: CALIBRATED SIMULATION APPROACH

Option D is intended for energy conservation retrofits where calibrated simulations of the baseline energy use and/or calibrated simulations of the post-installation energy consumption are used to measure savings from the energy conservation retrofit. Option D can involve measurements of energy use both before and after the retrofit for specific equipment or energy end use as needed to calibrate the simulation program. Periodic inspections of the equipment may also be warranted. Energy consumption is calculated by developing calibrated hourly simulation models of whole-building energy use, or equipment sub-systems in the baseline mode and in the post-installation mode and comparing the simulated annual differences for either an average weather year or for weather and operational conditions that correspond to the specific year during either the baseline or post-installation period.

4.4.1 Confirming Installed Equipment Performance. The primary difference between previously discussed options and Option D is that Option D uses calibrated simulations of either the whole building or of sub-systems in the building to determine the difference in the performance of the specific equipment being replaced (Calibrated simulations are recommended in certain instances under Option B and for chillers and boilers under Option C.) Option D may include, as needed, one-time or snap-shot measurements of the energy performance of energy consuming systems in the building in order to transcribe those characteristics into the simulation model during the calibration process.

Time allotted for installing portable, short-term metering devices during the baseline and post-installation periods depends on the type of equipment being simulated. Data from suitably equipped EMCSs can also be used, taking note of the exceptions previously noted. For example, the in-situ measurement for constant load motor replacements may take measurements for only a few hours or days before and some period of time after the retrofit. Measurement of the 24-hour profile of whole-facility lighting loads may take several weeks to one month to determine average weekday and weekend use (before and after the retrofit). Option D can also include measurements of whole-facility electricity, heating or cooling energy use, as well as measurements of ambient conditions which would be necessary to calibrate the simulation model. The simulation model is then used to calculate heating/cooling interaction of a lighting retrofit. Specific tests may need to be performed on the HVAC equipment to force it through all possible operating modes while input-output performance measurements are being taken. Examples of this type of testing include chiller efficiency tests (Gordon and Ng 1994, Anderson and Breene 1995, Brandemuel et al. 1996), boiler efficiency tests (CEE 1995, Dyer and Maples 1981, Dukelow 1991) and tests regarding pumps and fans (Brandemuel et al. 1996).

4.4.2 Types of Simulation Programs. Various simulation programs are available for simulating whole-building energy use or separate components of the building: whole-building, fixed schematic hourly simulation programs; whole-building, modular hourly simulation programs; bin models with simplified HVAC systems models; component models; and special purpose models. Additional information about the different types of 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 (Crawley et al. 1996). This information can be obtained by accessing DOE's information server on the World Wide Web at the following URL (www.eren.doe.gov).

Whole-Building, Fixed Schematic Hourly Simulation Programs. This is probably the most common type of general purpose simulation tool which has evolved over the past 20+ years (Ayers and Stamper 1995). Such programs as DOE-2 and BLAST fall into this category.

Whole-Building, Modular Hourly Simulation Programs. In the last ten years modular simulation programs have become available that allow unlimited flexibility in the choice and functionality of the simulation program (SEL 1996, Buhl et al. 1993). Many of these programs have a common method of creating and linking modules (Sahlin et al. 1995, 1996a, 1996b). A simulation consists of an assembly of modules that represent a building and its energy consuming systems. To simulate a building, one must either create a module for each component or have access to a library of previously created modules. Although creating every module from scratch is cumbersome, such programs can gain the advantage over fixed schematic programs once large libraries of the modules become available. Modular programs are also easier to modify and maintain since only certain aspects need to be changed versus changing the entire monolithic code.

Bin Models With Simplified HVAC Systems Models. In 1983 ASHRAE developed a simplified energy analysis procedure. This procedure uses the modified bin method to calculate thermal loads and uses simplified HVAC systems models. Complete explanations of the models and FORTRAN code are provided in the publication by Knebel (1983). Such models are appropriate for certain classes of buildings where the envelope and internal loads are well represented by the bin model, and the HVAC systems can be adequately simulated by simplified air-side HVAC systems models included in the publication.

Special Purpose Models. There are many other types of special purpose programs for simulating energy use and environmental conditions including emulators, CFD simulation models and general purpose equation solvers.

> *Emulation Programs.* Emulators such as HVACSIM+ (Park et al. 1985) have been developed to simulate HVAC systems as small time steps (i.e., several seconds) in order that very complex behavior can be studied, such as air valve movement in a terminal VAV box. Emulators are usually too complex and cumbersome to apply to buildings for energy retrofit analysis.

Computational Fluid Dynamic (CFD) Simulation Programs. These programs are used in analyzing the internal environment of large spaces such as atriums, theaters or coliseums. Such programs are capable of simulating the stratification of air in a heated (or cooled) environment, or the diffusion of smoke or contaminants. To date, analysts have chosen to use a combination of canned, or pre-written CFD programs that calculate fluid conditions based on snap-shot data fed to the program from DOE-2 or BLAST (BLAST 1997).

General Purpose HVAC Equation Solvers. Solvers such as TRNSYS (SEL 1996), and EES (EES 1997) are capable of solving groups of simultaneous equations and include functions that calculate moist air and other thermodynamic properties. Using either of these programs is similar to using the modular simulation programs with the exception that both programs can solve almost any series of equations used to represent complex, coupled energy dependencies in a building.

4.4.3 General Information About Calibrating Simulation Programs. The calibration of a simulation to 12 points of measured monthly utility data has been the preferred method for years (Diamond and Hunn 1981, Haberl and Claridge 1985, McLain et al. 1993). Recently, studies have reported calibrated models using hourly measured data (Hsieh 1988, Hinchey 1991, Bronson et al. 1992, Kaplan et al. 1990, Clarke et al. 1993, Manke and Hittle 1996). Most of the previous methods have relied on simple comparisons including bar charts, monthly percent difference time-series graphs and monthly x-y scatter plots. Calibrated simulation can be used to calculate savings from a retrofit when either the baseline or post-installation data are not available, or when the retrofit being measured cannot easily be identified with before-after measurements. Figure 2 provides a schematic of both the Option C before-after energy savings measurement technique previously discussed and the Option D calibrated simulation measurement technique.

In Figure 2, when before-after energy use data and coincident weather data are available, an empirical model of a building's energy use can be assembled using the techniques previously identified. For the left side of Figure 2 (where a dual duct constant volume air-handling system (DDCV) is being replaced with a VAV system) developing whole-building regression models of a building's baseline electricity use, cooling and heating energy use would be necessary. The baseline regression model (Epre) would then be recalculated with weather and occupancy data from the post-installation period to predict building consumption post-installation (Predicted DDCV Energy Use). Building energy use is also measured in the post-installation period after the DDCV is replaced with the VAV system (Emeas). Measured energy savings are then calculated by:

$$E_{save} = E_{pre} - E_{meas}$$

where

(E_{pre}) is the post-installation energy use predicted by the empirical model that was fitted to baseline energy use,

(E_{meas}) is the actual post-installation energy use

The right side of Figure 2 illustrates a case where calibrated simulation can be used to calculate energy savings from the same DDCV-to-VAV retrofit. In the case shown, baseline data is not available for the building being studied, only post-installation data is available. The engineering simulation would then be calibrated to the post-installation VAV energy use, and DDCV energy use simulated by changing parameters within the computer simulation. In some cases simulated DDCV energy use can also be calibrated to special test data for the building (e.g., where the VAV is run at 100 percent fan speed during several tests, and other operational parameters are set at the DDCV setting such as duct static pressure and damper settings).

Energy savings from the DDCV-to-VAV retrofit is then calculated by:

$$E_{save} = E_{DDCV} - E_{meas}$$

where

(E_{DDCV}) is the pre-retrofit energy use predicted by the simulation of the DDCV system, and

(E_{meas}) is the measured post-installation energy use of the actual VAV system.

Weather data from average-year, or on-site measured weather data that coincides with the actual baseline or post-installation period can be used depending upon negotiated contract provisions. However, calibration of the VAV simulation model will significantly improve if measured hourly weather data are available (Haberl et al. 1995a).

Limitations of Calibrated Simulations. Calibrated simulations are subject, at a minimum, to the following four limitations:

1. *Buildings That Can Be Readily Simulated.* Most buildings can be readily simulated. Buildings that may not be easily simulated include:
    - those facilities with large atriums where internal temperature stratification is significant, and thermal convection is an important feature of the heating/cooling system.
    - those facilities that are underground, or where ground coupling plays a major role in the energy consumption characteristics.
    - those facilities with unusual exterior shapes or extremely complex shading configurations.
2. *Building HVAC Systems That Can Be Readily Simulated.* Most HVAC systems can be simulated with programs now available. However, some control options in use are difficult to reproduce with a simulation program., e.g., local controls options in large buildings that have a high number of HVAC systems (since most simulation programs are limited to the number of zones they can simulate due to memory limitations in the computer).
3. *Retrofits That Cannot Be Readily Simulated.* Certain retrofits simply cannot be simulated without great difficulty. Two such examples include: i) savings from the addition of radiant barriers in an attic, and ii) changes to particular HVAC control settings which deviate from the allowable settings in today's "fixed schematic" whole-building hourly simulation programs.
4. *Results May Not Match Actual Differences In Before-After Utility Bills.* Since the "savings" from a calibrated simulation are calculated savings that often utilize a

standard weather file or standard occupant profile, the annual simulated energy savings total may not match actual savings at the site since weather conditions experienced by the simulation program may not match actual weather conditions post-installation. In order to better match actual retrofit savings, two weather files should be assembled and fed into the simulation program, one for the baseline and one for the post-installation period. Each weather file should consist of on-site ambient conditions (i.e., dry bulb temperature, humidity, wind, solar and ground temperatures).

4.4.4 Fundamental Principles for Calibrating Simulation Programs.

Calibration Effort Should Fit Project Resources. When using calibrated simulations, an important issue to consider is the creation and calibration of a reasonable building model within the project's time and budget constraints. When minimal time and monetary resources are available, monthly utility billing data could be used to calibrate the simulation, supplemented with snap-shot or limited on-site measurements of important parameters. Where possible, all monthly utility billing data should be used to calibrate the model including: monthly electricity usage, electric peak demand and heating fuel use. Calibrations based on monthly data and snap-shots can achieve an approximate accuracy of plus or minus twenty percent (±20%) or mean bias error (MBE) of monthly energy use. Depending on the size and complexity, such calibrations can be accomplished for 5-10 percent of annual utility costs with a minimum lower limit of at least one person per week (i.e., 40 hours) to create a credible simulation.

When accuracy is most important and time/budget constraints secondary, measured hourly energy use data and important environmental parameters should be used to verify the hourly simulation. Such hourly calibrations have been shown to achieve plus or minus ten to twenty percent (±10-20%) CV(RMSE) of hourly energy use, or plus or minus one to five percent (±1-5%) of the monthly utility bill. Usually, a minimum of 9-12 months of on-site hourly measurements are necessary to completely characterize an existing building's HVAC system operation and occupancy schedules, etc. Resources required often run as high as 100 percent of the annual utility bill and can require one person, per year per building.

Other Issues. In ASHRAE literature and elsewhere, there are many examples where calibrated simulations can be obtained for a given building and used effectively to measure energy savings. In almost every case authors support the importance of visiting the building and inspecting existing systems to determine current operation and system configuration. Additionally, authors report the importance of carefully measuring and calibrating those variables that significantly affect energy use. Although the determination of variables is difficult to determine in advance, guidelines are available.

4.4.5 Influential Variables. This section discusses the importance of various input parameters. It should be noted that although this topic has been previously researched by several authors, there is no conclusive evidence that important variables for one building will apply to another. Also, recent results by Manke and Hittle (1996) indicate there may be significant deviations in "observed" input parameters versus "effective" parameters. For example, significant differences have been observed in the effective weight of a building's thermal mass and the known weight of the actual construction materials, which suggests more work be conducted regarding the fundamental mathematical relationships inside the algorithms of building energy simulation programs.

Major input variables that influence simulation results include the following (Hseih 1988, Bou-Saada 1995a, 1995b):

- Building Plug & Lighting Loads
- Interior Conditions
- HVAC Primary & Secondary System Characterizations
- Building Ventilation & Infiltration Loads
- Building Envelope & Thermal Mass Characterizations
- Building Occupant Loads

Plug & Lighting Loads. These variables can be most easily verified through spot monitoring, field inspections and blink tests (Hsieh 1988, Houcek et al. 1993, Soebarto 1996). To verify these loads, visit the site and document the number, load and usage of receptacle plug loads. If the facility is wired such that plug and receptacle loads can be easily isolated (or a surrogate variable used), hourly measurements over one or more weeks can deliver valuable 24-hour weekday-weekend profiles of receptacle plug loads which can then be input into the simulation program (Jacobs et al. 1994).

Interior Conditions. The most important interior condition to document is zone temperature and humidity condition. This can usually be accomplished with stick-on loggers or other recording-type temperature/humidity devices placed strategically in the simulation zones. If an exact location which corresponds to the simulation cannot be determined easily, place the device in the return air duct or grille of the HVAC system. Use this option only if air is continuously drawn across the sensor to avoid recording duct stagnation temperature. HVAC system zoning is important to duplicate in envelope-driven buildings, and (to a lesser extent) in internal-load-driven buildings (Hinchey 1991).

HVAC Primary And Secondary System Characterizations & Setpoints. The next most important variables to determine are the primary (chillers, boilers, etc.) and secondary (AHUs terminal boxes, etc.) HVAC systems characteristics. An error in determining any one of these variables can cause a 100-500 percent variation in annual simulation results. It is also important to check and thoroughly understand all "default" input variables in the simulation program, since many default values have little resemblance to the actual building being simulated.

Building Ventilation/Infiltration. Often, input values for these loads are either determined parametrically or not determined at all. Where project resources allow, ventilation and infiltration parameters should be measured.

Building Envelope & Thermal Mass Characterization. The characterization of the building's envelope, shading and thermal mass is probably the simplest group of variables to ascertain for a given site. The process involves determination of the material properties (U-values thermal mass), orientation and dimensions of the walls, roofs and other exterior opaque surfaces. Transparent surfaces such as windows require the dimension, transmissive characteristics (visible light and infrared), thermal properties (U-values), orientation and exposure to incident radiation (direct, diffuse and reflected). Architectural rendering programs that display the simulation input are extremely useful for determining surface orientation and location relative to other surfaces (Huang 1993). Ground heat transfer may also play an important role in some buildings (Krarti and Choi 1996).

Building Occupant Loads. This includes building occupancy and how comfort needs and sensible/latent heating contributions may be affecting the building's HVAC system. Counts are needed of the number, schedule and activity level of the occupants. Reasonable representations of these characterizations are then put into the simulation program.

4.4.6 Calibrated Whole-Building Simulations Using Snap-Shot Measurements of Important Parameters and Monthly Utility Billing Data. For projects with limited resources, calibrated simulations can be obtained using monthly utility data, average daily ambient temperatures for the same period as utility billing data and snap-shot measurements of selected variables. Accuracy of simulation will be limited, however, since only 12 data points (i.e., the 12 monthly simulated predictions) are available for assessing how well the simulation matches the baseline.

Monthly Utility Bills And Ambient Temperatures. First, develop an accurate characterization of the building's envelope, occupant loads and HVAC systems. The results of the simulation are then compared to monthly utility billing data to determine the accuracy of the simulation compared to actual energy use. In most cases, this determination is made with a suitable weather tape using measured weather data from a location near the site which corresponds to the same period as the utility bill.

> *Sources Of Weather Data.* If average weather data must be used, it can be obtained from a variety of sources including: ASHRAE (WYEC2), the National Renewable Energy Lab (TMY2), the National Research Council of Canada (CWEC), the National Climatic Data Center (TRY) and the California Energy Commission (CTZ2). Each agency has designed weather data sets to meet a particular need (Huang and Crawley 1996).

Accuracy of Calibrating Whole-Building Simulation Programs to Utility Billing Data. One problem with calibrating whole-building simulation programs to monthly utility billing data is that the resolution of the data is so gross, i.e., only 12 data points, it is difficult to determine if there is an actual match to the building's energy use or if simulation cancellation errors are masking areas where improvement can be made. Therefore, snap-shot measurements should be taken to determine relevant parameters which may then be matched to the simulation.

Following the guidelines regarding input parameters in the previous section, snap-shot measurements of the following inputs will significantly improve simulation accuracy.

> *Hourly Plug And Lighting Loads.* This should include power (RMS Wattage) measurements of all 120 VAC receptacle plug loads. Where possible, 24-hour profiles of plug loads are preferred.

> *Motor Control Center Loads.* These measurements are necessary for modifying default assumptions regarding motor size, motor heat loss to air streams in the HVAC systems and the electricity required for chilled/hot water pumping. Where resources are available, on-

site clamp-on RMS power measurements (i.e., wattage) should be taken to determine motor consumption since motors often have power factors different than 1.0.

Heating/Cooling System Types and Efficiencies. Heating/cooling system type needs to be determined in order to select the correct system in the simulation program. Information regarding setpoint temperature schedules, air flow rates, boiler efficiencies, chiller efficiencies, economizer controls, etc. also needs to be determined to adjust default variables in the simulation program.

Interior Temperatures. A fundamental characteristic that needs to be determined is the interior setpoint temperature for each major thermal zone.

Air Flow Rates, Ventilation Loads And Infiltration Rates. Snap-shot information regarding air flow rates in AHUs and corresponding ventilation rates is also needed to accurately characterize secondary HVAC systems. Although usually more difficult to determine, infiltration rates measured with blower doors may be appropriate for some buildings (ASTM 1992).

Use Of Blink Tests. Where resources are limited, blink tests or on/off tests can be used to determine snap-shot end-use measurements of lighting, receptacle plug loads and motor control centers. Blink 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).

4.4.7 Calibration Of Whole-Building Simulations Using Hourly On-Site Measurements. Several steps should be taken when calibrating a computer model to hourly measured energy data. First, site-specific hourly weather data should be collected for the period under consideration. This data includes dry bulb temperature, relative humidity and peak wind speed gathered from the nearby NWS weather station (*Note*: Peak wind speed from the NWS is recorded for aviation safety purposes and can overstate average hourly wind speed by a factor of two to three. Therefore, it should be inspected, compared to local average hourly measurements and modified if necessary). Global horizontal solar radiation may be available in certain cities from NREL or other providers. If not, it needs to be measured on-site. A routine developed by Erbs et al. (1982) can be used to convert global solar radiation into beam and diffuse radiation (Bronson 1992, Bou-Saada 1995a, 1995b). In cases where ground coupling plays an important role, ground temperature data becomes important. This weather data is then joined into a single data file and packed onto a TRY or other weather tape format (Bronson 1992) for use with the DOE-2 simulation program.

4.4.8 Procedures Used to Calibrate the Simulation Program. ASHRAE GPC14P is in the process of defining specific procedures used to calibrate whole-building simulation models. These procedures include statistical comparisons of a simulation to measured data from a site as well as software that allows architectural rendering of the input simulation file. Further information regarding these procedures can be found in Huang (1993), Abbas and Haberl (1995), Cleveland (1985), Bou Saada and Haberl (1995a), Haberl et al. (1988, 1989, 1995a), Bronson (1992), Kaplan et al. (1990, 1992), Degelman (1995), Hirsch et al. (1995), and McLain et al. (1993).

4.4.9 Uses of the Calibrated Simulation Model METHOD. Calibrated simulations can be used effectively to measure post-installation energy savings and to assess the impact of new energy conserving design. When using a calibrated simulation program it is important to maintain tight security over access to the input and weather files used to generate simulated energy use. In cases where calibrated simulation is used in new construction there may be a several year period that elapses between the design of the building (and the creation of the baseline simulation) and the calibration of the post-construction simulation program. When using calibrated simulation it is recommended that the building owner carefully protect, document and control unauthorized access to the baseline simulation input file. This is because it is easy for an analyst to inadvertently make an undocumented change to an input file which may have a significant impact on total annual consumption. In some cases this can be a change to one code word nested inside thousands of lines of an input file - making it virtually impossible to find the change and assess its impact. Below is a summary of procedures required for using calibrated simulation to measure retrofit savings and in new construction.

Using The Calibrated Simulation Model To Measure Retrofit Savings. Calibrated simulations can be used to measure savings in facilities which are readily simulated by existing simulation models. To use a whole-building calibrated simulation, both a baseline model and a model that reflects ECM retrofits are needed. To measure savings, create a simulation model that is calibrated to the baseline (the pre-retrofit model), and compare it to a simulation program calibrated to the total post-installation data including all known ECMs as well as other changes to the building. The effect of individual ECMs can then be determined by selecting or excluding these measures within the simulation model.

Use of the Calibrated Whole-Building Model to Assess New Design Impact. Calibrated whole-building simulations can also be used to assess the impact of new design. Additional information regarding how this is accomplished is contained in the discussions concerning new construction in Section 6.0.

Use of Calibrated Component Simulation Models. In some cases it may be necessary to measure post-installation savings using a calibrated component simulation model. Such a model simulates the performance of a specific piece of equipment, e.g., chiller, boiler or dual-duct AHU. In some cases it may be cost-effective to develop an engineering, or mechanistic simulation model of the specific component and then calibrate the model to measured baseline data from a specific building or piece of equipment. A similar model is then created for the post-installation component, and energy savings calculated by comparing annual predictions of the energy used by the two different systems under similar input/output conditions. Prewritten engineering component models are available from ASHRAE for HVAC systems in the HVAC02 toolkit (Brandemuel 1993), and for plant-type 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).

4.4.10 Examples. Savings resulting from the following example projects can be measured using Option D provided both the owner and contractor/ESCO are willing to commit the resources needed to properly simulate the building or system to be retrofitted. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

Option D: Lighting Efficiency and/or Controls Project. To measure electricity savings and thermal take-back from lighting/controls projects: i) create a baseline simulation model of the building, ii) calibrate the baseline model to either monthly data supplemented with snap-shop measurements or hourly data for the whole-building, iii) retrofit the building, iv) make changes to the input file that accurately reflect the retrofit, v) create a calibrated post-installation simulation model, and vi) measure the savings by comparing the calibrated baseline model to the calibrated post-installation simulation model.

Calculating Electricity Savings. These savings are calculated by analyzing the difference between the calibrated baseline and post-installation simulation. Care should be taken to adequately capture the correct number of day-type profiles which accurately represent baseline electricity use during weekday, weekend and holiday periods and to verify that these daytypes have been input properly into the simulation program. Annual savings projections are then calculated by comparing the baseline simulation to the post-installation simulation. Savings are significant if the difference between the model-predicted baseline and post-installation energy use is greater than model error as determined by the RMSE.

Calculating Peak Electric Demand Reductions. Electric demand reductions can also be analyzed provided representative baseline and post-installation measurements have been taken and used to calibrate the simulation programs. Both the owner and contractor/ESCO should understand that this analysis provides an hourly demand savings estimate which may not represent actual demand savings from the lighting project, especially if 15-minute or less than hourly demand intervals are in effect.

Calculating Interactive Heating/Cooling Savings. Interactive heating/cooling savings estimates can be calculated by the calibrated simulation program providing other changes are not made to the baseline and post-installation simulation programs. The owner and contractor/ESCO should agree in advance which type of weather file will be used to perform comparative calculations. Measured weather data corresponding to the post-installation period will yield the most accurate results. In cases where this data is not available, average-year weather data may be used.

Limitations Of Calculating Retrofit Savings From Lighting Efficiency and/or Controls Projects Using Option D. These calculations can be adversely affected by the following factors:

1. Demand savings may not match buildings where actual demand intervals of less than 60 minutes are used.
2. Simulated savings using Option D may not match actual savings because the simulations use average operation profiles and specified equipment performance parameters. If operating profiles change or equipment performance changes, simulation programs will need to be modified to reflect these changes.
3. Savings estimates may vary if there is a significant number of lamp outages or if the actual operating schedule varies significantly from the stipulated operating schedule.

4. Thermal savings predicted by Option D are only as good as the simulation program's representation of the actual building envelope and HVAC systems.
5. Thermal savings are limited to how well the lights-to-space assumptions match actual building configuration.

Option D: Constant Load Motor Replacement Project. Baseline capacity, demand or power level (kW, Btu/hr or kJ/hr) should be measured using short-term, in-situ end-use measurements or may be estimated with representative sample measurements, and these measurements inserted into the baseline simulation program (Biesemeyer and Jowett 1994, Brandemuel et al. 1996). These measurements are then repeated post-installation to determine changes in motor energy use and the characterizations used to modify the post-construction simulation program. Depending upon the type of system or load, these measurements can either be representative (for constant speed, constant load systems) or continuous (for constant speed, varying load systems). Electricity savings due to reduced motor load are calculated in the same fashion described above in Option D for lighting/controls projects.

Calculating Electricity Savings. These savings can be calculated by analyzing the difference between the calibrated baseline and post-installation simulations. Both the owner and contractor/ESCO should understand that this analysis provides a simulated estimate which may not represent actual energy savings from the project due to such factors as lamp burnout, and usage profile changes.

Calculating Peak Electric Demand Reductions. Follow the same guidelines discussed above in Option D for lighting/controls projects.

Calculating Interactive Heating/Cooling Savings. Follow the same guidelines discussed above for Option D lighting/controls projects.

Limitations Of Calculating Savings From Constant Load Motor Retrofits Using Option D. These calculations can be adversely affected by factors 1, 2 and 4 listed above for lighting projects. Additionally, measurements using Option D are completely dependent on how well representative measurements match actual motor electricity consumption over an annual period, and how accurately these measurements have been transcribed into the simulation program. Estimates may vary if there is a change in motor load.

Option D: Variable Speed Drive Motor Project. Baseline capacity, demand or power level (i.e., kW) should be measured using short-term, in-situ end-use measurements, and these characterizations inserted into the baseline simulation (Biesemeyer et al. 1993, Brandemuehl et al. 1996). Short-term measurements are then repeated post-installation to adequately characterize the motor's variable electricity use in the post-construction simulation program.

Calculating Electricity Savings. These savings are calculated in the same fashion as constant load motor projects discussed in Option D above.

Calculating Peak Electric Demand Reductions. These reductions can be estimated in the same fashion as constant load motor projects discussed in Option D above.

Calculating Interactive Heating/Cooling Savings. These savings can be estimated in the same fashion as constant load motor projects discussed in Option D above.

Limitations Of Calculating Savings From VSD Projects Using Option D. These calculations can be adversely affected by the same issues which may affect constant load motor replacement projects discussed in Option D above.

Option D: HVAC and/or EMCS Project. Savings from HVAC/EMCS projects can be analyzed with the Option D approach using the previously described guidelines for Option B. Savings can be calculated providing a calibrated engineering model is developed for each HVAC system to adequately assess baseline performance, and either continuous measurements are made post-installation or a calibrated model is developed post-installation (Knebel 1983, Katipamula and Claridge 1992, Liu et al. 1995). Annual savings are calculated by comparing energy use predicted by the model(s) for the agreed-upon standard operating schedule and ambient conditions. These models are capable of determining electricity and thermal savings, as well as electric demand reductions.

Calculating Electricity Savings. These savings can be calculated using calibrated baseline and post-installation simulation models. To develop these models, each major HVAC system must be inspected and analyzed, and a separate baseline psychometric model developed to predict existing system energy use. This normally includes short-term measurements of in-situ performance of the HVAC system (Brandemuel et al. 1996, Balcomb et al. 1993, Liu et al. 1994, Katipamula and Claridge 1992). Post-installation, either continuous energy use is measured or calibrated post-installation HVAC system models are developed that reflect post-installation operational changes. These post-installation models also need to be calibrated to measure short-term data. Savings are significant if the difference between the model-predicted baseline and post-installation energy use is greater than model error as determined by the RMSE.

Calculating Peak Electric Demand Reductions. Hourly electric demand reductions can be calculated by comparing the difference between projected baseline and post-installation model electricity use. Be sure to ascertain whether or not the hourly demand billing interval agrees with the interval used by the local utility.

Calculating Heating/Cooling Savings. Cooling savings are estimated by comparing post-installation projections of the baseline HVAC cooling use to the HVAC cooling use predicted by the post-installation model. Appropriate calculations need to be made to determine the effect of the primary cooling system efficiency (i.e., kW/ton of the chillers) for varying loads.

Limitations Of Calculating Savings From HVAC And EMCS Projects Using Option D. These calculations can be adversely affected by the following factors:

1. HVAC/EMCS savings measured with Option D are estimates of electricity savings which utilize representative baseline and post-installation simulation models. These models utilize one-time measurements or short-term measurements of installed HVAC electricity and thermal performance for calibration. Therefore, the accuracy of the

measurements is completely dependent on how well representative measurements predict actual HVAC electricity and thermal consumption over an annual period.

2. Calculations may be affected if HVAC system operating characteristics do not match representative schedules used to drive the models.
3. Calculations may be affected if EMCS programming significantly differs from the representative schedule used to drive the models (setpoint temperatures, schedules, etc.)
4. Changes in heating/cooling savings may be affected by procedures used to operate the systems. In particular, the average chiller kW/ton ratio is affected by the rate of the cooling load on a particular chiller. Certain chillers that are loaded below 50 percent of their capacity tend to have significantly higher kW/ton ratios which can increase overall electricity consumption and reduce total retrofit savings. Boilers or furnaces run at low loads can cycle excessively, which decreases fuel conversion efficiency and reduces total retrofit savings.

Option D: Chiller Project. Savings from chiller projects can be analyzed with the Option D approach using the previously described guidelines for Option B. Savings can be calculated if calibrated baseline and post-installation chiller models are developed (Brandemuel et al. 1996, Gordon and Ng 1994, Anderson and Breene 1995). Such models are primarily sensitive to differences in chilled water supply temperatures, condenser water return temperatures (or refrigerant return temperatures for air condensers) and chiller loads. To calibrate such models, chiller thermal output, chiller electricity use, chilled water supply temperature and condenser water return temperatures need to be measured over the expected range of operation. Measurements are repeated post-installation. Annual savings are then calculated by driving the chiller models with an agreed-upon schedule of chiller loads which includes chilled water supply temperatures and condenser temperatures, and comparing the differences between the predictions from the two models.

> *Limitations Of Calculating Savings From Chiller Projects Using Option D.* These calculations can be adversely affected by the same factors that are described in Option B for chiller projects.

Option D: Boiler Project. These savings can be estimated using Option D if input-output boiler or combustion efficiency tests are taken before and after the retrofit in the same fashion as described in Option B (Dukelow 1991, Dyer 1981, Babcock and Wilcox 1992). For smaller boilers other test methods can be used (i.e., the “time to make steam” test [Center for Energy and Environment, CEE]). In order to be effective, these tests should be taken under varying operating conditions in order to capture boiler efficiency over its expected operating range, temperature and pressure. The results of these tests should yield a set of performance curves that can be put into calibrated simulation programs to establish annual boiler performance. Savings are then calculated by comparing differences between baseline and post-installation annual boiler performance.

> *Limitations Of Calculating Retrofit Savings From Boiler Retrofits Using Option D.* These calculations can be adversely affected by the same factors described in Option B for boiler projects.

4.4.11 Expected Accuracy. Calibrations which use monthly data and spot-checks of important parameters can achieve an accuracy in the range of plus or minus ten percent (±)10% difference or MBE of monthly energy use. Where accuracy is important and adequate time and monetary resources are available, measured hourly data of energy use and important environmental parameters should be used to verify the hourly simulation. Such hourly calibrations have been shown to be plus or minus ten to twenty percent (±10-20%) CV(RMSE) of hourly energy use, or plus or minus five to ten percent (±5-10%) of the monthly utility bill.

4.4.12 Expected Cost. The expected cost of Option D should be three to ten percent (3-10%) of the installed retrofit cost. For example, if a $100,000 retrofit was installed, roughly $3,000 to $10,000 should be allocated for estimating savings and producing necessary reports. Depending on the size and complexity, calibrations which utilize monthly data and snap-shot calibrations can be accomplished for five to ten percent (5-10%) of annual utility costs with a lower limit of at least one person per week to set up the simulation input files (40 hours). When hourly energy data and environmental data are measured and used to calibrate the simulation program, resources required to accomplish this performance can often run as high as 100 percent of the annual utility bill and can require one person per year per building. When hourly data is used, a minimum of 9 to 12 months of on-site hourly measurements are necessary to completely characterize an existing building's HVAC system operation and occupancy schedules, etc. Also, a significant number of data processing routines are necessary to collect on-site measurements and compare the data with hourly simulation outputs (Bou Saada et al. 1995, Bronson 1992).

4.5 EXAMPLES OF MEASUREMENT AND VERIFICATION - WATER PROJECTS

4.5.1 Toilet/Showerhead Replacement.

Establishing Baseline Consumption/Equipment Performance. Baseline consumption performance can be established by:

Reviewing Several Years Of Monthly Building Water Meter Records. This method is most useful when consumption is reasonably consistent and primarily domestic. The more complex the building, and the more end uses there are, the more difficulty there is in determining toilet water consumption.

- If the utility water meters are more than 15-20 years old, there should be some consideration of either testing the accuracy of the utility meters or installing meters independent of the utility meters. The encoded register meters used by most water utilities tend to register anywhere from zero to twenty-five percent (0-25%) slower than accurate over time and may not precisely represent consumption after long periods of service. Some utilities have instituted programs to test and replace such meters which are considered to be "slipping."

- Dependence on consumption data based on inaccurate meters could result in major difficulties in determining actual baseline consumption savings that could adversely affect savings projections.

- In some cases, a review of continuous, or at least hourly, meter readings may provide information about leaks and other building consumption patterns. However, in larger buildings with 24-hour consumption and many end uses, the value of continuous metering may decrease.

End-Use Metering. Baseline consumption can also be measured by placing meters on piping risers serving the end uses to be retrofitted. This works only as long as the risers serve those end uses exclusively, or at least primarily serve toilets and/or showerheads. In a large building, the number of risers to be metered obviously increases.

Stipulating Existing Fixture Consumption Through The Use Of Conservative Baseline Assumptions. Existing toilets which are nominal five gallon-per-flush (GPF) models (pre-1980) are often assumed to consume 4.5-5.0 GPF. "Low flush" toilets from the 1980s are generally said to have a nominal flush volume of 3.5 gallons. These assumptions are not always true, with significant variations possible due to internal refill settings and flush mechanisms. The flush volume of "flushometer" valve toilets may vary by as much as several tenths of a gallon depending on water pressure, valve condition and, in the case of piston-type flush valves, the position of the adjustment screw. The same is true of urinals. An assumption must also be made for the number of flushes per day. This is particularly difficult since it requires an understanding of how building occupants live/work and how often they "double flush" the existing toilet. While there has been much discussion of the need to double flush low-consumption toilets, increasing information indicates that higher-consumption toilets are being double flushed as well. The actual measured consumption of "water -wasting" toilets varies from 3.5-7 GPF. A stipulation of unit flush volumes for the existing toilets ignores the fact that part of the baseline consumption and water savings resulting from toilet replacement work (or repair retrofit of existing toilets) comes from ending internal leaks in the old toilets. These leaks can originate from seeping/leaking flappers, ball cocks out of adjustment, leaking supply lines, etc. Quantifying baseline loss through these leaks is difficult without a good deal of metering and monitoring. It is virtually impossible by stipulating an assumption.

Existing pre-1990 showerheads are assumed to flow at five gallons-per-minute (GPM). This may vary, depending on the specific showerhead model, water pressure and condition of the fitting, from well over five GPM to less than one GPM. Most older showerhead flow rates vary significantly with water pressure and long-term deposition (depending on water chemistry and, to some extent, frequency of showerhead cleaning which may reduce showerhead flow rates). An assumption must be made for the number and duration of showers per day. Although engineering calculations often assume that pre-1990 showerheads have flow rates of five GPM and sometimes even higher, field studies suggest that actual flow rates are closer to four GPM and sometimes even lower.

Taking Spot-Flow Measurements Of Showerheads And Toilets (Sample Option B Approach As Discussed Below). In the former case, showerhead and toilet spot-flow measurements can be taken through the use of small flow meters screwed onto individual showerheads or by timing the filling of a container of known volume. A toilet's nominal flush volume may either be based on manufacturer's information or determined by using a small in-line flow meter on the toilet supply line to measure flush volumes. Unlike toilets, where measuring unit flush volumes involves the installation of in-line flow meters on water lines, approximating showerhead flow rates can be accomplished with the use of: i) a graduated plastic bag and a stop watch at the lowest end, ii) a non-flexible graduated container and a stop watch at the lowest end, or iii) a 100+ calibrated measuring device (the Water Weir) which does not require a timer at the high end. After determining flow rates and flush volumes, an assumption must still be formulated concerning usage rates (number of flushes per day, number and duration of showers per day).

Establishing Post-Installation Consumption/Equipment Performance. Post-installation equipment performance can be established using the following methods.

Option A Methods. The Option A method for determining post-installation unit consumption rates involves stipulating toilet flush volumes and showerhead flow rates for the new equipment. In theory, this is fairly simple since new toilets are generally specified at 1.6 GPF and new showerheads at 2.5 GPM or lower. Depending on water pressure, showerhead flow rates may be lower than 2.5 GPM, with some models providing relatively flat pressure/flow performance and others dropping significantly in low pressure conditions. Some manufacturers market showerheads with nominal flow rates lower than 2.5 GPM (2.0-2.2 GPM). Still some other showerheads are easily modified (removable restrictors).

While a volume/rate stipulation may be the least expensive method of determining post-installation unit consumption rates, the process has a significant variable - the number of uses (flushes, showers and their duration). Also, there is considerable debate over the performance quality of various toilets/showerheads, and this issue affects number of uses in a potentially significant way. For example, pressurized-tank toilets may have unit consumption rates under 1.6 GPF and may be so much more effective than the original toilet, that the number of uses (flushes per day) may actually decrease compared to pre-retrofit conditions. Conversely, some gravity-tank models (which do not perform as well as others) may result in increased uses. The flush volumes of flushometer valve toilets vary with water pressure, and gravity tank toilet flush volumes may vary somewhat with water temperature and pressure, although these variations may be relatively minor.

Option B Methods. Baseline and post-installation metering of plumbing risers serving toilets and/or showerheads can provide detailed information about actual consumption and savings, providing the risers specifically serve the loads under consideration. This activity represents a cross between Option B (equipment-specific monitoring) and Option C (whole-building monitoring). It is possible, but probably not cost-effective, to perform unit measurements of post-installation flush volumes on each toilet and shower. However, this will still not provide frequency of use information.

Option C Methods. Detailed and frequent (even continuous) building-wide water consumption metering data may also provide sufficient information to assess equipment performance. The difference is that measurements at the meter represent "real" savings, although other negative changes in the building could mask some of the savings. Understanding and tracking changes in the building (population and load changes) is important in accurately obtaining building-wide water consumption data.

4.5.2 Outdoor Water Use.

Establishing Baseline Water Consumption. The first approach to establishing baseline water consumption is to begin with consumption for the entire facility, unless outdoor end uses are separately metered by utility meters. (This is sometimes the case if a water/sewer utility waives sewer charges on water consumption which is consumptive rather than flowing into the sewer system.) If the water utility separately meters outdoor water use, then establishing baseline use is relatively simple, except for concerns regarding old utility meter accuracy. The difficulty with monitoring whole-building consumption is that outdoor water use can be so variable that desegregating that end use from a facility which is, itself, quite variable in its water use can be quite problematic.

If outdoor end uses are not separately metered by the water utility, strong consideration should be given to the installation of new meters to track outdoor end uses.

The alternative to establishing baseline outdoor use (without new or existing metering) depends on the system providing outdoor end uses being a relatively constant flow system, operated on a regular schedule. For example, the consumption of a sprinkler system which flows constantly at X GPM/cubic feet per minute (CFM) for X hours per day can be reasonably estimated. It is common, however, for operators to vary the operation of outdoor systems depending on perceptions of need. Detailed system operation information is necessary for calculated estimates of use to be considered accurate. The project investment, however, may be small enough to tolerate some baseline estimate inaccuracy.

Methods of Monitoring Savings. Estimating savings from outdoor water use projects by stipulating or assuming changes in the system's operation is difficult compared to metered observations. Generally, efficiency improvements are focused on either modifying the schedule of irrigation, or improving the efficiency of water delivery to the lawn/crops.

Modifying the irrigation schedule is based on varying irrigation times with weather and the "evapotranspiration rate." These savings may be specific to plant species and vary with regional and even micro climates. Increasing water delivery efficiency involves the use of irrigation technologies (e.g., "drip irrigation" or more efficient sprinkler technologies) or other changes which result in lower evaporative losses. These savings are also dependent on local climate and evapotranspiration rate, as well as plant species.

If the system is large (when compared to the investment in controls or irrigation technologies), the use of calculated savings projections may be acceptable. These savings projections are calculated based on projecting future use through existing formulas which determine how the minimum required volume of water-per-acre/hectare varies with weather and tracking weather. Even metered baseline and post-retrofit data may need to be "normalized" with changing weather.

4.5.3 Graywater Use.

Establishing Baseline Consumption. Establishing baseline consumption or pre-retrofit consumption depends upon which end use(s) the graywater is displacing. The two most common end uses are irrigation and toilet/urinal flushing. In each case, the methods for assessing baseline consumption in the two examples above apply.

Methods of Monitoring Savings. If graywater is completely displacing the use of potable water for a specific end use, then the complications of toilet/urinal replacement fixture performance noted above are not an issue. As well, the performance concerns of drip irrigation or evapotranspiration controls discussed above are not as issue in this case. Understanding baseline consumption becomes an understanding of savings. To that end, it may be easier to meter the flow of graywater into a system, if it originates from one or a few point sources, than it would be to monitor the use of graywater at the end use(s). If the graywater is not displacing all of the potable water in a particular system, then metered flow of graywater is the simplest way to determine potable water savings.

4.6 CASE EXAMPLES OF COMMERCIAL/INDUSTRIAL WATER EFFICIENCY PROJECTS

4.6.1 Nursing Facility. An in-house laundry for a 200-bed nursing facility in California consumed about 3.8 million gallons of water per year. An initial estimate projected a savings of at least 1.3 million gallons of water per year from the installation of a closed loop water reuse system.

The reuse system takes warm rinse water, subjects it to physical filtration and then reuses the water for a future wash cycle. Savings were estimated at $20,000 per year after an investment of $30,000, for a 20-month payback. Actual measured savings ranged from 2,000-3,500 gallons per day, seven days per week.

4.6.2 Hotel. A hotel in Denver reduced consumption by 20 percent between 1989 and 1992. Although occupancy decreased somewhat during this time, the hotel also replaced 750 showerheads, 7.5 GPM (measured), with models measured at 2.7 GPM in late 1990 at a cost of $29,700, resulting in a reduction of 6.2 million gallons per year. The hotel also installed a control valve for once-through cooling of air compressors. At a cost of $1,500, the valves are estimated to have reduced consumption by 1.5 million gallons per year.

4.6.3 Manufacturer. A Denver manufacturer of large metal parts reduced consumption by 28 percent between 1989 and 1992. The measures implemented include the following:

- Replaced two water-cooled air compressors with air-cooled units, saving an estimated 4.2 million gallons per year.
- Modified a lubricant cooling system to recycle the water-based lubricant, saving 500,000 gallons per year.
- Replaced an old dishwasher with a newer model is estimated to have saved 300,000 gallons per year.
- Installed pumps to provide agitation in place of aerators formerly used for the same purpose. This is estimated to have reduced evaporative losses by two million gallons per year.
- Installed new reverse osmosis units which have reduced the amount of water lost as reject water by an estimated two million gallons per year.

These measures, other measures and the repair of leaks resulted in a savings of approximately 22.6 million gallons per year between 1989 and 1992. This effort not only saved the manufacturer $25,000 per year in purchased water costs, but also $300,000 per year in sewage pre-treatment costs.

SECTION 5.0: OTHER M&V ISSUES

5.1 REPORTING FORMAT AND INVOICING

Reporting is an essential part of any M&V plan because it is the method used to track and verify project value. Report formats and invoicing procedures should be agreed upon prior to contract execution for two reasons: (i) this planning helps avoid potential conflicts between the owner and contractor/ESCO, and (ii) this planning is necessary to accurately determine M&V costs. Formats should be established for metering and monitoring data reports to assure that data is presented in an organized manner, providing summaries and raw data documentation which allows for consistent review. Formats should also be established to gather survey (walk-through) data.

5.2 M&V PROFESSIONALS

A "payment based on performance" arrangement requires that both parties believe the information on which the payments are based is valid and accurate. Often, an unbiased third-party trained to measure and verify projects may be helpful to ensure agreement of measurement validity. Should conflicts arise over the course of the project pay-back period, this third-party professional can become an invaluable tool as an unbiased source of information, independent of the ESCO and owner. This professional's level of involvement depends on the amount of information necessary to determine contract value. M&V professionals are often registered professional engineers working independently or for larger architectural and engineering (A&E) and consulting firms. Many are members of industry professional societies such as The Association of Energy Services Professionals (AESP), the National Association of Energy Service Companies (NAESCO), or the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

5.3 INSTRUMENTATION AND MEASUREMENT TECHNIQUES

This section provides a review of the instrumentation and techniques applicable to measurement of electricity, runtime, temperature, humidity, flow and thermal energy. Although measurements of electrical power and energy form the basis for analyzing equipment performance and energy savings calculations, additional information may be required. Runtime information is sometimes useful alone, or to calculate electrical power and energy data. It is often desirable to adjust baseline energy use to account for indoor or outdoor temperature and relative humidity. Flow data is required to determine natural gas or water consumption and as part of thermal energy calculations.

5.3.1 The Measurement of Electric Parameters. While the measurement of electrical energy seems simplistic on the surface, there are numerous opportunities for error. All electrical system analyses are derived from two types of measurements - current and voltage. Numerous manufacturers have developed equipment to gather one or both of these types of measurements.

The most common way of sensing electrical current 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, either at the panelboard serving the load or directly at the load. These CTs are then connected to an ammeter or power meter. CTs are readily available, very reliable and offer a low cost solution (typically $50 to $100 per CT) to measure AC current. CTs are available in a 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. For safety purposes, many meter manufacturers have standardized CTs fitted with internal shunt resistors. These CTs have a full-scale output of 333 millivolts and eliminate the hazard of shock from secondary current.

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, to lower the voltage to safer levels at the meter.

The Nuances of Power Measurement. *Energy* is not the same as *power*. Power is an instantaneous quantity. Utility companies often bill customers based on “demand,” which is defined as “the average value of power over a specified interval of time (typically 15 minutes).” Energy includes a time function, i.e., the length of time the power has been applied. Most energy-efficiency projects measure electrical power in terms of kilowatts (kW), and electrical energy in terms of kilowatt-hours (kWh). These terms apply to practical units of active power (power that has the ability to perform work, e.g., to move air or pump fluids). This type of power is often termed "real" or "actual" power and is the basis upon which utilities invoice their customers. Utility revenue meters record whole-facility kWh which is the measurement that forms the basis for energy savings calculations. Kilowatt-hour information, however, is not usually available for specific end-uses. It is often impossible, therefore, to determine project-specific energy savings without additional metered data. Obtaining that data should follow the accepted engineering practices discussed in this section. Indiscriminate selection or use of metering equipment can lead to errors in the calculation of power and energy. Error is usually due to effects of the electrical engineering principle termed "power factor.”

In addition to real power, electrical power also exists in the form of reactive power, i.e., power required to generate the magnetic fields required of motors, transformers and lighting ballasts. Reactive power produces no work. Instead, it builds magnetic fields that collapse upon themselves and are then built again. Although most utilities do not bill customers directly for reactive power, it does exist and has an important place in power measurement theory.

Reactive power combined vectorially with real power determines apparent (or total) power which is measured in volt-amperes. Apparent power is an important power consideration and is the cause of many savings calculation errors. Using hand-held true RMS metering equipment, it is possible to measure both the voltage supplied to a load and the current drawn by that load. The product of these two measurements is volt-amperes, a measurement that includes real power (in watts) and any associated reactive power. Apparent power (in volt-amperes) is related to, but not always equal to, real power (in watts). An adjustment factor, the "power factor,” must be applied to the apparent power to obtain real power. This power factor (a number between zero and one) represents the ratio of real-to-apparent power. Electrical loads that are resistive in nature, such as incandescent lamps and heating strips, have a power factor of one (a "unity" power factor), thus the measurements of real and apparent power are the same. Electrical loads such as fluorescent lamps and motors do not have unity power factors, thus apparent power does not equal real power. Assuming that the two are equal could lead to errors of as much as 40 percent. Wattmeters on chiller equipment typically read much lower power levels than individual spot-metered current and voltage measurements due to lower power factors associated with partially loaded chillers.

A related caution involves the practice of using a current measurement as a proxy for power measurement for motor analyses. The problem is that current is not a linear function of load. At low loads, the current does not change much; it is the power factor that changes at low loads. The power factor of induction motors varies with load, dropping significantly below 75 percent load. Under-loaded motors are more the norm than the exception in industrial plants and cause excessive power consumption and low power factor. It is misleading to rely on current measurements to approximate motor power. If it is assumed that a motor is loaded over 65 percent, and it is actually loaded at 50 percent, the error due to power factor alone is 15 percent. One goal of M&V is to control and reduce the sources of estimation error. When estimating motor loading, motor efficiency or power factor, error quickly accumulates. This situation is compounded when phase voltage imbalances exist. Nominal system voltage variations also affect motor performance characteristics. A voltage of 90 percent of nominal results in an 11 percent increase in current and a one percent increase in power factor. A voltage of 110 percent of nominal results in a seven percent decrease in current and a three percent decrease in power factor. The recommended procedure to obtain motor power data is to follow the generally-accepted engineering practice of utilizing digital sampling true RMS power-metering equipment. This technique is even more necessary 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 Metering. Until recently, most loads were linear, i.e., the nature of the load remained essentially constant regardless of the applied voltage. These linear loads resulted in smooth sinusoidal voltage and current waveforms. Conventional meters usually measure the average value of the amplitude of the waveform. Some meters are calibrated to read the equivalent RMS value, equal to 0.707 times the sinusoidal peak value. This type calibration is a true representation only when the waveform is a non-distorted sine wave.

With the advent of computers, uninterruptable power supplies and VSDs, nonlinear waveforms are more the norm. When waveform distortion occurs, the relationship between average readings and true RMS values changes drastically. Peak-sensing and averaging meters are inaccurate and inappropriate technologies for the measurement of distorted waveforms. Instead, digital sampling technology is the recommended method of measuring non-sinusoidal waveforms. Solid-state digital metering equipment samples voltage and current simultaneously to produce instantaneous values which are stored in memory along with their product and individual squares. Periodically, the meter calculates RMS and average values to obtain true RMS power and energy.

True RMS power and energy metering technology, based on digital sampling principles, is recommended over individual voltage and current readings due to its ability to accurately measure distorted waveforms and properly record load shapes.

The numerous advantages of VSDs have caused a rapid growth of their applications in HVAC equipment. Power electronic converters, which are the heart of VSDs, shape current and voltage waveforms, making the waveforms nonsinusoidal. Accurate measurement of electrical power under nonsinusoidal waveform conditions poses a serious challenge, but is important for efficiency optimization of HVAC equipment. Contemporary power meters are digital solid-state instruments that obtain their accuracy by sampling current and voltage waveforms at high frequencies. IEEE Standard 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, requires a 3 kHz sample rate in the study of power system harmonics. It is recommended that power measurement equipment meeting the IEEE Standard 519 sampling rate 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 Measurement Equipment. Real power can be measured directly using watt transducers (devices that determine power-from-voltage and current sensors). Devices that integrate power over time are called "watt-hour transducers." They provide real energy data and eliminate the error inherent in assuming or ignoring power factor or variations in load over time. Stand-alone watt-hour transducers are available to produce pulses representative of some number of watt-hours.

Watt-hour transducer pulses are typically input to a pulse-counting data logger for storage and subsequent retrieval and analysis. It is noted that the power measurement issues of sampling rate, accuracy, etc. apply to the watt-hour transducer and not the data logger. No measurements are performed by the data logger. Data loggers are readily available from multiple vendors, typically configured as four-channel and eight-channel devices - a proven technology applicable to both short and long-term metering periods.

An alternate technology involves combining metering and data logging functions into a single piece of hardware. This integrated metering approach incorporates virtual digital watt-hour meters into a single solid-state device capable of metering multiple single and multi-phase power channels. Where pulse-counting technology makes kWh information available to the user, the integrated metering approach allows access to much more information. In addition to kW and kWh, each defined power channel may record voltage, current, apparent power in kVA, kVAh, reactive power and power factor. Many integrated meter/monitors have the ability to perform waveform analysis, capturing harmonic information for both voltage and current waveforms. This technology is applicable to both short and long-term metering periods, available in a selection of point counts and memory configurations.

In the past few years, specially equipped, hand-held wattmeters have become available for spot measurements of watts, volts, amps, PF and waveforms. These instruments usually contain on-board microprocessors that yield readings every five to ten seconds. It is recommended whenever possible that watt meters, rather than ammeters, be used for spot measurements.

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 Standard for Solid-State Electricity Meters, ANSI C12.16-1991, published by the Institute of Electrical and Electronics Engineers, Inc. This standard applies to solid-state electricity meters that are primarily used as watthour meters, typically requiring accuracies of one to two percent based on variations of load, power factor and voltage.

<u>5.3.2 Measurement Of Runtime</u>. M&V of energy savings often involves little more than an accurate accounting of the amount of time that a piece of equipment is operated or "on" which is then multiplied by a one-time power measurement. Constant load motors and lights are examples of equipment that need not be continuously metered with full-featured RMS power metering equipment 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 solution to energy savings calculations.

<u>5.3.3 Measurement Of Temperature</u>. The computerized measurement of temperature has become an "off-the-shelf" technology. The most commonly used computerized temperature measurements use one of four basic methods for measuring temperatures:

1. Resistance Temperature Detectors (RTDs)
2. Thermoelectric Sensors (Thermocouples)
3. Semiconductor-Type Resistance Thermometers (Thermistors)
4. Junction Semiconductor Devices Which Are Also Called Integrated Circuit Temperature (IC) Sensors

Resistance Temperature Detectors (RTDs). A common method of measuring air and water temperature in the energy management field is with RTDs which are among the most accurate, reproducible, stable and sensitive thermal elements available. The theory behind an RTD is that electrical resistance in many materials changes with temperature. In some materials this change is very reproducible, and therefore can be used as an accurate measure of the temperature. These devices 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 its 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 specifics, 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 performance contracting industry and are most commonly found in high-precision services or in the laboratory. Three-wire RTDs exist to compensate for applications where an RTD required a long wire lead, exposed to varying ambient conditions. This is because three 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 and Thermocouple Thermometry. Thermocouple thermometry is where two dissimilar metals are used to generate a voltage that varies with temperature. In general, thermocouples are used when reasonably accurate high temperature data is required. In thermocouple thermometry, the magnitude of the voltage is dependent on the type of material and temperature difference. The most commonly used thermocouple materials are:

- Platinum-Rodium (Type S Or R)
- Chromel-Alumel (Type K)
- Copper-Constantan (Type T)
- Iron-Constantan (Type J)

The main disadvantage of thermocouples is their weak output signal, making them sensitive to electrical noise and always requiring amplifiers. Few performance contracts require the accuracy and complexities of thermocouple technology.

Thermistors. Thermistors are semiconductor temperature sensors and usually consist of an oxide of either manganese, nickel, cobalt or one of several other types of materials that is milled, mixed, pressed and sintered. One of the primary differences between thermistors and RTDs is that thermistors have a large negative 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 encountered in performance contracting.

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. Temperature 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.

5.3.4 Measurement Of Humidity. Accurate, affordable and reliable humidity measurement has always been a difficult and time-consuming task. Recently, such measurements have become more important in HVAC applications for purposes of control, comfort and system diagnosis. The amount of moisture in the air can be described by several interchangeable parameters including relative humidity, humidity ratio, dew-point temperature and wet bulb temperature. In energy performance contract work, it will occasionally be necessary to measure relative humidity, the measure of moisture concentration expressed as a percentage of the moisture at saturated conditions. In general, most measurements of humidity do not actually "measure" the humidity, but measure the effect of moisture using an indirect measurement. Relative humidity measurements (indirect) include the following:

- The Evaporation Psychrometer
- Electrical Resistance Or Conductivity
- Elongation
- Capacitance-Reactance
- Infrared
- Radio-Frequency
- Acoustic Measurements

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 and should be carefully described and documented in any contract.

5.3.5 Measurement Of Flow. In many situations, whole-facility Btu measurements are needed for a facility or group of facilities. Most often this requires accurate measurements of liquid flow and temperature, usually at the service entrance to the facility. Even in cases where steam flow must be measured in a closed loop, it is easier (and much safer) to measure returning liquid condensate or boiler feed water than to measure live steam after it has left the boiler as it enters the facility. Water conservation projects often require flow data.

Flow Meters. Choosing a flow meter for a particular application requires knowing which type of fluid is being measured, how dirty or clean it is, what the lowest expected flow velocities for that fluid are and what type of budget is available. This Section 5.3.5 discusses the most common liquid flow measurement devices that are used either in a stand-alone configuration or in conjunction with temperature measurements to determine the thermal energy in a fluid flow.

In general, flow sensors can be grouped into four different types of meters:

1. Differential Pressure Flow Meters (e.g., Orifice Plate Meter, Venturi Meter, Pitot Tube Meter)
2. Obstruction Flow Meters (e.g., Variable-Area Meter, Positive Displacement Meter, Turbine Meter, Tangential Paddlewheel Meter, Target Meter, Vortex Meter)
3. Non-Interfering Meters (e.g., Ultrasonic Meter, Magnetic Meter)
4. Mass Flow Meters (e.g., Coriolis Mass Flow Meter, Angular Momentum Mass Flow Meter)

While there are specific applications for each of these metering technologies, the most common flow meters found in thermal energy calculations are meters 1 and/or 2 described above - differential pressure/obstruction meters. There is interest in non-interfering metering technology to defray the costs of shutting down pumps and cutting pipe.

New and improved microprocessors are increasing the performance and functionality of today's flowmeters. Flowmeter users now enjoy the many benefits derived from enhanced accuracy, digital communications and a range of diagnostic capabilities - the ability to monitor and regulate themselves.

Non-Pressure-Differential 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 much smaller target, weight or spinning wheel in the flow stream that allows fluid velocity to be determined by the force on the meter body (target or variable area meter), or by the rotational speed of the meter (turbine, paddlewheel meters).

Turbine meters 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 per manufacturer's specifications - most importantly installation along straight sections of pipe removed from internal turbulence. This type of meter can be hot-tapped into existing pipelines through a valve system without having to shut down the system. Insertion meters can be used on pipelines in excess of four inches with very low pressure loss. The speed of rotation of a bladed turbine, driven by the fluid, provides an output linear with flow rate. This output can usually be obtained either as a signal pulse representing a quantity of fluid flow or as an analog signal proportional to flow rate. Either output can be captured by meter/monitoring equipment to build trends. Care must be taken when using turbines, whether full-bore or insertion, as they can be damaged by debris and are subject to corrosion. Insertion meters are sensitive to pipe location and can be damaged during insertion and withdrawal.

Vortex meters 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 field after it splits into two flow streams around a blunt object. Vortex meters have no moving parts and are suitable for gas, steam or liquid flow measurements. They require minimal maintenance and have high accuracy and long-term repeatability. Vortex meters provide a linear digital (or analog) output signal that can be captured by meter/monitoring equipment to build trends.

Non-Interfering Flow Meters. In all meters previously discussed, some interference with the flow stream is necessary to extract a measurement. Recently, a new class of meters has been developed that is able to extract a measurement without placing an obstruction in the fluid stream. Ultrasonic flow meters 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. Various designs have been developed that utilize multiple pass, multiple path configurations. Accurate clamp-on ultrasonic flow meters have been developed that now facilitate rapid measurement of fluid velocities in pipes of varying sizes. An accuracy rate from one percent of actual flow to two percent 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 two and five percent of full scale and command prices somewhat less than the standard transit time-effect ultrasonic devices. Meter cost is independent of pipe size.

Magnetic Flow Meters. Magnetic flow meters measure the disturbance that a moving liquid causes in a strong magnetic field. Magnetic flow meters are usually more expensive that other types of meters and provide certain advantages that other meters cannot provide, including high accuracy and no moving parts which can wear out. Accuracy of magnetic flow meters are in the one-to-two percent range of actual flow. Meter costs are dependent on pipe size for magnetic flow meters whose bore or throat is the same size as the fluid.

5.3.6 Measurement Of Thermal Energy. The measurement of thermal energy used in a facility's heating or cooling system often requires the measurement and recording of Btus. The cooling provided by facility chillers is recorded in Btus and is a calculated value determined by measuring chilled water flow in gallons per minute (GPM) and the temperature differential (delta-T) between the chilled water supply and the chilled water return. A Btu meter, either a stand alone device or a "virtual" Btu meter as part of a larger meter/recorder device, performs an internal Btu calculation in real time based on input from a previously described flow meter and temperature sensors, as well as software constants for the specific heat of the fluid to be measured (either as an algorithm or matrix of numbers). These electronic Btu meters offer an accuracy better than one percent. They are most attractive on larger or more critical installations where accuracy is a prime concern. One additional benefit is the availability of real-time operating data such as flow rate, temperature (both supply and return) and Btu rate.

When measuring the narrow differential temperature (delta-T) range typical of chilled water systems, the two temperature sensors should be matched or calibrated to the tightest tolerance possible. For the purpose of computing thermal loads in Btu-per-hour, it is more important that the sensors be matched or calibrated with respect to one another than for their calibration to be traceable to a standard. Attention to this detail will maximize the accuracy of the Btu computation. 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 within a tolerance of 0.1^{o}F over the range 25-75^{o}F. A calibration data sheet is normally provided with each set.

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 measurements of steam flow or condensate flow only (i.e., assumes a constant steam temperature-pressure and feedwater temperature-pressure).

5.4 VERIFICATION OF PROJECT MAINTENANCE

Part of every performance contract is the implied fact that specified ECM maintenance will be performed. Independent of whether maintenance is performed by the ESCO, the owner or another party, the contract’s M&V section should include a clear procedure to verify the implementation of a maintenance plan and schedule.

5.5 MINIMUM ENERGY STANDARDS (FEDERAL, STATE AND LOCAL)

One of the difficulties in determining energy savings is defining the level at which baseline energy use should be established. Many facilities where retrofits are considered contain equipment that does not meet current energy-efficiency standards. An agreement must be made between the contracting parties as to whether: (i) the baseline will be established at the actual performance level of the existing equipment, or (ii) to ignore actual conditions and use the current standard as the baseline.

(See USDOE Building Energy Standards and Guidelines Program (BSGP), available on the internet at address: http://www.energycodes.org. which provides information about residential, commercial and Federal building codes. The residential energy code information includes a link to the Model Energy Code (MEC) compliance information and the MECcheck™ compliance tool. Those interested in commercial building codes can download software for envelope and lighting standards. These programs are for demonstrating compliance with Federal commercial building energy standard (10 CFR 435) and ASHRAE/IES Guideline 90.1-1996.)

5.6 DEALING WITH DATA COLLECTION ERRORS AND LOST DATA

No data collection is without error. Methodologies for data collection differ in degrees of difficulty, and consequently in the amount of erroneous or missing data. Regardless of the method, two concepts should be agreed to in advance by both parties. First, a minimum level of data performance should be established. This level should be part of the overall accuracy of results calculation needed to provide the confidence levels desired by both parties. The contract should stipulate penalties for the party who fails to collect the minimum data requirement. Higher levels of data accuracy may dramatically affect verification cost and should be decided as part of overall project economics. The second concept is the methodology by which missing or erroneous data will be interpolated for final analysis. In such cases, baseline and post-installation models can be used to calculate savings.

5.7 COMMISSIONING PROJECTS

Project commissioning is not only preferable, but highly recommended for performance-based projects. ASHRAE Standard 1-96, Guideline for Commissioning of HVAC Systems, should be consulted for recommendations concerning HVAC commissioning procedures. A properly chosen M&V option should reinforce the total commissioning process.

Commissioning may be divided into the following phases: pre-design, design, construction, acceptance and post-acceptance. Ideally, verification methods should be chosen during the design phase and implemented prior to the acceptance phase. The chosen M&V option should aid the commissioning agent (CA) in determining optimum performance and acceptability of a given retrofit project during the acceptance process.

Project commissioning also involves monitoring use, occupancy and maintenance beyond the project acceptance phase. Therefore, an additional benefit of implementing M&V protocols in conjunction with commissioning is that it allows the facility owner, CA or maintenance foreman to determine the point at which re-commissioning of a facility or project should be considered. In cases where projects are completed under a performance contract, this would allow M&V activities to proceed, possibly beyond the limits of the performance contract. In such cases, a qualified CA might act as the M&V agent as well.

5.8 SPECIAL NOTES ON RESIDENTIAL PROJECTS

All four measurement options presented in this Protocol (A, B, C and D) are applicable to residential projects, however there are some practical considerations and limitations that should be taken into consideration before choosing a measurement option. The choice of an M&V method is strongly influenced by the type of residence and purchaser, in addition to the type of retrofit. Projects can basically be grouped into three categories:

1. A Large Multi-Family Facility Or Complex (More Than 20-40 Units)
2. An Individual Residence Or A Small Multi-Family Facility
3. A Large Number Of Individual Residences

5.8.1 Large, Multi-Family Facilities. Large multi-family facilities or complexes on a single meter can be treated in much the same manner as commercial facilities. It is, however, important to recognize that less of the energy use in a residential facility is based on systematic scheduling than is the case in commercial or industrial applications. Hours of operation for interior lighting, for example, tend to fall in only two classes: (i) always on (hallways and other common areas) and (ii) unknown (private areas). Unitary HVAC equipment is more common in residential and small commercial facilities, so the M&V plan may also need to be adjusted to include sample measurements of equipment performance (i.e., Option B). In particular, there are many facilities in some areas of the country with central heat and unitary air conditioning. The design of the M&V plan must also consider whether the facility is "master metered" or if each residence has its own billing meter.

5.8.2 Individual Residences. For individual residences, performance contracting is rare. However, in the event that a performance contract needs to have a measurement plan that is accurate and affordable, Option C (using monthly utility billing data) can be effective in residences that have consistent monthly energy use as determined by a three or, in some cases, four parameter change-point model (Fels 1986, Reddy 1994). Specifically, the R^2 and CV(RMSE) or CV(NAC) (i.e., the Coefficient of Variation of the Normalized Annual Consumption) of the model should fall within guidelines established by Reynolds and Fels (1988).

In cases where utility billing data cannot be easily modeled, then Options A, B or D can be applied. Using Option A, verification of installation and the potential to perform is generally determined by nameplate and, in some cases, spot measurements. Stipulated values for hours of use are usually based on reasonable estimates for the particular case being considered. Using Option B, spot measurements of equipment performance are taken during the baseline period, and spot measurements or continuous measurements are taken post-installation. The difference in equipment performance is then applied to measured consumption in the post-installation period or to an agreed-upon consumption profile. Option B may be useful for boiler replacements in multi-family facilities, and/or other retrofits involving changes which justify added analysis costs. Option D uses calibrated simulation models of residential buildings.

5.8.3 A Large Number of Individual Residences. A large number of individual residences can receive efficiency improvements under a performance contract between an ESCO and utility or government entity. Occasionally, a utility acts as an ESCO under such an agreement, with its regulators acting on behalf of all customers. The largest programs of this type provide services to tens of thousands of homes, although the techniques are applicable to groups of less than 100 homes. All four M&V options are applicable to this type of program, with Option C (using monthly data) preferred in most situations.

Stipulated values using Option A are often based on prior research using Options B, C or D. Option B is expensive for individual residences, relative to the value of saved energy. However, with a large group of homes, sampling may be used, whereby Option B is applied to a sample of buildings, and the results are statistically extrapolated to the larger group. With a carefully stratified sample, as few as 40 points can yield 90 percent confidence of ten percent accuracy, while 200 points can achieve 95 percent confidence of five percent accuracy. Metering techniques are derived from those used by utilities for appliance load research. EPRI has a large body of literature on the topic.

Option C (using monthly utility billing analysis) is often the preferred method to measure energy savings from a large scale residential program. For example, when the conservation effort is comprehensive - including heating, cooling, water heating and lighting improvements. Consequently, the facility utility meter is the end-use meter. Sampling can be used, but most programs use a census of all treated homes. This improves accuracy without significant cost increase, since computer programs are capable of handling hundreds or thousands of houses. For large sample sizes, smaller savings levels can be found than would be possible for single buildings.

When using Option C in the residential sector, whether for single family or multi-family homes, an analysis tool is the three-parameter change-point model, or Princeton Scorekeeping Method (PRISM). The reason for this is that heating energy use in residences tends to exhibit a flat profile at or above the ambient temperature where heating is no longer needed. At temperatures below the change point, energy use is related to temperature. Cooling energy use has similar but opposite characteristics. PRISM is an automated process that develops baseline and post-installation normalized annual consumption. PRISM uses a regression of daily average use against variable base heating and/or cooling degree days to normalize and annualize the data. The program has been proven to be deterministic, so given the same data and input parameter, different analysts will get the same results. This makes the technique highly amenable for contractual use. A base period of three-to-five years can normally be easily assembled from utility-archived billing data. Although a single base year has been used, a longer period is preferable to mitigate unusual external events, since no normalization process is perfect. The post-installation period measurement can be as long as the expected life of the savings, but most projects limit the measurement to the first three-to-five years, to demonstrate savings and persistence. A comparison group of untreated homes is often used as a further normalization method (Fels, 1986).

Other physical models exist, usually employing fixed base degree day system to model the facility's response to weather. Econometric analysis is sometimes used, but cannot readily model physical reality and is difficult to reduce to contractual language.

Option D can also be applied to the analysis of energy conservation in residences providing that suitable occupant profiles can be agreed upon in advance. Although Option D may be expensive for the analysis of an individual house, it may be more economical to use in situations where a standard retrofit is being applied to a group of homes.

5.9 CALIBRATION OF INSTRUMENTATION

It is highly recommended that instrumentation used in M&V 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 ability to be and hold calibration. An attractive solution is the selection of equipment that is self-calibrating. Selected references on calibration have been provided in Section 8.0, including: ASTM (1992), Baker and Hurley (1984), Benedict (1984), Bevington and Robinson (1992), Bryant and O'Neal (1992), Cortina (1988), Doebelin (1990), EEI (1981), Haberl et al. (1992b), Harding (1982), Huang (1991), Hurley and Schooley (1984), Hurley (1985), Hyland and Hurley (1983), IES (1987), ISA (1976), Kulwicki (1991), Lee (1988), Leider (1990), Liptak (1995), Miller (1989), Morrissey (1990), Ramboz and McAuliff (1983), Robinson et al. (1992), Ross (1990), Sparks (1992), Taylor (1981), Wiesman (1989), Wise (1976), Wise and Soulen (1986). A more detailed discussion of calibration issues will be found in ASHRAE GPC-14P: Measurement of Energy and Demand Savings.

5.10 CALCULATING UNCERTAINTY

5.10.1 Sources of Uncertainty. There are several sources of uncertainty affecting savings estimates from M&V efforts. These sources include the following:

- Instrumentation Error
- Modeling Error
- Sampling Error
- Assumptions Of Stipulated Factors

Errors in assumptions may be considered as a part of both modeling and sampling errors, but are worthy of separate consideration.

For each source of error, there are both systematic errors, or biases, and random errors. Biases affect all measurements or estimates in a similar way, and are generally not possible to quantify. The best strategy to deal with biases is to attempt to minimize them by taking care with assumptions, modeling approaches, and sample design and execution. The likely magnitude of random errors can be estimated by statistical methods. This magnitude is reduced by taking larger samples.

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 misspecification. Misspecification errors include:

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

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

The most common models are linear regressions of the form

$$y = b_0 + b_1x_1 + b_2x_2 + ... + b_px_p + e$$

where

y and x_k, k = 1, 2, 3, ..., p are observed variables
b_k, k = 0, 1, 2, ..., p are coefficients estimated by the regression
e is the residual error not accounted for by the regression equation

{See Draper and Smith (1981) for a discussion of regression analysis.}

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 RMSE of the predicted mean. This accuracy measure is provided by most standard regression packages. The MSE of prediction is the expected value of

$$\left(y\big|_x - \hat{y}\big|_x\right)^2$$

where $y|_x$ is the true mean value of y at the given value of x, and $\hat{y}\big|_x$ 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 b^ is the expected value of

$$\left(b - \hat{b}\right)^2$$

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.

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 $\overline{y}$ is given by

$$SE(y) = \sqrt{(1 - n/N)\left[\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2 / (n-1)\right] / n}$$

For more complicated random samples, more complex formulas apply for the standard error. In general, however, the standard error is proportional to 1/√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 √f.

5.10.2 Value of Information. 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 requires the investment of more money. This investment must be justified by the value of the improved information.

The value of improved accuracy to ESCOs or owners depends on how they expect this improvement to affect them. The most obvious effect would be a change in payments, but there are other reasons for an interest in more accurate savings estimates. Owners may value a higher level of monitoring because they believe that the monitoring requirement itself will result in improved performance. Such improvement could be related to a commissioning effort, or to higher quality work by installers and operators as a result of their awareness of the monitoring and/or feedback from this information. ESCOs may value more accurate savings determination for its value in enhancing their credibility. Both owners and ESCOs may value the improved understanding that will affect similar projects they might undertake.

In cases where the overriding reason to consider additional accuracy is for its effect on payments, the value of the improved estimate to the owner and ESCO depends on what each party believes will be the effect of improved measurements. If both parties believe that savings will be close to the nominal level, and neither has asymmetric risks associated with savings errors, it may be reasonable to do no monitoring, and accept a stipulated savings agreement. On the other hand, if the owner believes that the nominal level that would be stipulated is higher than what will actually be achieved, the owner will have an incentive to invest more money in monitoring. Likewise, if the ESCO believes that the nominal level that would be stipulated is lower than what will actually be achieved, the ESCO will have an incentive to invest more money in monitoring. In either case, however, additional investments for improved accuracy should not exceed the expected change in payment, unless there are other reasons for monitoring. This issue is discussed in more detail by Goldberg (1996a).

5.10.3 Combining Components of Uncertainty. If the savings (S) estimate is a sum of several independently estimated components (C), then

$$S = C_1 + C_2 + C_3 + \ldots + C_p$$

the standard error of the estimate is given by

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

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

$$S = C_1 \text{ x } C_2 \text{ x } C_3 \text{ x } \ldots \text{ x } C_p$$

the relative standard error of the estimate is given approximately by

$$SE(S)/S \simeq \sqrt{[(SE(C_1)/C_1)^2 + (SE(C_2)/C_2)^2 + (SE(C_3)/C_3)^2 + (SE(C_p)/C_p)^2]}.$$

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.

5.10.4 Propagation of Error. The formulas 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 of prior condition or baseline. The second greatest source of error tends to be the level of use, typically measured by hours (Violette et al. 1993). Goldberg (1996) describes how to balance sampling errors against errors in estimates for individual units in this type of analysis.

5.10.5 Confidence and Precision. Confidence and precision issues in the context of performance contracting are discussed by Goldberg (1996a). The following is a condensation of that discussion.

Estimate accuracy specification requires not only the absolute or relative bounds (cost savings ±$20,000 or ±20%), but also the level of confidence that the true value is within those bounds. While this requirement can seem to be a fine point, a statistical precision statement without a confidence level defined is meaningless. By allowing the confidence to be low enough, the precision bounds can be made arbitrarily tight.

For example, suppose the precision for a particular estimate is around plus or minus ten percent (±10%) at 80 percent confidence. Then (using the normal distribution, which is the basis for most precision calculations) the precision would be around plus or minus five percent (± 5%) at 50 percent confidence, or plus or minus 20 percent (±20%) at 99 percent confidence. Providing the precision statement (±X) without the confidence level tells nothing. Likewise, comparing precision levels without knowing if they are reported at the same level of confidence is meaningless.

Statistical precision is not the only consideration in specifying monitoring requirements. However, it is useful to understand the meaning of statistical precision measures and the implications of different sampling strategies in terms of those measures.

Precision Standards. The need for precision standards in M&V has been the subject of some debate. In the context of evaluation, a 90/10 standard, meaning ten percent relative precision at 90 percent confidence, is often invoked. This standard is included in California's Monitoring and Evaluation Protocols and is also the basis for the sampling requirements of various M&V protocols.

The requirement of ten percent precision at 90 percent confidence has been adopted in part by the extension of the Public Utilities Regulatory Policy Act (PURPA) requirements for a class load research sample (PURPA 1978). Other precision standards are applied in other disciplines.

The extension of the 90/10 rule from load research to evaluation and verification has been made in several areas, but raises some questions. For example, to what parameters should the criterion be applied? A second question involves the level of disaggregation at which the criterion should be imposed. In the load research context, the parameter of interest is the load at a given hour, and the level of disaggregation is the revenue class. In evaluation, monitoring and verification the parameter of ultimate interest may be the savings in load, energy or energy costs at prevailing rates. The level of disaggregation is critical in the context of M&V. This level reflects - or implicitly defines - monitoring objectives, and strongly affects monitoring costs.

What Parameters? Measuring savings means measuring a difference in level rather than measuring the level of consumption or load itself. In general, measuring 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. The 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:

$$S = N\ H\ C.$$

The 90/10 criterion could be applied separately to each of these parameters. However, achieving 90/10 precision for each of these parameters separately does not imply that 90/10 is achieved for the savings, which is the parameter of ultimate interest. 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.

What Level of Disaggregation? 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.

5.10.6 Statistical Indices for Model Evaluation. Regression models are used, for example, to estimate the load for a population of motors based on a sampling of data. Inaccuracies in the load data (from poor instrumentation plan design or inaccuracies in load measuring equipment) can lead to uncertainties in the ability of the equation to predict true loads. Three statistical indices that can be used to evaluate the models are defined below (SAS 1990) :

1. The coefficient of determination, R^2 (%):

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

2. The coefficient of variation CV (%):

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

3. The mean bias error, MBE (%):

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

where

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

The regression equation is used in the energy savings calculation. After the retrofit action, data is obtained on the system operation and used as input to the regression equation. The equation is used to determine the load which would have occurred had the original equipment been left in place and the system operated under the conditions currently observed. Uncertainties in obtaining the base data upon which the equation is developed or in the equation structure will lead to unfounded savings projections. In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement. It is important that the equation express not simply a physical law, but a measurement process and, in particular, it should contain all quantities that can contribute a significant uncertainty to the measurement result. If the measurement situation is especially complicated, one should consider obtaining the guidance of a properly trained statistician.

In terms of prioritization, the greatest source of error in this process is in the collection of energy information and the externalities (i.e., temperature/humidity, runtime and occupancy) which affect energy use. A poorly designed metering and instrumentation plan can result in poor quality inputs to build regression equations. Consequently, equations so constructed will be poor predictors of energy consumption.

<u>5.10.7 Effect Of Short Pre-Retrofit Data Sets</u>. Ideally, a full year or more of energy use and weather data should be used to construct regression models. The data can then be deemed to contain the entire range of variation in both climatic conditions and different facility and HVAC system operating modes. In many cases however, a full year of data is not available and models must be developed using less than a full year of data.

How temperature-dependent regression models of energy use fare in such cases is discussed by Kissock et al. (1993). That study constructed temperature-dependent linear regression models of daily energy use from one, three and five month data sets. Annual energy use predicted by these models was compared to annual energy use predicted by a model based on an entire year of data. It was found that annual heating energy use can be more than 400 percent greater than the annual energy use predicted by models from short data sets. In addition, in the climate of central Texas, models of heating energy use have prediction errors four-to-five times greater than those of cooling energy models.

Two characteristics of data-sets were identified which influence their ability to predict annual energy use:

- As expected, longer data sets provide a better estimate of annual energy use than shorter data sets. In the sample of facilities chosen, the average cooling prediction error of short data sets decreased from 7.3 percent to 3 percent, and the average annual heating prediction error decreased from 27.5 percent to 12.9 percent as the length of data sets increased from one to five months.

- More important than the length of the data set, however, was the season during which it occurred. Cooling models identified from months with above-average temperatures tend to over-predict annual energy usage and vice-versa. The converse seems to hold true for heating models.

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.

5.10.8 Uncertainty In Savings Determination. The duration of metering and monitoring must be sufficient to ensure an accurate representation of the average amount of energy used by the affected equipment both before and after project installation. The measurements should be taken at typical system outputs within a specified time period, such as one month. These measurements can then be extrapolated to determine annual and time-of-use period energy consumption.

The required length of the metering or monitoring period depends on the type of project. If, for instance, the project is 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 is used to determine annual and time-of-use period 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. If these variances cannot be integrated into regression equations for whatever reason, they can be built into the annual energy consumption figure through an agreed-upon mathematical adjustment.

In statistics, ascertaining the uncertainty of a prediction is as important as the prediction itself. Hence, determining the uncertainty in the retrofit savings estimate is imperative. Model identification has direct bearing on determining the uncertainty because the same issues equally affect the nature and magnitude of errors. Savings uncertainty can be attributed to measurement errors (both in independent and dependent variables) and to errors in the regression model. The former are relatively well known to engineers, and the methodology of estimating their effect is adequately covered in classical engineering textbooks. Errors in regression models, on the other hand, are more complex and arise from several sources.

Model prediction errors arise due to the fact that a model is never perfect. Invariably, a certain amount of the observed variance in the response variable is unexplained by the model. This variance introduces an uncertainty in prediction. Model extrapolation errors arise when a model is used for prediction outside the region covered by the original data from which the model has been identified.

Additional advice and information about calculating model and instrumentation uncertainty can be found in ASHRAE's Guideline GPC-14P, and in the summary report of ASHRAE research project RP827 (Brandemuehl et al. 1996).

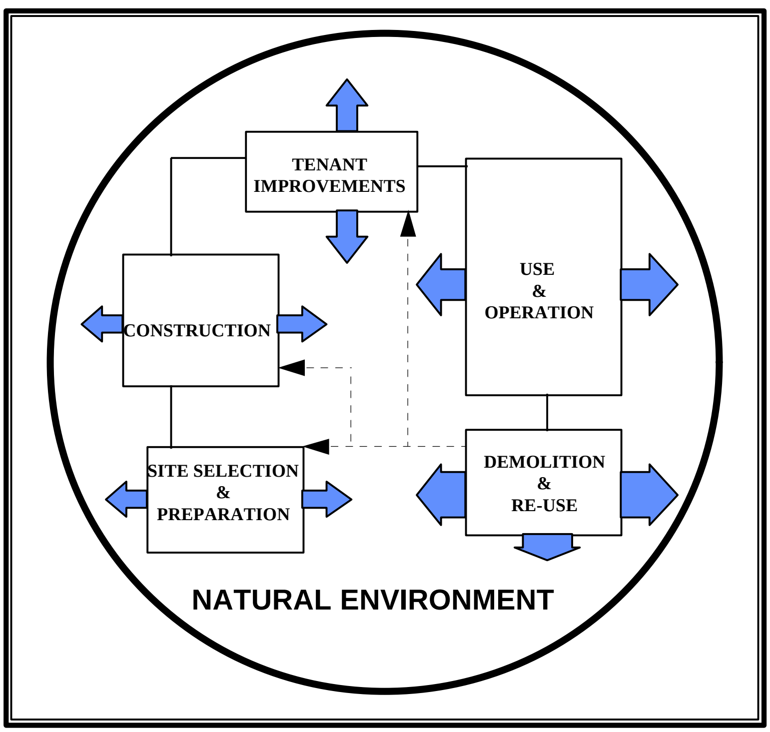
SECTION 6.0: MEASUREMENT AND VERIFICATION FOR NEW BUILDINGS

6.1 INTRODUCTION

Construction is one of the nation's largest manufacturing activities. For example, the construction industry contributes $800 billion to the U.S. economy, or about 13 percent of the Gross Domestic Product, and provides nearly 10 million professional and trade jobs. Because of this industry's impact on national economies, even small changes in practices that promote energy efficiency can make significant advances in economic prosperity and the environment.

A building's life span includes its design, construction, operation, and reuse or demolition (see Figure 1 below). The entity that designs, builds and initially finances a building is usually different from those operating it and paying its operational expenses and employees' salaries. For a three-year-old building in the United States, initial building costs (including design and construction) account only for approximately two percent of the total, while O&M costs (half energy, half other) typically equal six percent, and personnel costs generally equal 92 percent. It is important to remember, however, that decisions made by the design team can significantly affect cost and efficiency later.

Figure 1: LIFE CYCLE OF A BUILDING



Source: Gregg Ander, AIA-Southern California Edison

Sustainable building technology considers the following:

- Energy Efficiency
- Water Efficiency
- Waste Reduction
- Indoor Air Quality
- Construction
- Building O&M
- Insurance And Liability
- Occupant Health And Productivity
- Building Value
- Local Economic Development Opportunities

Energy costs in commercial buildings typically represent a small portion of total business costs, which limits management attention to energy-efficiency opportunities. Vendors of energy efficient technology and energy performance contractors have, until this time, lacked standardized methods for measuring and verifying the resulting energy savings of these measures, and are only slowly gaining market shares in the commercial building design/build sector. This section discusses a standardized method for measuring and verifying those energy savings integrated into new building design.

New construction offers a "lost opportunity" resource: when the design/build team does not incorporate efficiency into a building when it is first constructed, the owner (and community) can either incorporate these opportunities later at a much higher cost, or permanently lose efficiency opportunities during the building's life. Buildings often last at least 50 years, so the inherent lost opportunity is significant. In rapidly developing countries such as Malaysia and Indonesia, new construction is an even larger portion of the building industry, making the opportunity for energy and water efficient building design even greater.

Including energy and water efficiency in new construction design is crucial because in the future, a high percentage of building stock will consist of buildings not yet constructed. In the United States, for example, more than 3.3 billion square feet of new commercial buildings were constructed over the last 10 years, with an anticipated 170 percent increase in building stock likely by 2030. That future building stock is expected to have a lifetime of 50 to 100 years. A recent study by four of the United States' most respected environmental organizations found that applying all currently known cost-effective efficiency measures would cut U.S. commercial sector energy use in half by 2030, saving almost six quads of energy.

Recent studies have concluded that the overall potential for reducing energy use in buildings through cost-effective investments is a potential 30 percent by 2015, with an overall enhancement of indoor air quality, employee satisfaction and comfort. Estimates indicate that climate-sensitive design using available technologies could cut heating and cooling energy consumption by 60 percent and lighting energy requirement by at least 50 percent in typical new buildings.

6.1.1 Barriers and Opportunities in New Building Design Energy Efficiency. The greatest barrier to new energy efficient building design is the current structure of the building industry. The building process is often fragmented and driven by “lowest first cost” and keeping projects on schedule. In a recent strategic issues paper, Colorado-based energy expert Amory Lovins reported that the structure of the U.S. building industry creates systematic conflicts between the interests of the players and energy efficient design. When inefficiencies occur, each party is likely to blame the other. "Fee-for-service" contracts lack incentives for designers and contractors to pay attention to energy efficiency, operating costs and building performance. Under this system, energy efficiency costs designers time (equaling money) which they cannot recover. Designers from the other various disciplines are not paid and do not benefit for designing cooperatively and interactively with other professionals.

Under typical practice, design and construction fees are based on a percentage of building costs, which is a disincentive for optimizing equipment sizing. For example, a super-efficient design that results in significant downsizing of a building's mechanical system would reduce the design/build team’s fees. In addition, there is usually no incentive for a designer to recommend new (and perhaps "unproved") technology. The new construction industry typically lacks incentives to guide new products and technologies to the marketplace. Moreover, the construction industry is not configured to plan and manage the flow of technology from basic research and development through commercialization. In the United States, investment in new construction research and development (R&D) is below 0.4 percent of the total amount of money spent on constructing buildings (as compared to automotive and oil R&D with investment rates of 1.7 and 2.9 percent, respectively).

The opportunities for new building design energy efficiency include lower life-cycle costs, increased efficiency and comfort, lower energy and O&M costs, better visual and acoustic comfort and improved indoor environmental quality - all factors which add value to the basic structure. These attributes will likely lead to enhanced occupant productivity.

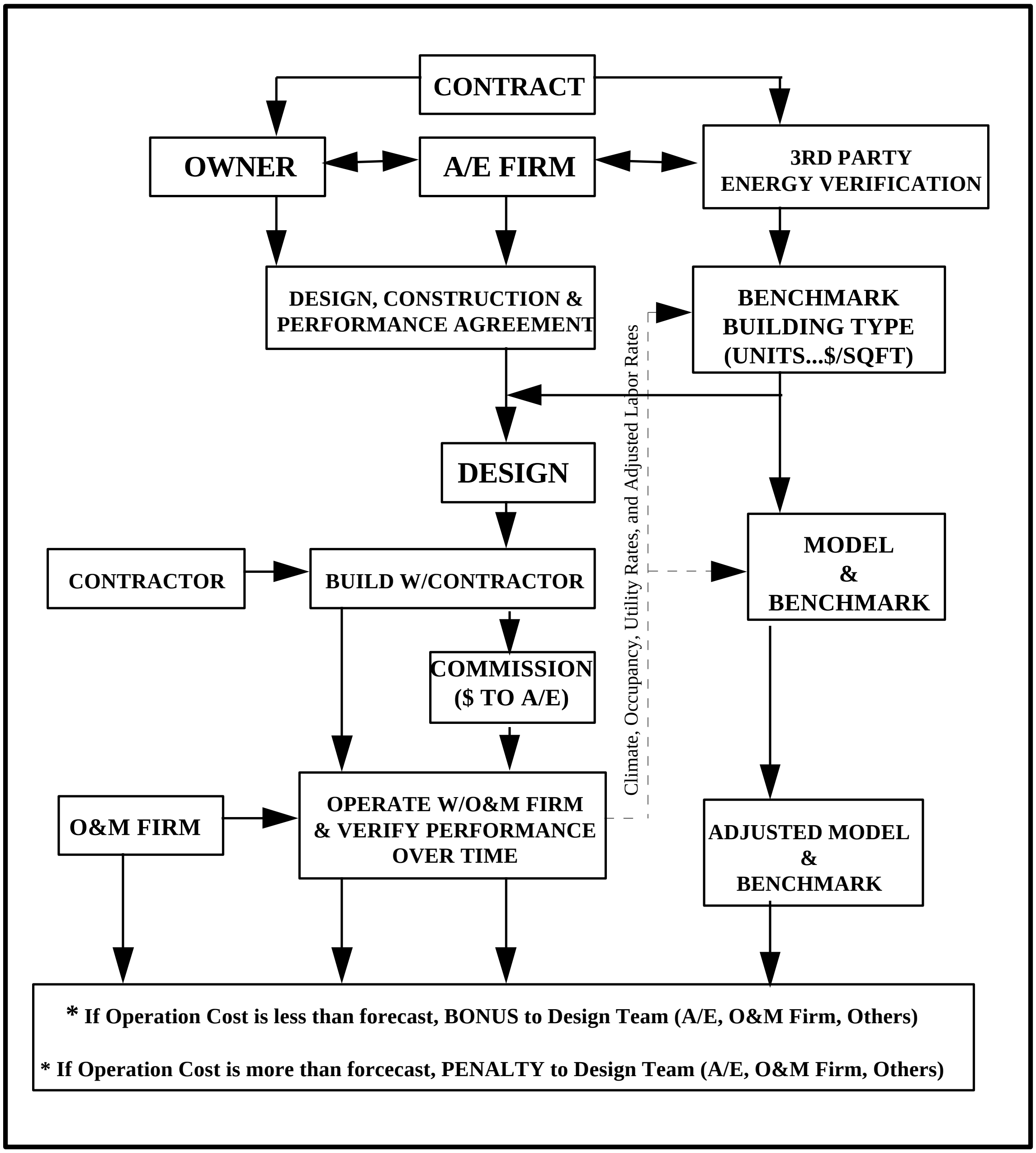
A building should be viewed as a complete, integrated system with the building siting, form, envelope, systems and contents continually interacting. When designed and operated with this perspective, a building will be resource-efficient and cost-effective and will enhance occupant productivity and health. The only way to achieve this interaction is for the design team to adopt a whole-team approach early in the design process. This approach fosters the creation of energy efficient, environmentally responsive buildings that benefit their communities throughout their life span.

6.1.2 Purpose of M&V in New Building Energy Projects. In switching to a performance-based approach to building design, M&V is the key element which determines the design team's compensation and an owner's satisfaction. It takes rigorous continual measurement and evaluation to ensure that an owner is getting the required performance out of a building. These same factors will deliver long-term performance incentives for the design/build team.

Performance-based contracts are a means of compensating a building's design/build team based on actual building performance (see Figure 2 on the following page). This approach rewards the team for the effort required to produce efficient buildings. If the team delivers a building that exceeds specified performance levels, they are monetarily rewarded. Should the building not meet those levels, the design/build team is required to compensate the owner for any added expense of energy cost overruns or savings. Both the penalties and the rewards have a cap at a specified level.

Rewards are determined by comparing the building's actual energy bill with established energy baseline targets in building codes. Performance contracts allow the building owner to share the investment risk and associated energy savings with the design/build team.

Figure 2: INCENTIVE BASED COMPENSATION MODEL



Source: Gregg Ander, AIA-Southern California Edison

Unlike existing building retrofits, new buildings have no before-and-after experience. This presents a unique problem because it is therefore difficult to define a measurement against which utility cost savings can be assessed. Furthermore, when applying performance targets to new construction, certain variables may impact actual building performance which are not under the design/build team's control, such as building operation, weather and utility rates.

Another complexity relates to the interaction of individual ECMs in new buildings. Isolating the energy usage input of individual ECMs from whole-building usage is expensive and complicated. However, reviewing only the whole-building performance may over or under credit the incentivized ECMs due to the impact of other measures or design factors. For example, the efficiency of an incentivized efficient air conditioning system may be offset by unexpectedly high lighting levels.

Several computer-based building simulation tools have been developed to model complex, weather-dependent measures and groups of measures with interactive effects. The simulation tools model the building envelope's characteristics needed for traditional measures (insulation, windows, shading and thermal mass), as well as more modern measures (daylighting, cool roofs and evaporative cooling). These tools allow the design team to predict the effect of architectural design on energy use, peak loads and other performance variables. It is important that these simulations be performed at the earliest opportunity in the design phase, so that the most effective, innovative and practical approaches can be considered.

An ideal baseline for measuring and verifying building performance is the efficiency level of current standard building practice without the influence of efficiency programs. Since the mid-1970s, most state and many local building codes have imposed significant energy-efficiency requirements on new commercial buildings. However, despite the efforts of professional organizations, Federal agencies and national building code organizations, there is still a considerable gap between economically desirable building construction and actual practice. (Code enforcement at the local level also seems to be a problem.) The U.S. Energy Policy Act of 1992 requires that new nonresidential buildings must meet or exceed ASHRAE Efficiency Standard 90.1. The implementation of this standard for new buildings is expected to reduce U.S. energy bills an average of $2.1 billion per year by 2010. In the new world of performance-based contracting, therefore, the method of establishing baselines, performance expectations and M&V protocols is critical.

M&V requires continual real time feedback by means of metering and commissioning once the building has been constructed and as it settles into routine operation. Through this feedback, individual ECM performance can be improved, and the entire system's integrated performance can be optimized.

Section 6.2 of this document describes generic steps for performing new building M&V methods. It includes specific guidelines for establishing a general M&V approach, preparing project-specific M&V plans and defining baselines and projected savings. It also presents guidelines for verifying and commissioning ECMs, determining savings using post-installation conditions and re-evaluating ECMs at regular intervals during the performance contract term.

Section 6.3 describes the tasks involved in each of the four M&V methods. Section 6.4 presents several issues typically encountered in the new building M&V process. These include commissioning, use of actual versus typical operating conditions, use of energy standards for defining baselines and computer simulation model issues. The interaction of the design, construction and evaluation teams and the use of energy management systems for data collection and analysis are also discussed here, along with the reality check of actual utility bills and quantifying non-energy benefits.

6.2 GENERIC MONITORING AND VERIFICATION STEPS

6.2.1 M&V Basic Steps - All Methods. M&V of new buildings differs fundamentally from retrofit projects in that performance baselines are hypothetical rather than materially existent, and are therefore generally not physically measurable or verifiable. The implications of this increase with the complexity of measures and strategies to be monitored and verified. Yet the basic steps in new building M&V do not vary significantly in concept from retrofit M&V. These steps are as follows:

1. Define Baseline. Definition of a baseline is actually a two-part process. First, a design baseline must be developed and defined. This can range from the stipulation of specific baseline equipment to specifying whole-building compliance with energy codes or standards. Once the design baseline has been established, computer-aided analytical tools are used to estimate the associated energy performance baseline.

2. Define Energy efficient Design and Projected Savings. The energy efficient design is defined through the building design process, and is the natural final outcome of that process. Computer-aided tools are then used to estimate performance of the energy efficient design, which is subtracted from the baseline energy performance to generate projected savings. The estimation process should also include the identification and, if possible, quantification of factors which could affect the performance of both the baseline and energy efficient design.

3. Define General M&V Approach. Section 6.2.2 presents new building M&V methods which are roughly analogous to the M&V retrofit Options A, B, and C previously presented in this protocol. The A and B analogs are directed at end-use measures, and C addresses whole-building M&V methods. The relative suitability of each approach is a function of:

   - the M&V objectives and the requirements of any related performance contracts.
   - the number of ECMs and the degree of interaction with each other as well as with other systems.
   - the technical practicality and issues associated with M&V of particular ECMs or broader whole-building ECMs and strategies.
   - current trends toward more integrated and holistic new building design which are moving M&V requirements more to the C end of the A-B-C spectrum.

4. Prepare Project-Specific M&V Plan. Development of an effective and efficient M&V plan for new buildings tends to be more involved than retrofit projects since performance strategies are usually more complex and the technical issues more challenging. Development of an M&V plan should begin during the early design phases of the project for the following reasons:

   - Technical analyses which are performed in support of design decisions concerning energy performance during the building design process provide a starting point in defining the M&V objectives and approach. The key elements of energy analyses are also usually key factors in M&V. Therefore, the energy analyses and projections should be well documented and organized with this in mind.

- M&V considerations can, and should affect certain design decisions such as instrumentation, building systems organization, etc.

5. Verify Installation and Commissioning of ECMs or Energy efficient Strategies. Installation and proper operation is verified through site inspections as necessary combined with review of commissioning reports, fluid balancing reports, etc. Any deviations should be noted and addressed through adjustment of the affected performance projections.

6. Determine Savings Under Actual Post-Installation Conditions. Virtually all energy performance projections are predicated upon certain assumptions regarding operational conditions, e.g., occupancy, weather, etc. This affects both the baseline and energy efficient design estimations. Deviations from the operational assumptions must be tracked by an appropriate mechanism (site survey, short and/or long term metering, etc.) and the baseline and energy efficient projections modified accordingly to determine actual savings.

7. Re-evaluate at Appropriate Intervals. Ongoing performance of ECMs or energy efficient strategies and the associated energy savings must be re-evaluated and verified at intervals and over a time frame appropriate to M&V and related performance contract requirements. This also allows ongoing management and correction of significant deviations from projected performance.

6.2.2 Overview of New Building M&V Methods. The methods for new building M&V are analogous to retrofit methods. Table 1 on the following page summarizes the methods and a description of each is provided below.

Estimating Tools. All methods (with the exception of NB-C-02 below) rely upon "estimating tools" to generate the necessary baseline and energy efficient performance projections. These tools are presumed to be computer-based and can range in sophistication from spreadsheets programmed using engineering calculation methodologies, to hourly whole-building simulations. The level of sophistication should be appropriate for the complexity of the ECMs, the M&V method used and the necessary degree of accuracy or confidence. Tools used in a performance contract context should not only be mutually agreeable to the parties, but should also be technically comprehensible, at least in concept, to all concerned. In this regard, more demanding analyses (such as hourly simulations) should be conducted using one of the more widely recognized and validated packages.

Method NB-A-01, Stipulated Baseline and Savings, Verified Equipment Performance. This method is suitable for projects where the potential to perform needs to be verified, but actual savings can be stipulated using estimations of baseline performance versus estimated ECM performance based on the verified as-built performance potential. Note that while ECM performance potential must be physically verified (through one-time and/or periodic verification), the savings stipulation is made using assumed typical operating conditions for both the baseline and energy efficient estimations. Also note that this is a modification of the initial performance estimations which supported the decision to implement the ECM. It is not sufficient to simply use the initial estimates as-is without performance potential verification.

Although the most rudimentary of M&V methods, this approach is adequate for many purposes including performance contracts. It can be applied to essentially any end-use ECM such as motors, lighting ballasts, chillers, etc., and is particularly well suited to constant or predictable loads. The method of verification of performance potential depends on the confidence level required and the practicality of physical performance measurement. This can range from physical inspection and verification of nameplate data to short term metering.

Advantages:

- Simplicity
- Low Cost
- Reasonable accuracy with constant or predictable loads

Disadvantages:

- Diminished accuracy with non-constant or unpredictable loads

Table 1: New Building M&V Methods

M&V METHOD	IPMVP OPTION	BASELINE DEFINITION	INITIAL SAVINGS ESTIMATE	POST-INSTALLATION VERIFICATION	FIRST YEAR SAVINGS ESTIMATE	ANNUAL SAVINGS ESTIMATE	OPERATING CONDITIONS FOR ESTIMATING TOOLS
NB-A-01 Stipulated baseline & savings, verified equipment performance	A End-Use ECMs	Design for building without ECMs or complying with energy code or standard; performance determined using estimating tool	Comparison of energy perfor-mance of base-line and energy-efficient building using estimating tool	Verify proper installation and potential to perform	Initial savings estimate modified to account for as-built verified conditions	Verification of operation and continued poten-tial to perform	Assumed typical
NB-B-01 Stipulated baseline, savings based on verified equipment performance & estimating tool calibrated with short or long term data	B End-Use ECMs	Same as NB-A-01	Same as NB-A-01	Same as NB-A-01	Initial savings estimate modified to account for as-built verified conditions and calibrated with monitoring data of operating conditions	Same as NB-A-01 with re-calibration of savings estimate with monitoring data of operating conditions	Estimated typical and/ or actually monitored
NB-C-01 Stipulated baseline, savings based on metered performance & estimating tool calibrated with actual operating data	C Whole-Building	Design for building without ECMs or complying with energy code or standard; performance determined using energy simulation tool	Comparison of energy perfor-mance of base-line and energy-efficient building using energy simulation tool	Same as NB-A-01	Comparison of utility bills of energy efficient building with baseline simulation estimates calibrated with monitoring data of operating conditions	Same as NB-A-01 plus comparison of utility bills of energy efficient building with base-line simulation estimates calibrated with monitoring data of operating conditions	Assumed typical and actually monitored
NB-C-02 Stipulated baseline, savings based on comparison with similar buildings with and without ECMs	C Whole-Building	Same as NB-A-01	Same as NB-A-01	Same as NB-A-01	Comparison of utility bills of energy efficient building with baseline building(s)	Same as NB-A-01 with new utility bill comparison	Utility bill comparison adjusted to account for operating variances

Method NB-B-01, Stipulated Baseline, Savings Based on Verified Equipment Performance and Estimating Tool Calibrated with Short or Long Term Data. This method is suitable for projects where end-use ECM potential to perform needs to be verified, and savings need to be estimated to more accurately reflect actual operating conditions. Performance potential is verified in the same manner as NB-A-01. However, the savings estimation is made by using metered data to adjust and calibrate the savings estimating tool. The metering can be short or long term depending on the constancy and/or predictability of the load. The variables metered can be any factor which materially affects the generation of savings, and can include the consumption of the end use itself. Operating hours and power draw over a period are typical examples. Increased metering complexity produces higher verification accuracy at the expense of M&V cost. Using statistical sampling of similar multiple end-use points (such as motors or lamps) instead of extensive metering is an effective cost mitigation strategy.

Advantages

- Relatively simple
- Flexibility in trading off metering complexity and cost with accuracy
- Ability to isolate and prioritize critical variables affecting savings

Disadvantages

- Physical metering or monitoring of necessary variables can be problematic
- Metering equipment must be calibrated and maintained

Method NB-C-01, Stipulated Baseline, Savings Based on Metered Performance and Estimating Tool Calibrated with Actual Operating Data. This method is directed mainly at whole-building M&V where numerous ECMs are highly interactive or where the building design is integrated and holistic, rendering identification and M&V of explicit individual ECMs impractical or inappropriate. Installation and operation of the building as-designed must still be verified.

In most cases the estimating tool will be an hourly computer energy simulation package. The baseline building is stipulated and modeled, as is the energy efficient design building as a usual matter of course in the design process. Actual operating conditions of the as-built building which materially impact energy use are monitored and/or metered throughout the M&V term. These conditions include, as a minimum:

- Weather Data
- Occupancy - Density And Schedule
- HVAC Run Time And Set Points
- Lighting Schedules
- Plug Load Power Density And Schedules

The baseline simulation model is adjusted and re-run under actual operating conditions for a given period. The resulting adjusted baseline performance is compared to the actual utility billing meter data for the same period to generate the savings. A simulation calibration reference point and quality control check can be generated by also running the energy efficient simulation model under the same actual operating conditions. The results should be reasonably close to actual utility billings. Any significant deviation in whole or end-use performance suggests a quality control review of both baseline and energy efficient simulation models is in order. The more similar the two buildings are in basic design, features, etc., the easier it is to draw conclusions on calibration issues and problems between the two. (A supplementary quality control reference for the baseline is compared with the utility data of similar buildings.)

Aside from adjusting simulation models to reflect actual operating conditions, the single greatest factor affecting the accuracy of this M&V method is the quality of computer modeling and simulations. Most hourly simulation programs tend to underestimate actual energy use due to factors such as precise default equipment sizing (i.e., no over-sizing to accommodate equipment increments or safety factors), broad HVAC zoning (either due to zone handling limitations in the software or user lack of attention to detail), and HVAC air volume sizing based solely on thermodynamic requirements.

The margin of simulation error resulting from these factors is not constant or proportional, and can change significantly with only slight variations in the configuration of the simulation model. It is for this reason that this M&V method compares actual utility billing data with a single high-quality simulation baseline rather than comparing the baseline and energy efficient simulations. Error is not likely to be constant or proportional between the simulations.

Advantages

- Allows M&V of complex ECMs and holistic buildings
- Does not require extensive end-use metering
- Encourages integrated building design since M&V considerations do not limit ECMs to end-use or discrete systems

Disadvantages

- Requires high level of building design and simulation expertise to achieve acceptable accuracy
- Can be costly due to high level of professional labor
- Monitoring of actual operational conditions can be problematic
- Simulation complexity and quality control concerns can be a basis for contention; this is not an analytically "transparent" process

Method NB-C-02, Stipulated Baseline, Savings Based on Comparison with Similar Buildings With and Without ECMs. This method is suitable for projects which do not require a high level of savings accuracy and where there is a statistically significant population of existing buildings which are physically and operationally similar to the stipulated baseline building. M&V consists of comparing the actual utility data of the energy efficient building with data from the existing baseline building(s) for the same period. Some engineering analysis may be necessary to adjust for variations in building configuration or operating conditions.

Advantages

- Relatively simple and low cost

Disadvantages

- May be difficult to find reliable and statistically meaningful baseline comparison buildings

Advantages (continued)

- Limits technical contentiousness (if method is mutually agreeable in concept)

Disadvantages (continued)

- Securing the cooperation of baseline building owners/managers can be problematic
- Variability in operation, maintenance, etc. between baseline and energy efficient building(s) limit accuracy of the method
- Accuracy issues limit the method to energy efficient buildings with ECMs or performance strategies which are expected to generate significant savings; the anticipated savings must substantially exceed the accuracy tolerances of the comparisons

6.2.3 Common Tasks Associated with All New Building Methods.

Defining the Baseline. The method of defining the performance baseline is a direct function of the ECMs involved and the M&V method used. Simple end-use ECMs can be analyzed in isolation from the rest of the building, and defining the baseline consists of projecting the performance of the specific baseline equipment or systems. The baseline can reflect "typical" design practice, a code or standard, or simply a possible design option.

More complex ECMs or integrated whole-building design strategies tend to be a developmental product of the building design process itself. Consequently, the baseline is often the "starting point" in design evolution. This can again reflect typical design practice or codes and standards. However, baseline definition can be challenging in that baselines are seldom "designed" in detail. They are usually postulated in concept with little design follow-through. Yet a high level of design detail is often necessary to develop the estimating tools needed to accurately project baseline performance. In this regard, energy codes or standards are invaluable not only in setting widely recognized and understood performance benchmarks, but also providing considerable prescriptive detail which can assist in defining a baseline and developing the necessary estimating tools. Many energy codes and standards go to the extent of explicitly defining baselines for use with certain compliance paths. For these reasons, the use of energy codes and standards to define performance baselines is highly recommended.

Alternately, it is sometimes appropriate to “back-engineer” a baseline by deleting specific ECMs or features from the energy efficient building. This approach can be particularly useful for whole building M&V using NB-C-01 with computer simulation methods.

Initial Savings Estimating. ECM and energy strategy savings estimates are usually performed as part of the building design process to support the evaluation of design options. Estimating tools can range from simple spreadsheets for end-use ECMs to whole-building energy simulations for elaborate strategies. Adequacy and accuracy of these estimates for M&V purposes, particularly under a performance contract, should be considered when the tools are developed and the estimates generated. In general:

- Use "first-cut" estimating tools or techniques to perform cursory evaluations. Use more sophisticated tools for promising ECMs or strategies. These secondary and more detailed tools and estimations should form the basis for subsequent M&V.
- The estimating tools should be sufficiently accurate and flexible to meet M&V purposes.
- Assumptions and operating conditions under which the initial estimates were made should be reasonable and well-documented. If possible, a sensitivity analysis of changes in operational assumptions and variables for future reference is advisable.

Computer Simulation. The accuracy of computer simulations is an issue which has been the subject of considerable debate in all building engineering sectors. The reality is that most mainstream hourly computer simulation programs tend to underestimate actual energy usage, particularly when applied by less experienced users. Some of the main reasons are:

- Default or automatic HVAC plant and large secondary equipment sizing is usually "right on" the load, with perhaps some provision for a user-specified safety factor. In reality, available equipment capacity increments, load pickup considerations, and redundancy/backup considerations result in considerably larger as-built systems and equipment than the software defaults or auto-sizing.
- HVAC air supply volumes are usually default or auto-sized based only on thermodynamic load. In real practice, air volume required to meet the pure heating or cooling load is usually a fraction of what is normally considered necessary for adequate air circulation in the space. Consequently, default or auto-sizing of air supply volumes inevitably results in a considerably undersized air system in the simulation. This can result in catastrophic underestimation of energy use if a reheat-based system is being evaluated.
- The default HVAC configurations and control sequences for ventilation in many programs simply presume an exact specified ventilation rate to the space without consideration of the practicalities of central air handling design and how they may drive up overall building ventilation rate. The result, again, is significant underestimation of energy use in reheat-based systems.
- Broad block HVAC zoning in all simulations results in the mixing and canceling of local heating and cooling loads which are normally met individually in a properly zoned real-world HVAC system. The result is energy use underestimation. In this regard, it is a general axiom that the more tightly and accurately and HVAC zoning is modeled, the more accurate the simulation results.
- A related HVAC zoning issue is the "corner office effect.” This occurs when a real-world chronic problem zone (such as a corner office or boardroom) is consolidated into a larger simulation zone. The high chronic load is "diluted,” and sometimes effectively neutralized. This is a serious problem in the simulation of supply air reset strategies. Since the simulation does not "see" a chronic high load area, the supply air reset modulates through a much wider range than would be the real-world case. This results in underestimation of system reheat as well as plant demand.

The knowledge and experience of the simulation engineer and rigor of the simulation model are paramount to result accuracy. All of the issues listed above can be avoided, but that requires a thorough understanding of building design principles, with particular emphasis on HVAC design and operation. Simulation "shortcuts" and program defaults should only be used if there is a clear understanding of their implications.

In many cases, it is impossible to model all ECMs with a single estimating tool. In these instances it is acceptable to use a number of estimating approaches and consolidate the results in a single final result. Many simulation programs have provisions for "manual override or input" of certain operational variables or factors, and many stock system models or components can be programmed to mimic a non-stock configuration or operational sequence. The latter should only be attempted by the most experienced users.

Post-Installation Verification. All three categories of new building M&V methods rely upon some form of installation verification - essentially verifying the potential to perform.

> *Initial*. Site inspection of systems and equipment immediately after construction combined with review of commissioning reports comprises the initial installation verification. The objective is to verify that the installation is in accordance with plans and specifications upon which performance projections are based. The level of detail and documentation is a function of M&V objectives and any related performance contract requirements.
>
> *First Year*. The first year of operation of most buildings is a period of start-up and transition, system debugging and commissioning adjustments. Deviations from the planned future "steady state" operational conditions, changes to system design or equipment operation, warranty remediations, etc. must be documented. Some of these changes will be of a permanent nature (requiring permanent adjustment of performance projections) while others will fall into the category of start-up problems or transitions. Regardless, all significant deviations will affect first year energy performance and must be reconciled with initial performance projections.
>
> *Annual*. Most building design and operational issues should be resolved by the end of the first year. Subsequent annual verification consists of documenting the normal operational variances that most buildings experience such as weather, occupancy, periodic breakdown, etc., and adjusting performance projections as required.

6.3 NEW BUILDING M&V METHOD DESCRIPTION

This section presents and discusses specific sequential tasks associated with each new building M&V method presented in Section 6.2. Detailed methodologies pertaining to site metering, power measurement and similar tasks are comparable to retrofit M&V methodologies.

6.3.1 Method NB-A-01, Stipulated Baseline And Savings, Verified Equipment Performance. This method is suitable for end-use ECMs where the potential to perform needs to be verified, but actual savings can be stipulated using estimations of baseline performance versus estimated ECM performance based on the verified as-built performance potential. Typical operating conditions are assumed for the estimations.

Task 1 - Define the Baseline. The baseline in any new building M&V is purely hypothetical, and under this method it is usually a specific piece of equipment, a particular system configuration or design, or a performance level as specified by a code or standard.

> *Equipment*. A specific equipment selection such as a motor, lighting ballast, boiler, or chiller is postulated and performance data are acquired. Manufacturers' data are the most common source, although independent performance data, if available, are usually preferable if a performance contract is involved. The data must match or be adjusted to suit actual operating conditions, e.g., chiller evaporator and condenser water temperatures, boiler load factors, etc.
>
> *Systems.* A specific hypothetical system design or configuration is stipulated as the baseline, e.g., HVAC configuration, lighting control system, etc. In the absence of reliable data concerning the probable "generic" performance of the baseline, it is usually necessary to develop the system design to the point where a meaningful estimation of performance can be made, e.g., HVAC system layout and zoning for estimation using a computer simulation tool.
>
> *Codes or Standards*. If a code or standard prescribes specific equipment or systems, then baseline definition is as described above. Alternately, many codes and standards prescribe quantitative performance levels, e.g., maximum fan power requirements per unit air flow.

Task 2 - Estimate Baseline Energy Performance. Baseline energy performance is estimated using appropriate analytical tools. This can involve simple spreadsheet calculations or can require computer estimation tools for more complex baselines such as chiller energy use or HVAC operation. Document all operational assumptions.

Task 3 - Define the ECM. Defining the ECM is an essentially identical process to defining the baseline. The ECM can be a hypothetical piece of equipment, a system, or a performance level specified by a code or standard. The postulation of ECMs usually occurs as an integral part of the building design process.

Task 4 - Estimate ECM Energy Performance and Calculate Initial Savings Estimate. ECM energy performance is estimated in a similar manner to baseline energy performance. It is important to use the same estimating methodologies, tools and operational assumptions for both baseline and ECM performance estimates as much as possible to maintain consistency and minimize error. Subtracting the ECM energy performance estimate from the baseline estimate provides the initial savings projections.

Task 5 - Verify Post-Installation Performance. This M&V method requires that the in-situ performance of the ECM be verified upon completion of installation, and that any deviation from estimated performance be used to modify the initial savings estimate. Verification typically consists of physical site inspection combined with one-time, in-situ metering or measurement. Fluid balancing or commissioning reports can also be used to verify immediate post-installation performance. Verification can subsequently be made at appropriate periodic intervals, e.g., annually, and savings estimates adjusted accordingly.

6.3.2 Method NB-B-01, Stipulated Baseline, Savings Based On Verified Equipment Performance And Estimating Tool Calibrated With Short Or Long Term Data. This method is suitable for end-use ECMs where the potential to perform needs to be verified, and savings need to be estimated to account for actual operating conditions rather than assumed typical conditions. Specific tasks are similar to NB-A-01 with the exception that operating variables are monitored over short or long terms and incorporated into ongoing saving estimations for the duration of the M&V program.

Task 1 - Define the Baseline. As with NB-A-01, the baseline is a hypothetical specific piece of equipment, a particular system configuration or design, or a performance level as specified by a code or standard.

Task 2 - Estimate Baseline Energy Performance. Baseline energy performance is estimated using appropriate analytical tools. This can involve rudimentary calculations with simple systems or can require computer estimation tools for more complex baselines such as chiller energy use or HVAC operation. Document all operational assumptions, and determine key operational variables which could affect baseline energy performance. Determine the physical logistics of monitoring key variables. A sensitivity analysis may be advisable to allow the setting of monitoring priorities.

Task 3 - Define the ECM. As with NB-A-01, defining the ECM is an essentially identical process to Task 1 - Defining the Baseline as discussed above.

Task 4 - Estimate ECM Energy Performance and Calculate Initial Savings Estimate. ECM energy performance is estimated in a similar manner to baseline energy performance. If possible, it is important to use the same estimating methodologies, tools and operational assumptions for both the baseline and ECM performance estimates to maintain consistency and minimize error. Determine key operational variables which will affect ECM energy performance as well as the physical logistics of monitoring these variables. ECM variables may or may not coincide with variables affecting baseline energy performance. A variable sensitivity analysis may be advisable to allow the setting of monitoring priorities. Subtracting the ECM energy performance estimate from the baseline estimate provides the initial savings estimate. The sensitivity analyses can further be used to estimate a potential savings variance range.

Task 5 - Develop and Implement Data Collection Plan. The key operational variables identified in Tasks 2 and 4 must be monitored and data collected for incorporation into revised ongoing savings estimates. As with all M&V methods, there is a natural trade-off between monitoring complexity, cost and accuracy. Whether data collection needs to be short or long term can also affect the monitoring strategy and associated costs. Operational variables will vary with the ECM, but can include factors such as operational hours, power draw of key pieces of equipment, building occupancy and weather conditions. Some variables may be impossible to cost-effectively and/or conclusively monitor on an ongoing basis, and "spot checking" combined with reasonable estimations must be used. Statistical methods such as regression or sampling of multiple pieces of similar equipment are other effective strategies. Thoroughly document all monitoring methodologies, particularly in a performance contract context.

Task 6 - Verify Post-Installation Performance. Post-installation verification is similar to NB-A-01, with immediate post-construction and subsequent annual verifications used to modify ongoing savings estimates. However, in this method operational data collected through monitoring are used to calibrate the estimating tools to provide a savings estimate which reflects actual operating conditions. This is particularly important during the first year of operation when normal building start-up and debugging can result in large operational variances. M&V experience through subsequent years can reveal operational stability or predictable patterns which may allow scaling down or even termination of monitoring data collection.

6.3.3 Method NB-C-01, Stipulated Baseline, Savings Based On Metered Performance And Estimating Tool Calibrated With Short Or Long Term Data. This method is intended mainly for whole-building M&V where numerous ECMs are highly interactive or where the building design is integrated and holistic, rendering identification and M&V of explicit individual ECMs impractical or inappropriate. In most cases the estimating tool will be a high quality hourly computer energy simulation package. The baseline building is stipulated and rigorously modeled, and actual operating conditions of the as-built building which materially impact energy use are monitored through the M&V term. The baseline simulation model is adjusted and re-run under actual operating conditions for a given period (usually annually). The resulting adjusted baseline performance is compared to actual utility billing meter data for the same period to generate the savings estimate. Usually a simulation model of the as-built energy efficient building is available (from the design process) to provide a quality control check of estimations as well as assist with the resolution of adjustment issues.

Task 1 - Define the Baseline. Complex ECMs or integrated whole-building design strategies tend to be a developmental product of the building design process itself. The baseline is often the starting point in the design evolution. However, in the normal course of building design these starting points are seldom developed in sufficient detail to provide the information necessary for accurate modeling using simulation tools. If a specific and unique baseline is desired, the design must be developed to a level where accurate modeling and simulation become feasible. As a minimum, this requires stipulation of:

- siting, orientation, general building configuration and architectural massing/programming.
- envelope construction (mass and R-value as a minimum), including fenestration types and configurations.
- lighting, plug and miscellaneous electrical power densities.
- HVAC configuration, including layout, zoning and control.
- complete applicable utility rate structures.

In the absence of this level of information, energy codes or standards provide not only recognized performance benchmarks, but also considerable prescriptive detail which can assist in defining and modeling a baseline building. Many codes and standards comprehensively define baselines for whole-building performance compliance, and this approach is recommended due to its consistency and wide-spread acceptance.

Task 2 - Estimate Baseline Energy Performance. The baseline building is modeled and simulated in accordance with the simulation guidelines previously provided. Document all operational assumptions and determine key variables which will materially affect baseline energy performance. At a minimum these include:

- Weather Data
- Occupancy - Density And Schedule
- HVAC Run Time And Set Points
- Lighting Schedules
- Plug Load Power Density And Schedules

Determine the physical logistics of monitoring key variables. A sensitivity analysis may be advisable to allow the setting of monitoring priorities.

Task 3 - Define the Energy Efficient Building and Estimate Energy Performance. Normally, the energy efficient building will be the end result of an evolutionary design and decision-making process which has been supported by energy simulation tools. While there will likely be a "working" final simulation model of the building as a matter of course, it only serves an ancillary role as: i) a secondary reference point for savings verification and ii) a tool for addressing calibration issues in the baseline simulation model. In this regard, it may be advisable to determine key operational variables affecting the performance of the energy efficient building and conduct a sensitivity analysis if warranted.

Note: Alternate Method for Tasks 2 and 3. In some cases it may be appropriate and desirable to “back-engineer” the baseline energy performance estimate by deleting specific ECMs or altering features of the energy efficient building simulation model, thereby creating a baseline simulation model. This method is suitable when the baseline and energy efficient buildings are similar rather than divergent in basic nature, and there is no requirement to explicitly estimate the baseline energy performance as an initial step in the design process. In this case the order of tasks 2 and 3 is essentially reversed. All requirements for determination of key variables affecting both baseline and energy efficient performance remain the same. In this case calibration of the energy efficient model is possible.

Task 4 - Develop and Implement Data Collection Plan. Key operational variables identified in Task 2 (and possibly Task 3) need to be monitored and data collected for incorporation into the baseline simulation model for the period under consideration. Note that key variables affecting the baseline may not necessarily coincide with those affecting the energy efficient building. Monitoring of the latter is necessary if the energy efficient simulation model is to be used as a savings reference and tool for assisting baseline calibration.

Task 5 - Verify Post-Construction Status. Task 5 is identified as a separate step in this particular M&V method since it can be a relatively intensive task. It requires verifying that the building has been constructed and is operating in accordance with the design intent, drawings and specifications. Compliance in this regard is seldom 100 percent, so thoroughness and documentation of material deviations is necessary. These deviations must be incorporated in revised savings estimates. The typical method of verification is a combination of physical inspection and review of commissioning and maintenance documentation.

Task 6 - Estimate Post-Construction Savings. Using the data collected on actual operating conditions, the estimated performance of the baseline under actual conditions is compared with actual utility billing data for the same period to generate the savings estimate. Obvious anomalies can be diagnosed through a quality control review of the baseline simulation model combined with reference checking with the energy efficient simulation model. As with NB-B-01, monitoring and incorporating operational variations through the first year of operation is important since large performance variances are not uncommon. This can also assist in the detection of operational problems or deficiencies in the building. As the M&V period progresses, operational stability or predictable patterns may become apparent which can allow scaling down or even termination of operational data collection.

6.3.4 Method NB-C-02, Stipulated Baseline, Savings Based on Comparison With Similar Buildings With and Without ECMs. This method is suitable for projects which do not require a high level of savings accuracy and where there is a statistically significant population of existing buildings which are nominally similar to the stipulated baseline building. M&V consists of comparing actual utility data of the energy efficient building with data from the existing baseline building(s) for the same period, with engineering analysis as warranted to adjust for variations in building design or operation.

Task 1 - Define the Baseline. Defining a baseline is similar in concept to NB-C-02. However, design detail is required only to the extent of defining the general characteristics which will allow similar buildings to be identified. As a minimum these should include the following:

- Location And/Or Local Climate
- Occupancy And Scheduling
- General Configuration, E.G., Low-Rise, High-Rise, General Size, Aspect Ratio
- Envelope Construction, Including Mass, R-Value, Fenestration Type And Configuration
- Lighting, Plug, And Misc. Electrical Power Densities
- General HVAC Configuration
- Utility Rate Schedules

Task 2 - Identify Similar Existing Buildings and Determine Energy Performance. Possible sources for this information include building association directories, utility or government databases and building research establishments. Enlisting the direct cooperation of building owners and managers for both characterizing their buildings and obtaining utility billing data will often be required. A comparison sample population of several buildings is necessary for statistical validity depending upon the degree of variance in configuration and performance.

Task 3 - Define the Energy Efficient Building and Estimating Energy Performance. The energy efficient building is defined as the normal end result of the design process. Use of this M&V method implies that performance estimates of the energy efficient building design are not rigorous, and likely consist more of performance expectations based on empirical knowledge or cursory analyses. Regardless, they are not used directly in the M&V savings estimation.

Task 4 - Verify Post-Construction Status. Although not as rigorous as required by NB-C-01, post-installation verification is necessary to ensure that the building has been at least materially constructed and is operating in accordance with the design intent, drawings and specifications. The typical method of verification is a combination of physical inspection and review of commissioning and maintenance documentation.

Task 5 - Estimate Post-Construction Savings. Compare actual utility bills of the energy efficient building and the baseline-similar buildings for the same periods. Some engineering estimation may be necessary to account for large variances in design or operation between buildings, particularly if a sufficiently large statistical baseline sample is not available. The most common adjustments concern occupancy scheduling and equipment operating times. This can be estimated using informal feedback from baseline building operators. Given the level of intrinsic error and intent of this M&V method, rigorous analysis of baseline building operating conditions much beyond this cursory level is probably not warranted.

6.4 MONITORING AND VERIFICATION ISSUES REGARDING NEW BUILDINGS

6.4.1 Commissioning.

Introduction. Commissioning is the process by which the design intent of the building systems is translated to the fully working system. It is unfortunately too often the stage in the construction process where the energy saving intent of the design is lost in the real building. There are several reasons for this, some major reasons are as follows:

- Commissioning occurs at the end of a project, and the time scheduled for it is reduced to make up for time lost during the main construction period.
- HVAC commissioning is a subcontract to the mechanical contractor and no independent verification is performed.
- The owner occupies the building before commissioning is complete.
- The static installation is not correct and checked prior to the start of dynamic commissioning.
- The commissioning of air and water systems is not coordinated with controls commissioning.

If buildings are to realize the full potential of proposed ECMs then adequate resources must be allocated to the commissioning process. This means that time scheduled cannot be arbitrarily reduced, and an independent commissioning authority should be appointed. This person or agency should review the design documents to confirm that there is sufficient information and commissioning components to allow the systems to be correctly commissioned. They should then oversee the complete commissioning process as described in ASHRAE Guideline 1-1989.

The design team should also be involved in the commissioning process. This is especially important for the post-acceptance phase when the systems need tuning according to actual building use. Adequate money should be set aside for this involvement, so that the full potential of the building can be realized.

Some ECMs such as natural ventilation, day-lighting, nighttime flushing, use of building thermal mass, etc. result in a building that behaves in a different way from a conventional building. It is important that the commissioning contractor, the building maintenance staff and the occupants understand how the building works. The level of knowledge required by these groups will vary, and it’s better that they have more information than not enough. There are examples of systems which allow occupants individual control, but none of the occupants knew they could change comfort conditions.

Building owners often expect that their new building will work perfectly at commissioning. However, all buildings require some degree of post-acceptance commissioning and tuning. All parties should plan for this. Although it might cause some inconvenience as controls settings are adjusted and rebalancing is performed, this is outweighed by the benefits in terms of both energy use and occupant comfort.

Standards. The minimum suggested standards to be used are as follows:

- NEBB Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems, Vienna, VA: National Environmental Balancing Bureau, 1983.
- AABC National Standards 1982, Washington, DC: Associated Air Balance Council, 1982.
- ASHRAE G-1-1989 Guideline for Commissioning of HVAC Systems, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1989.
- ANSI/ASHRAE 111-1988, Practices for Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilation, Air-Conditioning and Refrigerating Systems, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1988.
- In addition to recommendations in the above Standards, the Commissioning Authority as defined in ASHRAE G-1-1989 must be independent of the installing contractor.

DDC Controls Commissioning. Nearly all buildings today (aside from very small ones) have some form of DDC controls. While procedures for checking valve stroke and operation, location and calibration of sensors are well documented, there is less clarity on commissioning and verification of the software functions and sequence of operations. It is not the intention of this Protocol to define a commissioning procedure for DDC control systems. It is vitally important that the system is correctly commissioned especially if the system is to be used for verifying energy performance. True system verification requires each point and sequence of operation to be checked. For a large and complex building, this may involve two controls engineers for approximately four weeks.

Documenting the Process. Documentation of the commissioning process becomes critical for performance contracting. Clear documentation of all setpoints and air and water quantities as well as any deviations from the design documents will form an essential part of the post-installation verification process. Both the Commissioning Agent and the Performance Verification Agent need to review the proposed documentation before commissioning starts. This should ensure that the level of information presented in completed documents is adequate for the performance verification method selected.

6.4.2 Using Actual Versus Typical Operating Conditions.

General. Whenever a new building's energy performance is to be compared with an estimate of performance calculated during design, real building performance or input to the calculation has to be modified so that the two can be compared. Even if the new building is being compared to other typical buildings, local climate, occupancy, internal load, etc. must be noted. Some major parameters effecting energy use in real buildings are discussed below.

Weather. Most computer simulations used for estimating energy use typical annual weather data for input. If relevant data are recorded at the building, then the computed energy can be modified to account for actual annual weather conditions. It is important that the actual data recorded matches the input requirements of the computer analysis. For instance, if the program uses hourly weather data, hourly data should be recorded. And if the program uses solar insulation data, this information needs to measured (a solar pyranometer would not normally be specified for a building control system).

Lighting. Actual lighting load may vary significantly from the lighting use profile assumed in the computer analysis. Metering the overall power load will not give a true indication of lighting use profiles. If lighting circuits are metered, a better indication can be obtained. For buildings that feature extensive day-lighting schemes, the metering of lighting circuits needs to be broken down to fairly small zones so that predicted reductions in lighting energy can be checked against actual use. Monitoring a large number of lighting circuits can be expensive. Alternate methods are to monitor typical circuits on each facade of the building and some interior zones.

Small Power. The issues for small power measurement are similar to those for lighting. Ideally each panel board should be monitored, however a representative sample may be sufficient. The practice of estimating cooling loads based on the nameplate rating of computing equipment has led to over-designed systems. Real measurements of power consumption of office equipment over time would be a valuable resource for HVAC system designers. If monitoring of actual power consumption is not available, an actual count of equipment in-use can be made. A few spot measurements of power draw can then be used to estimate the diversity factor to be applied to the equipment ratings.

Occupancy. Occupancy loads are the most difficult building loads to compare. Most computer analysis programs assume a uniform distribution of people throughout the building. However in actual buildings, neither the total number nor the location of people remain static. The computer analysis assumes an occupancy profile for the building, but in the case of a multi-tenant building, real occupancy profiles may vary significantly from floor to floor. A practical solution to estimating real occupancy profiles is to observe actual occupancy on a few representative days each year, and use this data to extrapolate annual occupancy patterns.

Internal Temperatures. Internal temperature set points are often varied by facility staff in response to occupant complaints. Actual set points must be recorded so that meaningful comparisons can be made with predictions. This information should be available from the energy management system.

User-Controlled Buildings. Naturally ventilated buildings and mixed mode buildings (combination of natural ventilation and air-conditioning) pose a difficult problem for comparing predicted versus actual operating conditions. These buildings often have high occupant satisfaction due to the fact that occupants have some control over their environment. Tracking these effects is difficult, and is most accurately achieved through EMS or other system sensors.

6.5 BASE BUILDING OPERATIONAL PERFORMANCE

Energy calculation programs assume that all systems within the building are operating correctly. However, equipment failure, poor maintenance and incorrect commissioning will affect performance measurements of the building in use. In reality most buildings, even if perfectly commissioned, drift away from optimum performance over time. There are several approaches that can be adopted for dealing with this issue.

Agree upon a percentage fall off in total building performance over time. Add statistical failure and depreciation models for equipment to analytical tools. This would be interesting but nothing is commercially available at present and the costs of analysis would go up.

Perform sensitivity studies with the analysis program to review the effect of various pieces of equipment not working or control points incorrectly set. This will determine what system failures have significant effects on energy performance.

Life cycle costing accounts for replacement & maintenance costs of different systems/equipment. However, if the maintenance is not carried out how will this effect the energy performance? If the Performance Contractor is responsible for maintenance then this is not really a problem as the Contractor has a strong incentive to keep the building maintained.

Where the building owner is responsible for maintenance then certain minimum requirements must be agreed upon. When a piece of equipment is replaced or added then determining the effect on the overall building/ energy performance can be difficult. A separate verification using methods described in Section 4 is often necessary. The cost of this procedure compared to the potential energy cost saving needs to be considered.

6.6 Interaction Of Design, Construction, Operation, And Evaluation Teams

Good communication between design, construction and building operation teams is an essential prerequisite of any high performance building. For performance contracts the evaluation team is an additional essential player.

The evaluation team must be fully conversant with design intent and be informed of any variations that occur during construction. Both input from the evaluation team during design and feed back from them when the building is in use should be readily available to both the design team and the owner.

The owner should be fully briefed on the design intent and be clear on how operational changes may effect the energy performance. In buildings that use daylighting and natural ventilation it is important that the occupants have at least an outline understanding of how their building works. The owner must keep the evaluation team fully aware of any modifications of equipment, set-points or building use. As a matter of course all documentation for modifications should be forwarded to the evaluation team.

6.7 Use Of Energy Management Systems For Data Collection And Analysis

The building energy management system (EMS) can provide much of the monitoring necessary for the verification process. However, the system and software requirements need to be specified so that the EMS can be a useful tool for verification as well as its primary function of controlling building systems.

There may be parameters that need monitoring for verification, but are not required for control. These 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 verification.

Other functions that can easily be incorporated into the software are automatic recording of changes in set-points. The evaluation team can have a direct read-only connection into the EMS via a modem link. This allows all the trending data to be analyzed and collated by the evaluation team in their office. It is not unusual for many of the trending capabilities required for verification to be incorporated in an EMS. However, all too often the building facility staff is not properly trained in the use of the system and is unaware of the many additional monitoring and diagnostic capabilities of the system.

6.8 CHANGES IN BUILDING OPERATION AND ECMS DURING TERM OF PERFORMANCE CONTRACT

Under a performance contract all changes in operation, from times of system operation to change of set-points, must be recorded. Methods for estimating what effect these changes have must be agreed upon, preferably at the start of the contract. Changes in the system such as additional ECMs can be addressed using the methods already developed for existing buildings. There may also be changes in set-points during the first year to optimize the performance of the systems. These changes are part of the commissioning process of the original ECMs and so do not require a separate analysis.

Buildings with high turnover rates and changes of occupancy present a significant workload in recording and re-evaluation of energy performance. In many cases these changes may have a significant effect on the building energy consumption, therefore the method for recording and incorporating them into the verification method must be defined.

6.9 NON-ENERGY BENEFITS

There are many benefits that performance contracts bring to building operation in addition to reduced energy bills. The requirements for rigorous commissioning and verification of system performance at construction completion may result in better commissioned buildings. This should produce a higher satisfaction rate for owners and occupants of new buildings. Data generated during the verification period will help design teams better understand how buildings perform under real life conditions. Better information on real small power consumption and occupancy levels for office buildings could reduce the trend to oversize HVAC systems.

Because changes in equipment and building layout affect energy performance, there is greater incentive to document changes accurately. Building operators gain useful feedback on the energy effects of changing set-points, leading to better-managed buildings.

SECTION 7.0: DEFINITION OF TERMS

TERM	DEFINITION
Annual Energy or Water Savings Audit	*A procedure established within the contract for determining the annual energy or water savings attributed to a project.*
Building Automation System	*A computer that can be programmed to control the operations of energy consuming equipment in a facility.*
Baseline Usage (Demand, Energy, & Water)	*The calculated energy or water usage (demand) by a piece of equipment or a site prior to the implementation of the project. Baseline physical conditions such as equipment counts, nameplate data and control strategies will typically be determined through surveys, inspections, and/or spot or short-term metering at the site.*
Billing Data	*Energy or water data collected from invoices sent to the owner from the power supplier, i.e., an electric, gas or water bill, usually monthly.*
Commissioning	*A process for achieving, verifying and documenting the performance of buildings to meet the operational needs of the building within the capabilities of the design, and to meet the design documentation and the owner's functional criteria, including preparation of operator personnel.*
Demand Cost	*The actual unit cost of a level of electric power (i.e., $/kW).*
Demand Cost Savings	*Reductions in the cost of electric demand.*
Demand Savings	*Reductions in the electric demand due to reductions in the peak electric power level (kW).*
Demand Reduction Estimates	*Electric demand reductions (in kW) derived from sample metering and estimation equations, in accordance with the provisions of the contract's approved measurement and verification plans, and documented in regular true-up, or follow-up reports.*
Demand Savings	*Peak period baseline electric demand (kW) less peak period post-installation electric demand (kW).*
Demand Side Management (DSM)	*The concept of achieving overall energy use reductions through the use of conservation techniques at the end use equipment, rather than changing or controlling the supply of the energy source.*

Detailed Energy Survey	*Often referred to as an energy audit. A complete inventory of the energy consuming equipment at a given facility. This information is used in determining the scope of work for a project.*
Energy or Water Audit	*Procedure whereby energy or water conservation options are identified and their potential for saving energy or water determined.*
Energy or Water Savings Audit	*Procedure to establish baseline energy or water use and verify achievement of energy or water savings.*
Energy Conservation Opportunity	*A change to a new or existing system or component specifically intended to reduce energy consumption.*
Electricity Cost	*The actual unit cost of electricity, i.e., electricity cost = $/kWh.*
Energy Cost Savings	*Reduction in the cost of energy expenses.*
Energy Conservation Measure (ECM)	*Installation of equipment or systems, or modification of equipment or systems, for the purpose of reducing energy use and/or costs.*
Energy Management System (EMS)	*See building automation system.*
Energy Performance Contracting	*A performance contract that specifically pertains to providing services which result in energy and/or operating cost reduction. The common term for performance contracting in Europe.*
Energy Savings	*Actual reduction in electricity use (kWh), electric demand (kW), or thermal units (Btu).*
Energy Savings Estimates	*Electric energy savings (in kWh) derived from sample metering and estimation equations, in accordance with the provisions of the contract's measurement and verification plans, and documented in regular true-up reports.*
Energy Savings Performance Contract (ESPC)	*A contract where the cost of ECM implementation is recovered through savings created by the ECMs.*
Energy Services Company (ESCO)	*A firm which provides a range of energy efficiency and financing services and guarantees that the specified results will be achieved.*
Error Analysis	*A mathematical determination of the errors present in the representation of any savings reports.*

Gravity Flush Toilet	*A toilet designed with a rubber stopper that releases water from the toilet's tank, after which gravity forces the water into the bowl and through a trap.*
Graywater	*Used water discharged by sinks, showers, bathtubs, clothes washers, etc.*
Investment Grade Audit	*Detailed energy or water survey with sufficient detail to allow for project value with respect to financing.*
Measurements, Long-Term	*Measurements taken over a period of several years.*
Measurements, Short-Term	*Measurements taken for several hours, weeks or months.*
Measurements, Spot	*Measurements taken one-time; snap-shot measurements.*
Measurement & Verification (M&V)	*Determining savings using one of the four IPMVP M&V options.*
Metering	*Collection of energy and water consumption data over time at a facility through the use of measurement devices.*
Metered Data	*Data collected at a facility over time through a meter for a specific end-use energy or water using system or location.*
Models, Calibrated Engineering	*Simulation models (i.e., which use engineering equations or mechanistic models) that are forced to fit measured data.*
Models, Regression	*Inverse models that require data to extract parameters.*
Models, Simulation	*An assembly of algorithms that calculate energy use based on engineering equations and user-defined parameters.*
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 for energy and water performance contracts.*
M&V Method	*A generic, not-project specific, M&V approach defined which applies one of the four M&V options to a specific ECM technology category such as lighting or water efficiency retrofits, constant-to-variable load motor retrofits, variable operating hour project retrofit.*
M&V Technique	*An evaluation tool for determining energy, water and cost savings. M&V techniques discussed in this document include engineering calculations, metering, utility billing analysis and calibrated computer simulations.*

Non-Variable Loads — *Power consuming equipment that has steady, non-changing energy consumption over time.*

Outsource — *The concept of subcontracting an entire area of service in exchange for a fee; often referred to as "turn-key operations."*

Owner — *Person or persons who have possession of a facility or facilities where an ESCO provides ECM-related services.*

Performance Contracting — *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.*

Potable Water — *Clean, drinkable water; sometimes referred to as "white" water.*

Preliminary Energy/Water Survey — *A quick inventory of energy or water consuming equipment often used for the first determination of whether a potential project exists for improved energy or water performance. Not to be used for investment decisions.*

Pressurized Tank Toilet — *A toilet that utilizes a facility's waterline pressure by pressurizing water held in a vessel within the tank, compressing a pocket of trapped air. The water releases at a force 500 times greater than a conventional gravity toilet.*

Project Pre-Installation Report — *Documentation that provides a description and inventory of existing and proposed energy and water efficiency equipment, estimates of energy and water savings and a site-specific M&V plan (if not included in contract). The ESCO, prior to the installation of energy or water efficient equipment, will provide pre-specified documentation that verifies the proposed equipment/systems and associated energy savings, and demonstrates proper maintenance and operation to have the potential to generate the predicted savings.*

Project Post-Installation Report	*Documentation that provides a description and inventory of old and installed energy and water efficiency equipment, estimates of energy and water savings and M&V results. The ESCO, after the installation of energy efficient equipment, will provide pre-specified documentation that verifies the installed equipment/systems and associated energy savings, and demonstrates proper maintenance and operation to have the potential to generate the predicted savings.*
Post-Installation Energy Use (Demand)	*The calculated energy use (or demand, e.g. in kW) by a piece of equipment or a site after implementation of the project. Post-installation energy use is verified by the ESCO and the Host Customer that the proper equipment/systems were installed, are operating correctly and have the potential to generate the predicted savings.*
RMSE	*Root mean square error - see Section 5.10 "Calculating Uncertainty."*
Variable Loads - Accuracy	*Power consuming equipment that has a changing energy consumption level over time.*
Variable Speed Drive (VSD)	*Motor drives which are capable of operating over a range of speeds, allowing the output power to be matched to the load at any given time.*
Walk -Through Audit	*See "Preliminary Energy Survey."*
Water Conservation Measure (WCM)	*Installation of equipment or systems, or modifications in equipment or systems, for the purpose of reducing water use and/or costs.*
Water Cost	*The actual unit cost of water, i.e., water cost = $/gallon, $/cubic meter.*
Water Cost Savings	*Reduction in the cost of water and sewer expenses.*
Water Savings	*Actual reduction in water use by volume, i.e., gallons, cubic meters, etc.*
Water Service Company (WASCO)	*An organization which designs, procures, finances, installs, and possibly maintains one or more WCMs at an owner facility or facilities.*

7.1 CONVERSION FACTORS

1 Cubic Foot	7.48 U.S. Gallons
1 Acre-Foot	325,851 U.S. Gallons 271,330 Imperial Gallons 1233.3 Cubic Meters
1 Million U.S. Gallons	3.07 Acre-Feet
1 U.S. Gallon	8.33 Pounds
1 Cubic Meter	1,000 Liters 264.2 U.S. Gallons
1 Imperial Gallon	1.20094 U.S. Gallons 4.546 Liters
British Thermal Unit (Btu)	The Energy Required To Raise One Pound Of Water One Degree Fahrenheit.
Btus	(U.S. Gallons Of Water * 8.33 Pounds Per U.S. Gallon) / (Boiler Efficiency * Temperature Increase)
Energy	Btu Divided By A., B., C., D., E., As Below
	A. Natural Gas - *One Therm = 100,000 Btus* *(One Cubic Foot = 1,000 Btus)* *B. Electricity* - *One kWh = 3,423 Btus* *C. Oil* - *One Gallon = 140,000 Btus* *D. Steam* - *One Pound = 670 Btus* *E. Propane* - *One Gallon = 91,500 Btus*

SECTION 8.0: REFERENCES AND BIBLIOGRAPHY

8.1 REFERENCES

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

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Appendix I

EMISSIONS TRADING

PART 1: INTRODUCTION

Burning fossil fuels releases pollutants that cause health and environmental damage as well as damage to property, agriculture and other sectors of the economy that cost an estimated several hundred billion dollars per year, globally (Schipper and Geller, 1990; US OTA, 1990). This widespread damage, and the desire to achieve lower pollution levels at lowest possible cost, has prompted a growing international trend to develop market-based trading systems to limit or reduce emissions. Experience to date with emissions trading to reduce acid rain under the 1990 U.S. Clean Air Act Amendments, for example, has not only reduced compliance costs beyond the most optimistic projections, but also has produced scientifically measured emissions reductions significantly ahead of schedule.

Emissions trading rewards firms that reduce emissions below a regulatory limit with emission currency, whether credits or allowances, generally measured in tons of emissions avoided. Reductions can be realized through investments such as energy-efficiency, clean renewable energy, fuel switching, boiler retrofits and pollution control equipment. Once created, revenue can be generated through the sale of credits/allowances to firms that need emission reductions in order to comply with regulatory requirements. For example, strong U.S. market demand for acid rain emission (sulfur dioxide) allowances under the Clean Air Act has reduced annual emissions from 10.0 million tons in 1990, to 5.3 million tons in 1995, 39% below the regulatory of 8.7 million tons. The ability to measure and capture, through the use of "emissions currency" (whether credits or allowances), emissions reduction value (including health and environmental) is a fundamental first step in allowing the market to value and reward investments in energy-efficiency and renewable energy.

This Appendix provides an overview of emissions trading programs. 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. In addition, this Appendix discusses how the Protocol may be used in some regions to help secure financial benefits.

1.1 ROLE OF PROTOCOL

The IPMVP provides an international, methodologically sound, industry consensus approach to measuring and verifying energy-efficiency savings. Its application can help cut transaction costs and increase consistency and reliability in determining emissions credits. The challenge of determining actual emissions reductions resulting from investments that reduce pollution, such as energy efficiency, is substantial. The Protocol is intended to provide a useful tool to meet this challenge by offering a standard, industry consensus approach to measure and verify energy use and changes in use.

It is important to note that this Protocol and Appendix do not constitute an accreditation Protocol for emission reduction. An accreditation Protocol would require a more comprehensive discussion of emission rates in awarding emissions currency and would also require detailed and precise guidance to tie the results of an emissions protocol with the energy usage data obtained using IPMVP. Accreditation would occur under state or Federal emissions trading programs, and would recognize uncertainty in measurement and in emissions factors.

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 hoped that the Protocol will be an increasingly useful tool in the development of pollution trading programs.

The Protocol is also expected to become an important element in any international greenhouse gas emission mitigation and trading program because of the broad international participation in its development, and its growing adoption internationally and by institutions such as the World Bank.

It should be noted that the IPMVP is a collection of M&V methods suitable for various forms of financing for energy efficiency projects. Some of those methods (e.g., all applications of Option A) *stipulate* rather than *measure* actual savings and are therefore not suitable for quantifying emission reductions. The IPMVP should only be used in emission reduction quantification in conjunction with an Emission Reduction Protocol that ensures that actual measurement of energy savings has been applied.

PART 2: EMISSIONS TRADING OVERVIEW

2.1 WHAT IS EMISSIONS TRADING?

Emissions trading (with a cap) is an alternative approach to command and control type regulatory programs. It provides choices for meeting pollution reduction goals cost-effectively. With emissions trading, firms can meet established emissions goals by:

- reducing emissions from a single source,
- reducing emissions from another place within the same facility, or
- securing equivalent emission reductions from another facility.

Emissions trading under a cap and trade system provides price signal incentives to achieve emissions reductions at a lower cost and, in many cases, earlier than might have been achieved using command and control approaches. For example, an "emissions cap or budget" that declines over time is established for emission sources in an airshed. The cap is then subdivided and allocated within the airshed. To operate within their declining allocation, a firm can under control and buy credits, over control and sell credits, or curtail operations. New entrants must buy-in by securing an allocation of air credits from existing sources.

Over the last 20 years there have been thousands of emissions trades. When compared to command and control systems, trading has allowed compliance costs to be reduced by billions of dollars globally. Individual firms have, according to Cantor Fitzgerald, made or saved tens of millions of dollars through emissions trading. These cost savings continue to grow as regulators integrate emissions trading into strategies to achieve local, regional, national and global emission reduction.

2.2 CURRENT REGULATIONS AND PRACTICE

The emission types most commonly associated with trading systems involve pollutants that violate air quality standards or contribute to regional or national environmental problems. NOx and VOCs (precursors to ozone), and particulates and SO2 (a precursor to acid rain) are the focus of many trading programs. The first and, to date, only global emissions trading program is intended to phase out production of chlorofluorocarbons (CFCs) that destroy the ozone layer. The Montreal Protocol, signed in 1987, allocates CFC-producing countries a declining, nationally set production level for CFC production, and allows countries to trade these rights (although trading has been extremely limited).

2.2.1 Europe. Environmental credit and trading programs in Europe include the following examples.

Germany. Under a program initiated in 1974, Germany allows for the construction of new facilities in areas that do not meet air quality standards, providing that mitigating offsets are secured from either the same facility or through the acquisition of emission reductions at other facilities in the same impact area.

Netherlands. The Netherlands initiated a SOx and NOx control program in 1990 that provides for inter-firm trading of emissions from power plants. Both Belgium and Denmark have similar programs.

United Kingdom. In 1996, the United Kingdom launched an SO2 control program directed at power plants that allows for intra-firm trading of allowances within a declining cap. The program may be expanded to allow for inter-firm trading and other emission sources (e.g., refineries).

2.2.2 United States. One of the first environmental trading programs in the United States is the offset, netting, bubble and banking program. Since its inception in the mid-1970s, this program has helped protect air quality while providing existing polluters alternative means of compliance and allowing the opening of new emitting facilities. Another example, the Lead Gasoline Trading Program, spanned the years between 1982 to 1987. The practice of emissions trading was greatly extended by the Clean Air Act of 1990 (CAA) and subsequent amendments, and falls into two categories: i) programs designed to accommodate new growth and ii) programs to improve air quality. Critical to both is the common currency, the air credit.

The Southern California RECLAIM, national Title IV Acid Rain, and the Ozone Transport Commission's NOx budget are three examples of emissions trading programs intended to clean up the air. The ability to trade under RECLAIM allows industries to achieve compliance at a cost that is $60+ million per year less than without trading. Savings due to trading within the OTC NOx budget is projected to be $72 million per year in Phase II (1999-2003) and $89 million per year for the first four years of phase III - 2004 and beyond (ICF Resources, 1995). Cumulative savings from the National Acid Rain Program are projected to exceed $10 billion by 2005.

Title I of the Clean Air Act covers attainment of the National Ambient Air Quality Standards for criteria pollutants, including ozone (and its precursors NOx and VOCs), particulate matter and carbon monoxide. The programs may involve an urban area, a group of counties, an entire state or group of states. Boundaries are often drawn to contain the sources contributing to and suffering from the problem.

The Southern California RECLAIM program is an example of a declining cap and trade program that is focused on a four-county area. The Ozone Transport Region is an example of a multi-state program under which inter-state trades will be operable in 1999, with the goal of reducing NOx. Multi-state NOx trading programs will likely evolve out of the Ozone Transport Assessment Group (which currently has 12 participating states). A larger region of 37 states is evaluating trading as a means of limiting interstate ozone pollution.

The most prominent emissions trading system in the U.S. is for SO2 emissions from power plants which contribute to acid rain. The value of SO2 trades in 1997 are estimated to be up to 1.2 billion dollars (Fialka, 1997). Title IV of the Clean Air Act Amendments of 1990 (CAAA) applies a strict cap on SO2 emissions from power plants in the 48 contiguous states, beginning in 1995 for the dirtiest plants and in 2000 for the remainder. Power plant emissions must be measured continuously, and an emission allowance must be surrendered for each ton of SO2 emitted. A fixed number of emission allowances is allocated to existing power plants, and these allowances can be freely traded among any entities that seek to participate in the SO2 allowance market.

Improvements in end-use energy efficiency will generally reduce a power company's generation and resulting emissions, thereby saving valuable emission allowances. In addition, utilities that use energy efficiency or Renewables to reduce SO2 emissions before their first compliance deadline (either 1995 or 2000) can earn bonus SO2 allowances from a special reserve. Investments by non-utilities are eligible for these bonus allowances, provided the utility helps pay for the investment.

PART 3: POTENTIAL IMPEDIMENTS TO TRADING

Project managers seeking emissions credits or allowances must deal with complexities imposed by emissions trading systems. Measuring and allocating emissions currency first requires an accurate accounting of actual energy savings from investments. Investments in energy efficiency result in lower usage of electricity, in turn reducing the burning of fossil fuels and the associated emissions by the provider utility. The Protocol is intended to help determine emissions reductions by providing a cost-effective tool to achieving a consistent, reliable and replicable methodology for determining actual energy savings from efficiency. The Protocol contains some methods that do not include real time measurement, and instead allow prospective measurement through stipulation. These methods are suitable for some forms of energy efficiency investment, but they are not suitable and should not be used for emission reduction quantification. The Protocol contains methods designed to allow real time and retrospective measurement of energy savings, which in turn directly relate to emissions reductions. (The 1998 version of the Protocol will seek to provide an industry consensus for ensuring a consistent and more accurate methodology for determining energy generated by renewable energy sources.)

The second step in translating energy savings into emission reductions is to assign an emission rate or rates to the energy savings. This can be done as an estimate of the average marginal or average emission rate of the power pool. Alternatively, an emission rate can be assigned that is lower than the estimated actual rate. Accrediting efficiency as described above allows emission trading programs to lower overall costs of compliance, while rewarding investments that result in emissions reduction.

The efficiency and renewable energy industries believe they can provide an enormous and cost-effective contribution to meeting local, national and global environmental, economic and health objectives of emissions reductions programs. But these industries hold that credits must accrue to investors at the project investment level. If trading programs are designed to let market forces work, then the value of credits from efficiency and renewable energy projects will help influence investors to invest in those types of projects.

3.1 IMPORTANCE OF A CAP

Establishment of a cap and trade system creates a market-based trading system that can achieve targeted reduction in emissions at lower overall cost. In order for credits to have and retain value, an effective cap and trade system is essential for a number of reasons:

- It forces regulated industries to operate within overall state allocation.
- It preserves the integrity of the currency.
- It provides financial incentives through provision of credits for investments that reduce pollution.

A cap provides assurance of achieving environmental goals regardless of how credits are allocated under the cap. If investments (whether by utilities or companies) for switching to cleaner fuel or for efficiency are awarded emissions currency for reducing pollution, some of those investments would have happened anyway without that financial motivation awarded for pollution reduction. However, a cap eliminates the risk of environmental harm that could be associated with accrediting actions that might have occurred anyway. New Jersey provides one example of a cap and trade program that provides emissions currency to investments, such as efficiency, that cut pollution:

The Energy Efficiency Incentive in the New Jersey NOx Budget Rule

In May of 1993, New Jersey, along with ten other states in the Northeast, signed a Memorandum of Understanding obligating the state to NOx reductions from all major stationary sources. By 1999, the reductions will be 65 percent of the 1990 baseline or .2lbs/MMBtu, whichever was less stringent. In 2003, those numbers will drop to 75 percent reduction or 0.15lbs/MMBtu. Work began in subcommittees of the Ozone Transport Commission (OTC) and two years later, a model rule was issued which incorporated the limits and outlined an OTC-wide trading system for helping sources meet the new limits cost-effectively. State NOx budgets for the major stationary source sectors were calculated for all MOU signatories. Once this work was completed, it was up to each of the states to fashion a rule to implement the NOx budget in their state and to allocate their budget, in the form of NOx allowances, to the sources.

New Jersey has been a leader in energy efficiency for many years, and the state hosts an active market in energy efficiency services. When the NOx budget source representatives met with the state Department of Environmental Protection (DEP) to develop a proposed allocation system, some of the public sector energy efficiency customers asked for representation in the group. It was the belief of these public entities that efficiency deserved a share of the allowances, like any producer of electricity. It was clear that NOx reductions from energy efficiency were going to benefit the electricity suppliers in the state, by giving them excess allowances from reduced generation. The energy efficiency customers believed these allowances should be allocated to investors in energy efficiency, the ones ultimately responsible for creating the emission reductions. The New Jersey DEP listened to arguments for and against *establishment of an incentive for energy efficiency. It was the conclusion of the DEP that clean forms of electric generation, including energy efficiency, should be rewarded. The DEP set up an incentive for environmentally beneficial forms of electricity production, which included energy efficiency, and combustion of landfill gas and digester gas.*

Seven aspects of the DEP's proposal are worth special mention. First, the allowances were to be given out directly to the customers of energy efficiency at the project level, not to the utilities or other power producers. Second, efficiency was to be rewarded on a per kWh basis. Third, the kWh savings had to be measured and verified according to a Protocol (the New Jersey progenitor to the IPMVP) which requires in-situ metering of the savings. Fourth, the emission rate for the incentive was a fixed rate of 1.5 lbs. NOx per MWh. This emission rate, which is approximately 30 percent of the emission rate of the local power pool, is equivalent to the EPA's recently adopted New Source Performance Standard rate of .15lbs/MMBtu at 34 percent efficiency. Fifth, the DEP allocation is to be recalculated annually, which allows a performance-based incentive to exist. Sixth, the total number of incentive allowances is allowed to expand to accommodate any amount of energy efficiency, up to the size of the total budget. Seventh, the energy efficiency incentives are subtracted from the overall budget, so that they do not cause the overall cap to inflate. These seven criteria form an incentive in a cap system that is performance based, gives allowances directly to energy efficiency project investors, has environmental integrity and is simple.

3.2 IMPORTANCE OF BEING ABLE TO SECURE CREDITS AT THE PROJECT INVESTMENT LEVEL

A pollution cap and trade system creates two financial incentives to increase investment in pollution reduction. If utilities, to meet new pollution reduction targets, must invest in new pollution reduction technologies or buy emissions currency, this will increase their cost, which can be expected to translate into a higher cost of electricity. Higher cost of electricity, in turn, makes alternatives to buying electricity, such as investing in efficiency or in renewable energy, slightly more attractive. A second and potentially larger incentive to invest in efficiency or renewable energy technologies is provided by the value of credits that result from investments which reduce pollution.

Investments in efficiency retrofits reduce energy usage, which translates into lower emissions. For the price signals provided by credits to influence increased investments in efficiency, credits must accrue to the investor. Since utilities can make investments that reduce emissions (fuel switching, efficiency upgrades, pollution controls, etc.), it is important that utilities can secure credits that can motivate and reward these investments. Similarly, investments in efficiency and Renewables by corporations or public institutions, whether carried out internally or by ESCOs, should be able to secure credits for pollution reduction resulting from their investments.

Experience has shown that giving the incentive directly to investors in pollution reducing investments has the largest impact. Although under current trading programs the return is low - typically under one-half cent per kWh - this is an incentive that can prompt significantly increased investment. There appear to be factors that, in addition to direct financial savings, motivate investors to seek emissions currency. A 1996 study of 49 energy efficiency investment projects in New Jersey in which credits were available found that over 50 percent of kWh savings was attributable in whole or part to the customer's desire to receive emissions currency (Sycom, 1996).

Allowances are available to utilities in the 48 contiguous United States for DSM through the Conservation and Renewables Reserve of the Acid Rain Program, as mentioned above. Few states offer the incentives for NOx emission reductions directly to energy efficiency project investors (New Jersey, Massachusetts), although a few other states are considering the possibility (Connecticut, California).

If the value of the credit is not recognized at the project investment level, but accrues to a non-investor, this is a market distortion that prevents the price signal of credits from influencing the investment decision. As the number and expected value of pollutants that are traded increases (including, perhaps CO2), the value of credits will increase and with it the potential for credits to provide an important source of financing for investments, such as efficiency or Renewables, that reduce pollution. The energy efficiency and renewable energy industries naturally want investors in their technologies to be able to receive credits and view this as a critically important feature in pollution trading programs. For emissions trading programs to incent investments that cut emissions, they must provide emissions currency to investors who make investments which ultimately reduce pollution. Any new trading program should be designed so that efficiency investors are allocated credits under the cap. Use of this Protocol can help ensure that these energy savings are reliably demonstrated.

PART 4: CREATING AIR CREDITS AND TURNING CREDITS INTO MONEY

4.1 TRANSACTIONS AND PROGRAMS

Air credits may be required by industries seeking to site new facilities or expand existing operations in areas that do not attain ambient air quality standards for the criteria pollutants and their precursors (e.g., VOCs, NOx, SOx and PM10). To mitigate the impact of emission increases, such facilities must either reduce emissions on-site, in other facilities of their own or purchase credits to offset the increase. To date in the United States alone, there have been at least 5,000 to 12,000 netting transactions and several hundred offset transactions. Savings associated with netting in the United States have been conservatively estimated to be 300 million to several billion dollars, according to Cantor Fitzgerald, the leading private U.S. trader of credits.

As discussed above, there are a range of different pollutants trading programs, varying from country to country, state to state and regionally. Using these trading programs, building managers have the ability to create credits through investment in efficiency and renewable energy and other emission reduction investments and to generate cash through the sale of these credits. Claiming emissions currency at the project level is a relatively new and growing phenomenon. We can expect an increase in number of pollutants that are traded, and a growing number of areas with trading regimes. While some ESCOs have begun to claim credits directly, other firms may find it easier to work with public or private companies to aggregate and handle emissions resale, simplifying the process for project developers.

4.2 CLAIMING CREDITS

The expected increase in availability of emissions currency for emissions trading programs has prompted development of pilot or operational state programs. The steps to claiming credits described below should provide assistance in documenting and claiming credits for both operational and pilot programs.

Measuring and verifying the emissions reductions from efficiency investments is a two-part process. First, the kWh savings must be measured and verified, then an emissions rate must be applied for a specific period of savings. The first step can be accomplished using the real measurement methods from the Protocol. Options B-D provide some methods for real time measurement of actual savings and hence can provide a higher degree of precision than use of Option A for determining actual emissions reductions.

Following is a set of steps followed for securing credits in New Jersey. This list is not intended to be complete or definitive. Rather, it provides an illustrative set of steps that work in one specific state.

1. Determine if you are in a region where one or more pollution credit and trading program(s) exists. Decide which emission type(s) you would like to apply for credit.
2. Notify utility and aggregator (if any involved) of your action and negotiate ownership issues, if necessary.
3. Adopt an industry-recognized approach to measuring and documenting the energy savings resulting from an investment in efficiency or renewable energy. Use only retrospective measurement based on actual operation as measured by permanent in-situ metering. (This Protocol offers an accepted methodology to measure and verify these energy savings). Apply this Protocol to measure baseline and post-installation energy usage.
4. Determine emission rates for the emission types you are applying for. The emission rate will be the marginal emission rate for each emission type on the local utility power pool or your electricity provider, if it is not part of the grid. Multiply the MWh saved from the project by the marginal emission rate, and convert to tons-of-emissions-reduced for each emission type. NOx emissions reduced should be distinguished by ozone season (typically May through September) versus non-ozone season.
5. Document Steps 3 and 4 according to emission reduction protocols. Examples may be found in the Northeast States for Coordinated Air Use Management/Mid-Atlantic Regional Air Management Association. (NESCAUM contact: Jason Gerumet/Charla Rudisill, Telephone (617) 367-8540, CRUDISILL@NESCAUM.org; MARAMA contact Susan Wierman, Telephone (410) 467-0170, ssgw@jhunix.hcf.jhu.edu).
6. Give notice to the state(s) of actions taken. Follow state guidelines for demonstrating the emission reduction. Attach protocols and project data as appendices. Post credits with a state or regional registry.

Note: Greenhouse gases (GHGs) follow federal guidelines in rule 1605 of Department of Energy for reporting greenhouse gas reductions. Reporting the reductions is not equivalent to accrediting them. No formal process for accrediting GHGs exists yet.

PART 5: LIMITING THE EMISSION OF GREENHOUSE GASES

5.1 INTERNATIONAL LIMITATION OF GREENHOUSE GAS EMISSIONS

International efforts to respond to the threat of climate change have also increased the need for industry consensus approaches to measuring and verifying the economic and environmental benefits of investments in efficient or lower emission energy choices. The IPMVP can help project developers and policy makers to develop the practical experience and methodologies needed for fully operational emissions trading systems to abate greenhouse gas emissions.

The world community has responded to the growing international scientific consensus that human activities have begun to affect global climate by agreeing to reduce greenhouse gas emissions, primarily from fossil fuel use. 160 nations are parties to the 1992 United Nation's Framework Convention on Climate Change (U.N. FCCC), committing them to voluntary efforts to reduce emissions that contribute to this problem. With the December 1997 Kyoto Protocol to the U.N. FCCC, the industrialized nations committed to legally binding emissions reduction targets and timetables.

Based upon the success of existing emissions trading programs, the Kyoto Protocol embraces trading as a cost-effective method of meeting emissions targets and timetables, and the overall objectives of the U.N. FCCC. Emissions trading, either within or between countries, allows those companies or countries with high marginal abatement costs to buy emissions reductions from countries with lower marginal abatement costs.

Existing trading programs have measurably reduced emissions at a fraction of the cost of command and control regulatory alternatives. For example, sulfur dioxide allowance trading was expected to be the most cost-effective approach for many U.S. firms to abate acid rain with prices starting at less than $300/ton in 1993. However, emissions trading has exceeded expectations, with allowance prices dropping to less than $100/ton by 1996.

The Kyoto Protocol provides four methods of reducing emissions that will require effective and reliable performance measurement and verification. Specifically, these are: 1) domestic emissions trading programs; 2) trading between the industrialized nations of Annex I (e.g. between the UK and Russia); and 3) project specific emissions crediting through joint implementation between Annex I parties (e.g. for France and the Czech Republic); and 4) project specific emission crediting through the Clean Development Mechanism for Annex I nations and developing countries (e.g. for the U.S. and Mexico). Joint Implementation projects are already underway in the current pilot phase and emissions crediting for projects under the Clean Development Mechanism provisions of the Kyoto Protocol and could begin as early as the year 2000.

The effective measurement and verification of emissions reductions is a fundamental component of each of these systems. Many of the details needed to fully develop and implement these systems under the U.N. FCCC need to be completed through practical applications and future negotiations. However, the U.N. FCCC body that develops scientifically based operation procedures, is now developing and defining monitoring and verification methodologies. Their work will continue for some time, but decisions will be made at the next conference of the Parties in Buenos Aires, in November 1998.

Energy-efficiency improvements are explicitly recognized within the FCCC as the low or no-cost "no-regrets" measures of first choice for parties seeking to reduce emissions. Therefore, the emissions trading and crediting systems being developed under the FCCC present a tremendous opportunity for cost-effective energy-efficiency project and reinforce the need for the International Performance Measurement and Verification Protocol. Similar performance-based monitoring, reporting and verification efforts are being developed in the land use sector.

Project development and early purchases of emissions reductions are underway in anticipation of the emissions trading and crediting provisions of the Kyoto Protocol becoming operational. The IPMVP provides project developers, those interested in purchasing emissions reductions, and policy-makers around the world, with an industry consensus for an economically efficient, and environmentally effective standard to begin measuring greenhouse gas reductions from energy efficiency projects today.

5.2 THE INTERNATIONAL PERFORMANCE M&V PROTOCOL

The IPMVP helps provide for a single, consistent approach to measuring and verifying savings and associated emissions reductions in a broad range of energy sectors, including buildings and industry. In 1997/98 the Protocol will be extended to more formally cover important industrial energy end uses, including Cogeneration. Together, the buildings sector plus select industrial uses account for about half of energy-related greenhouse gas emissions. In addition, the Protocol is being extended to address investments in renewable energy. The 1998 Protocol, with industry and renewable extensions, will continue to provide international consensus on best industry practices for M&V.

5.3 U.S. EMISSIONS REDUCTION REPORTING

In the United States, CO2 emissions are not regulated, but there is a voluntary reporting system. A building owner/manager can report CO2 reductions under the Department of Energy's 1605b Voluntary Reporting Program. It should be noted that filing the 1605b does not give access to a CO2 credit, it simply registers the fact that the action has been taken. This program is an important first step, however (Contacts: Voice: (800) 803-5182, Fax: (202) 586-3045, Email: infoghg@eia.doe.gov, Internet:http://www.eia.doe.gov/oiaf/1605/frntend.html). Pilot projects are currently underway to test the creation of CO2 trading programs and the creation and trading of CO2 credits. The Northeast States for Coordinated Air Use Management, for example, is planning a demonstration project for greenhouse gases.

5.4 CONCLUSION

The extension and development of emissions trading programs, if properly designed, provides a proven and cost-effective way to achieve emission reductions. For programs to incent investments that cut emissions - whether in fuel switching by utilities or company investments in efficiency - the credits should accrue at the point of investment.

It should be noted that the creation of emissions currency for any emission type would typically be made more accurate and reliable through the use of this Protocol to verify kWh savings. All trading systems - those that exist today and those that are just now emerging - require verifiable energy savings for calculating emissions currency created. This Protocol can provide an important part of a consistent and reliable savings verification program, but it is not an accreditation Protocol. This Protocol should be used in conjunction with a document that provides greater specific technical guidance that addresses emission rates and specifies how to translate the IPMVP energy savings data into equivalent emissions reduction. The building or plant owner/manager (and in the future, investors in renewable energy) that wish to get credit for emission reductions should consider use of the Protocol as a valuable tool.

Appendix II

MEASUREMENT & VERIFICATION GUIDELINES
A GENERIC APPLICATION OF THE IPMVP

ACKNOWLEDGMENTS

Adapted by Cary Bullock from the
Guidelines for Energy Measurement & Verification for the Federal Energy Management Program
prepared by
Steven R. Schiller
Lorna D. Stucky and
David A. Jump
of Schiller Associates - Oakland, California.

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This Appendix is a part of the
International Performance Measurement and Verification Protocol (IPMVP).
It is consistent with and references sections of the IPMVP which outline measurement and verification methods for a variety of projects.
The material contained herein was drawn from the ***Measurement and Verification (M&V) Guidelines for Federal Energy Projects,*** which was in turn developed in conjunction with the North American Energy Measurement and Verification Protocol.
Detailed descriptions of each method are contained in the ***Measurement and Verification (M&V) Guidelines for Federal Energy Projects*** (available on-line at http://eande.lbl.gov/CBS/femp/MVdoc.html).

PART 1: INTRODUCTION

This Appendix provides procedures and guidelines for quantifying savings resulting from the installation of ECMs under energy performance contracts and is intended to comply with the International Performance Measurement & Verification Protocols (IPMVP). The IPMVP was developed to provide a commonly accepted methodology for measuring energy savings associated with performance contracts. This Appendix is intended for general application in commercial, industrial, institutional and local public sector facilities.

1.1 PURPOSE AND SCOPE OF DOCUMENT

The purpose of this Appendix is to provide M&V guidelines that could be referenced along with the IPMVP in customer/building owner Requests for Proposals (RFPs) for seeking performance contractors and in performance contracts themselves.

1.1.1 General Approach To Measurement And Verification. There are two components of M&V for Energy Saving Performance Contracting (ESPC) projects:

- **Verifying ECM potential to perform and generate savings -** by confirming that: i) baseline conditions are accurately defined, and ii) the appropriate equipment components or systems are properly installed, performing per specification and have the potential to generate predicted savings.
- **Verifying ECM performance (savings) -** by determining the actual energy savings achieved by the installed ECM.

As the ESPC program is based on pay for performance, each ECM or site will have a site-specific verification process to determine its savings.

1.1.2 Level of Verification Effort and Definitions. Accuracy requirements for measuring and verifying savings is either defined by the customer's RFP or negotiated with the ESCO. The required level of M&V effort is then specified in the contract between the customer and ESCO. If any discrepancy arises between the definitions provided in IPMVP and the customer/ESCO contract, the definitions in the contract prevail.

PART 2: GENERAL M&V OVERVIEW

2.1 GENERAL APPROACH

The general approach to determining energy savings involves comparing the energy use associated with a facility, or certain systems within a facility, before installation of the ECM (baseline) and after installation of the ECM (post-installation). Therefore, in general:[1]

[1]Exceptions to this simple equation include new construction projects and projects in which baseline energy use is determined from similar facilities or from applicable new building performance standards, not from the facility where the retrofit actually occurred. Please see Section 6.0 of the IPMVP.

energy savings = (baseline energy use) - (post-installation energy use)

As ESPC projects are based on pay for performance, each ECM or site will have a site-specific verification process to determine its savings. For each site or project, the baseline and post-installation energy use will be defined using any or all of the following: metering, billing analysis and/or engineering calculations (possibly including computer simulation). In addition, values for certain factors that affect energy use and savings, *and that are beyond the control of the ESCO* (i.e., building occupancy), may be stipulated by the customer sponsoring the project.

After each project is completed, the ESCO submits a report that defines projected energy savings for the first year. This post-installation report must be accepted and approved by the customer. Typically, first year payments to the ESCO will be based on the projected savings values submitted in the report.

For the remaining years of the contract, the ESCO provides annual (or at some other regular interval) true-up reports. These reports include inspection documentation of the installed equipment/systems and (perhaps) updated savings values using data obtained and analyzed during each year of the contract. Previous payments would be reconciled as necessary based on the results of the periodic report. Each year, payments would be calculated based on information in the latest periodic report.

2.2 VERIFYING ECM POTENTIAL TO PERFORM

2.2.1 Maintaining Service Quality. The Demand Side Management (DSM) measures installed under ESPC programs should maintain or improve the quality of service provided to the customer by the affected equipment or systems. For example, lighting projects that reduce lighting levels must maintain some minimum standards, i.e., the minimum standard for the facility's primary use. This Appendix, however, does not address verifying performance standards. Specific facility performance requirements are defined in the solicitations/RFPs for ESCO services.

2.2.2 Baseline Verification. Baseline conditions may be defined by either the customer or the ESCO. If the baseline is customer-defined, then the ESCO will have the opportunity to verify it. If the baseline is defined by the ESCO, the customer will verify it. Baseline physical conditions such as equipment counts, nameplate data, energy consumption rate and control strategies will typically be determined through surveys, inspections and/or spot or short-term metering activities. Variables which affect baseline energy calculations such as weather and building occupancy are identified.

2.2.3 Post-Installation Verification. In a post-installation M&V verification, the ESCO and customer agree that the proper equipment components or systems were installed, are operating correctly and have the potential to generate the predicted savings. Verification methods may include surveys, inspections and/or continuous metering. The ESCO, or third party, is expected to complete the system/equipment commissioning. Current editions of ASHRAE's commissioning guideline GPC-1[2] can be the basis for commissioning activities.

[2] *Guidelines for Commissioning of HVAC Systems*, ASHRAE Guideline 1 (1989).

2.2.4 Regular Interval Post-Installation Verification. The ESCO and customer, at defined intervals during the term of the contract, will verify that the installed equipment components or systems have been properly maintained, continue to operate correctly and generate savings.

2.3 VERIFYING ECM PERFORMANCE

Either after the ECM is installed, continuously or at regular intervals, the ESCO and customer will determine energy savings in accordance with an agreed-upon M&V method using verification techniques defined in a site-specific M&V plan.

2.3.1 Verification Techniques. Baseline energy use, post-installation energy use and energy (and cost) savings will be determined using one or more of the following M&V techniques:

- Engineering Calculations
- Metering And Monitoring
- Utility Meter Billing Analysis
- Computer Simulations (e.g., DOE-2 Analysis)
- Mathematical Models (e.g., Regression Formulas)
- Agreed-Upon Stipulations By The Customer And The ESCO

2.3.2 Estimating Energy Savings. There are numerous factors that can affect energy savings during the term of a contract such as weather, operating hours, process loads and heat exchanger fouling. In general, one ESPC contract objective may be to adjust baseline energy use up or down for factors beyond the control of the ESCO (e.g., changes in building occupancy or weather), and adjust post-installation energy use for ESCO-controlled factors (e.g., maintenance of equipment efficiency).

In order to calculate energy savings, the customer may in some cases stipulate the value of factors that are difficult to determine or that may vary during the contract term. For example, in a lighting project the customer (or ESCO) measures the baseline and post-installation lighting fixture power draw and then stipulates the operating hours of the facility. For a chiller replacement project, the customer measures the baseline and post-installation chiller performance factors (e.g., IPLV kW/ton) and then stipulates the ton-hours of cooling at the facility in order to calculate annual energy savings. Stipulated values need to be checked for reasonable accuracy through comparisons between: i) total predicted savings against utility energy consumption data, and/or ii) values of actual conditions observed during site inspections. These are Option A techniques to measure and verify energy savings.

In other situations, continuous or regular interval measurements throughout the term of the contract may be compared to baseline energy measurements to determine savings. For a constant speed motor to variable speed drive motor conversion project, post-installation motor energy use may be continuously metered and compared against baseline measurements of motor energy use. These are Option B techniques to measure and verify energy savings.

There are many factors that affect energy consumption and various methods for estimating savings. A sampling of typical methods is contained in parts 2, 3 and 4 of this Appendix.

2.4 FACTORS AFFECTING APPROPRIATE LEVEL OF M&V

The level of certainty required for verifying ECM potential to perform (generate savings) and performance (actual savings) will vary from project to project. The necessary confidence level used for establishing savings is a function of the value of the project and cost-effectiveness of the level of M&V sophistication. Factors that will affect the level of effort and cost (how much the effort costs), include the following:[3]

- Value Of ECM In Terms Of Projected Savings
- Complexity Of ECM And M&V Procedures
- Number Of ECMs At A Single Facility And The Degree To Which Their Savings Are Interrelated
- Number Of Interrelated ECMs At A Single Facility
- Uncertainty Of Savings
- Risk Allocation Between The ESCO And The Customer For Achieving Savings
- Other Uses For M&V Data And Systems

Factors that typically affect M&V accuracy and costs are as follows (some of these are interrelated):

- Level Of Detail And Effort Associated With Verifying Baseline And Post-Installation Surveys
- Sample Sizes (Number Of Data Points) Used For Metering Representative Equipment
- Duration And Accuracy Of Metering Activities
- Number And Complexity Of Dependent And Independent Variables Which Are Metered Or Accounted For In Analyses
- Availability Of Existing Data Collecting Systems, e.g., Energy Management Systems
- Contract Term
- Confidence And Precision Levels Specified For Energy Savings Analyses

Discussion and definition 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 the ECM savings. For certain types of projects, a statistical definition of accuracy could be included in a contract. For other types of projects, it may be possible only to define a subjective accuracy range or percent of payment budget for M&V. For each M&V method discussed in Section 3 of the IPMVP and throughout this Appendix, varying levels of effort and accuracy can be defined.

2.5 METERING AND MONITORING PROTOCOLS

A site-specific M&V plan should demonstrate that any metering and monitoring will be done in a consistent and logical manner. Metering and monitoring reports must address exactly what was measured, how, when, by whom and with what kind of meter it was measured. Calibration is

[3]These factors are discussed in more detail in Part 4 of this Appendix.

required. Readers may wish to view the sample forms in the FEMP Guidelines. These forms are not required, but they give an indication of the level of detail typically required. Both raw and completed data should be submitted to the customer with post-installation and regular interval reports.

The duration of metering and monitoring must be sufficient to ensure an accurate representation of the amount of energy used by the affected equipment both before and after project installation. The measurements should be taken at typical system outputs within a specified time period, such as one month. These measurements can then be extrapolated to determine annual and time-of-use period energy consumption.

The required length of the metering period depends on the type of project. If, for instance, the project is a system that operates 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.

If the project's energy use varies both across the day and seasons, as with air-conditioning equipment, however, a much longer metering or monitoring period may be required to characterize the system. In this case, long-term data or a model correlated to short-term data are used to determine annual and time-of-use period energy savings.

For some types of projects, there may be uncertainty as to how long the metering must be conducted. For example, there is still controversy over how long lighting operating hours must be measured in office buildings to determine a representative indication of annual operating hours. In these situations, a discussion is required between project participants to determine the appropriate answer for the ECM under consideration.

If the energy consumption of the metered equipment or systems varies by more than ten percent from month to month, sufficient measurements should be taken to account for these variances. Any major energy consumption variances due to seasonal activity or periodic fluctuations should also be monitored. If these variances cannot be monitored for whatever reason, they must be built into the annual energy consumption figure through an agreed-upon adjustment.

Extrapolation can take the form of measuring and normalizing energy consumption as a function of some independent parameter, such as ambient temperature, humidity or percent occupancy of a building. Once the relationship between equipment energy consumption and the parameter(s) are established, then extrapolation can be done by extending the relationship over a one year period. Therefore, the site-specific M&V plan should identify critical variables, explain how they will be measured or documented and discuss how they will be used in the extrapolation. The assumptions and mathematical formulas that are used in the M&V plan must be clearly stated. Any auxiliary energy-consuming equipment must be metered or accounted for if its energy consumption changes as a result of the project installation.

2.6 ENERGY COSTS

The ultimate goal of an ESPC is to reduce energy costs at customer facilities. The IPMVP is designed to provide energy savings information in such a way that cost savings can be estimated.

Energy cost savings may be calculated using energy savings and the appropriate cost-per-unit of energy saved. In most cases, the unit cost of energy will be based on a servicing utility's energy rate schedules at the time the project is implemented. The unit cost of energy that will be used in calculating energy cost savings must be defined in sufficient detail in the contract to allow calculation of savings using each of the factors that affect cost savings. These factors include items such as (for electric bills) kWh saved, kW saved, power factor, kW ratchets and energy rate tiers.

For performance contracts based on energy cost savings, an M&V method will need to be selected that provides energy savings data by time-of-use periods of the facility's rate structure. For example, at a prison the water heating peak load 252 kW over a two-minute averaging period, 228 kW over 15 minutes, or 192 kW using 60-minute time periods of analysis. Considerable error in cost savings estimates are introduced by data that does not correspond to the rate structure (15 minutes, in this case). Thus, it is critical that M&V plans should be able to reflect the effects of time-of-use and block rate schedules.

2.7 STANDARDIZED FORMS

Equipment surveys submitted by ESCOs are expected to be comprehensive, accurate (±5%) and current (completed within a reasonable time before submittal). Data and surveys submitted should be provided in both electronic and hard copy formats as specified by the customer. Sample survey forms for lighting and motors projects can be found in the appendices of the FEMP Guidelines.

2.8 INSPECTIONS

Pre-installation, post-installation and regular interval inspections (e.g., annual) by customer representatives may be conducted to confirm documentation submitted to the customer by the ESCO. These inspections, or confirmation visits, by customer representatives are important. If the customer believes conditions at the site are not accurately represented by the documentation, the ESCO may be allowed the opportunity to address the problem and re-submit the information.

2.9 INTERACTIVE EFFECTS

It is commonly understood that various ECMs interact with each other. Reduced lighting loads, for example, can reduce air conditioning energy consumption, but increase heating consumption. However, the detailed relationship between most dissimilar, but interactive ECMs is not known, and the methods for measuring interactive effects are not cost-effective for many applications.

For lighting projects, three approaches to account for savings associated with interactive effects include the following:

1. Ignore interactive effects.
2. Use mutually agreed-upon default values that are applicable based on the site-specifics associated with building type and HVAC equipment type. The default values can be assigned based on either available information for typical buildings, or developed based on computer model simulation for typical building conditions. A critical element of this approach is for the ESCO or customer to demonstrate in the baseline lighting survey that the measures are in air-

conditioned space. If the space is also heated, post-installation energy consumption needs to be adjusted upward to account for heating load increases caused by losses in internal heat gains from efficient lighting equipment.

3. Propose a method to measure and estimate interactive effects. The customer and/or ESCO will need to agree on the merit and reasonableness of the proposed approach that may include: i) directly measuring, ii) simulating the HVAC (heating and cooling) interactive effects using a fully-documented computer program, or iii) using a utility meter billing analysis approach that captures interactive effects in the total predicted savings. All methods need to be proposed and reviewed on a site-specific basis.

PART 3: M&V METHODS

3.1 M&V METHODS BY ECM

ECMs covered in this section are the most common types currently being implemented though performance contracts, including:

- lighting efficiency retrofit projects and constant load motor retrofit projects that are representative of constant load, constant operating hours projects.
- lighting controls retrofit projects that are representative of constant load, variable operating hours projects.
- variable speed drive retrofits and chiller replacement projects that are representative of variable load, variable operating hour projects.

Generic variable load, variable operating hours, utility billing analysis and computer simulation M&V methods are also presented.

Table 1 presents a summary of 24 methods that have been defined for different ECM categories (these are representative of most anticipated situations). Detailed descriptions of each method are contained in the *Measurement and Verification (M&V) Guidelines for Federal Energy Projects.*

Tables 2-6 provide summary points regarding M&V methods by end-use technology:

- *Table 2 - Lighting Efficiency Retrofits*
- *Table 3 - Lighting Controls Retrofits*
- *Table 4 - Constant Load Motor Retrofits*
- *Table 5 - VSD Retrofits*
- *Table 6 - Chiller Retrofit Projects*

The measure codes (XX-Y-Z) in the tables below use the following format:

- *XX - Refers To The Technology*
- *Y- Denotes Option A, B Or C*
- *Z – Refers To The Specific Approach*

Note that Option D methods are not included in the tables below, because at the time of printing, FEMP Guidelines had not been updated to include Option D.

Table 1: Summary of M&V Methods by Technology and M&V Approach

Method & Reference	Technology	Option	Approach
LE-A-01, Chapter 5	Lighting Efficiency	Option A	No metering
LE-A-02, Chapter 5	Lighting Efficiency	Option A	Spot metering of fixture wattage
LE-B-01, Chapter 10	Lighting Efficiency	Option B	Continuous metering of operating hours
LE-B-02, Chapter 11	Lighting Efficiency	Option B	Continuous metering of lighting circuits
LE-C-01, Chapter 18	Lighting Efficiency	Option C	Utility billing analysis
LC-A-01, Chapter 6	Lighting Controls	Option A	No metering
LC-A-02, Chapter 6	Lighting Controls	Option A	Spot metering of fixture wattages
LC-B-01, Chapter 12	Lighting Controls	Option B	Continuous metering of operating hours
LC-B-02, Chapter 13	Lighting Controls	Option B	Continuous metering of lighting circuits
CLM-A-01, Chapter 7	Constant Load Motors	Option A	Spot metering of motor kW
CLM-B-01, Chapter 14	Constant Load Motors	Option B	Continuous metering of motor kW
CLM-C-01, Chapter 18	Constant Load Motors	Option C	Utility billing analysis
VSD-A-01, Chapter 8	VSD Retrofit	Option A	Spot metering of motor kW
VSD-B-01, Chapter 15	VSD Retrofit	Option B	Continuous metering of motor kW, speed frequency, or controlling variables
VSD-C-01, Chapter 18	VSD Retrofit	Option C	Utility billing analysis
CH-A-01, Chapter 9	Chiller Retrofit	Option A	No metering
CH-A-02, Chapter 9	Chiller Retrofit	Option A	Verification of chiller kW/ton
CH-B-01, Chapter 16	Chiller Retrofit	Option B	Continuous metering of new chiller
CH-B-02, Chapter 16	Chiller Retrofit	Option B	Continuous metering of new chiller and cooling load
CH-C-01, Chapter 18	Chiller Retrofit	Option C	Utility billing analysis
CH-C-02, Chapter 19	Chiller Retrofit	Option C	Computer simulation
GVL-B-01, Chapter 17	Generic Variable Load Project	Option B	Continuous metering of end-use energy use
GVL-C-01, Chapter 18	Generic Variable Load Project	Option C	Utility billing analysis
GVL-C-02, Chapter 19	Generic Variable Load Project	Option C	Computer simulation

Table 2: Lighting Efficiency Retrofits - M&V Methods

M&V Method	**Method LE-A-01: No Metering**	**Method LE-A-02: Metering of Fixture Wattages**	**Method LE-B-01: Metering of Operating Hours**	**Method LE-B-02: Metering of Lighting Circuits**	**Method LE-C-01: Utility Billing Analysis**
M&V Option	Option A	Option A	Option B	Option B	Option C
Fixture Counts	survey which is checked to defined accuracy	same as LE-A-01	same as LE-A-01	same as LE-A-01	same as LE-A-01
Fixture Wattages	fixture wattage table or manufacturer data	one time (before and after) measurements of representative fixture wattages	fixture wattage table or fixture measurements	measured circuit wattage	required - as a check, and for future baseline modifications
Pre-Installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre-monitoring	same as LE-A-01	assumed equal to post-installation hours which are monitored	same as LE-B-01	not required - unless as a check, or for future baseline modifications
Post-Installation Operating Hours	same as pre-installation operating hours	same as LE-A-01	monitoring of operating hours	measurement of circuit average power draw implies operating hours	not required - unless as a check
Interactive Factors	a) not allowed, or b) stipulated percentage, or c) based on simulation	same as LE-A-01	same as LE-A-01	same as LE-A-01	Included in billing analysis results

Table 3: Lighting Controls Retrofits - M&V Methods

M&V Method	**Method LC-A-01: No Metering**	**Method LC-A-02: Metering of Fixture Wattages**	**Method LC-B-01: Metering of Operating Hours**	**Method LC-B-02: Metering Lighting Circuits**
M&V Option	Option A	Option A	Option B	Option B
Fixture Counts	survey which is checked to defined accuracy	same as LC-A-01	same as LC-A-01	same as LC-A-01
Fixture Wattages	fixture wattage table or manufacturer data	one time measurements of representative fixture wattages	fixture wattage table or one time fixture measurements	measured circuit wattage
Pre-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre- monitoring	same as LC-A-01	operating hours are monitored for representative sample(s) of fixtures	the circuit measurement of average power draw also provides operating hours
Post-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term post-monitoring	same as LC-A-01	operating hours are monitored for representative sample(s) of fixtures	the circuit measurement of average power draw also provides operating hours
Interactive Factors	a) not allowed, or b) stipulated percentage, or c) based on simulation	same as LC-A-01	same as LC-A-01	same as LC-A-01

Table 4: Constant Load Motor Retrofits - M&V Methods

M&V Method	**Method CLM-A-01: Metering of Motor kW**	**Method CLM-B-01: Metering of Operating Hours**	**Method CLM-C-01: Utility Billing Analysis**
M&V Option	Option A	Option B	Option C
Motor Counts	survey which is checked to defined accuracy	same as CLM-A-01	same as CLM-A-01
Baseline and Post-Installation Motor Power Draw	spot wattage/rpm measurements	spot and short-term wattage/rpm measurements	not required - unless as a check or for future baseline modifications
Pre-installation Operating Hours	a) stipulated based on estimates, or b) stipulated based on some short-term pre-monitoring	assumed equal to post-installation hours which are monitored	not required - unless as a check or for future baseline modifications
Post-installation Operating Hours	same as pre-installation operating hours	monitoring of operating hours or kWh	not required - unless as a check
Confirmation of Constant Load	a) stipulated, or b) short-term metering of sample of motors	same as CLM-A-01	not required - unless as a check

Table 5: Variable Speed Drive Retrofits - M&V Methods

M&V Method	**Method VSD-A-01: Metering of Motor kW**	**Method VSD-B-01: Continuous Metering of Motor kW or Controlling Variables**	**Method VSD-C-01: Utility Billing Analysis**
M&V Option	Option A	Option B	Option C
Inventory of Motors and Drives/Controls	survey which is checked to defined accuracy	same as VSD-A-01	same as VSD-A-01
Verification of System Operation	functional verification of VSD operation	same as VSD-A-01	same as VSD-A-01
Baseline Motor Power Draw At Different Operating Conditions	stipulated based on a) spot or short-term wattage/rpm measurements (baseline is constant load), or b) short-term wattage/input measurements (baseline is variable load)	a) spot or short-term wattage/rpm measurements (baseline is constant load), or b) short-term wattage/input measurements (baseline is variable load)	not required - unless as a check or for future baseline modifications
Baseline Operating Hours[4]	stipulated based on estimates or some short-term pre-monitoring	a) assumed equal to post-installation conditions - which are monitored, or b) if variable, then long-term pre-monitoring	not required - unless as a check, or for future baseline modification
Baseline[5] **Operating Conditions - Independent Variables That Impact Energy Use, Operating Hours e.g. weather**	not used for method	assumed equal to post-installation conditions - which are monitored	not required - unless as a check, or for future baseline modifications
Post Installation[6] **Motor Power Draw at different operating (input) conditions**	a) stipulated based on manufacturer data, or b) spot or short-term wattage/ rpm measurements	continuous or regular interval wattage measurements	not required
Post-Installation[7] **Operating Conditions - Independent Variables That Impact Energy Use**	not used for method	long-term post-monitoring for input into post- and pre-installation model	not required

[4]With some VSD projects the replaced motors are always at constant load so that the baseline energy use is equal to the product of motor kW and motor operating hours.
[5]With some VSD projects the replaced motors have variable loading depending on the independent factors such as weather which impact valve or damper positions.
[6]Post-installation energy use can be directly measured.
[7]Post-installation energy use can be calculated based on measurement of independent variables, e.g. ,weather, once a correlation has been established between post-installation energy use and the independent variable.

Table 6: Chiller Retrofit - M&V Methods, Page 1 of 2

M&V Method	**Method CH-A-01: No Metering**	**Method CH-A-02: Verification of Chiller kW/ton Ratings**	**Method CH-B-01: Continuous Metering of Chiller (post-installation)**
M&V Option	Option A	Option A	Option B
Inventory Of Chillers And Auxiliary Equipment	survey which is checked to defined accuracy	same as CH-A-01	same as CH-A-01
Verification Of System Operation	functional verification of chiller system operation	same as CH-A-01	same as CH-A-01
Baseline Chiller And Auxiliary Equipment Power Draw (At Different Cooling Loads)	stipulated based on manufacturer data and/or other sources	a) stipulated, or b) spot or short-term kW/cooling load measurements to determine performance curve or kW vs. cooling load	same as CH-A-02
Baseline Cooling Load (Stated In Average Ton Hours Per Year Or Percent Time At Different Cooling Loads)	stipulated based on estimates e.g., computer model simulation	same as CH-A-02	a) stipulated, or b) assumed equal to post-installation cooling load which is determined from measurement of new chiller kW and use of new chiller performance curve
Post-Installation Chiller And Auxiliary Equipment Power Draw (At Different Cooling Loads)	stipulated based on manufacturer data, and/or other sources	a) stipulated, or b) spot or short-term kW/cooling load measurements to determine performance curve or kW vs. cooling load	continuous or regular interval metering of chiller kW to determine post-installation energy use
Post-Installation Cooling Load (Stated In Average Ton Hours Per Year Or Percent Time At Different Cooling Loads)	stipulated based on estimates	same as CH-A-01	not required for this method

Table 6 Continued, Page 2 of 2

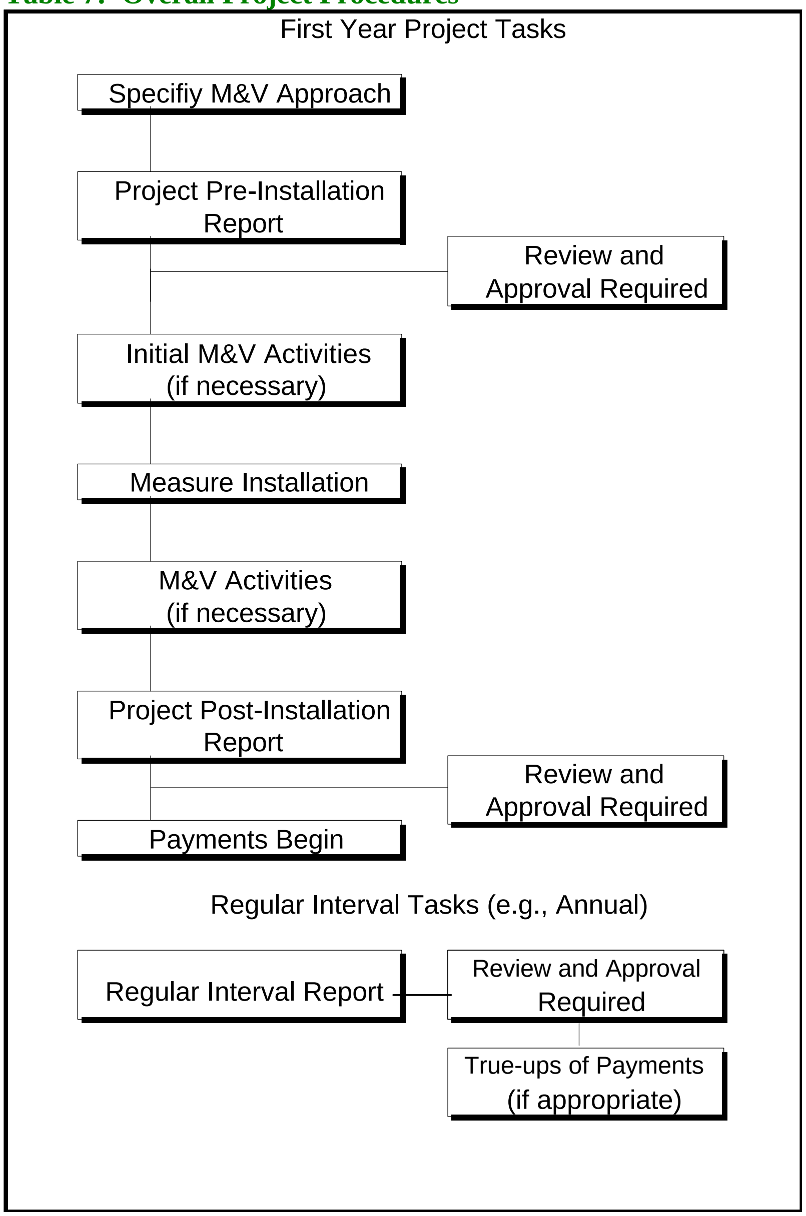
M&V Method	**Method CH-B-02: Continuous Metering Of Chiller And Cooling Load (Post-Installation)**	**Method CH-C-01: Utility Billing Analysis**	**Method CH-C-02: Computer Simulation Calibrated To Whole Building Utility Data**
M&V Option	Option B	Option C	Option C
Inventory Of Chillers And Auxiliary Equipment	same as CH-A-01	same as CH-A-01	same as CH-A-01
Verification Of System Operation	same as CH-A-01	same as CH-A-01	same as CH-A-01
Baseline Chiller And Auxiliary Equipment Power Draw (At Different Cooling Loads)	same as CH-A-02	not required - unless as a check, or for future baseline modifications	use of: (a) typical data, (b) manufacturer data, or (c) spot or short-term wattage/cooling load measurements to determine performance curve
Baseline Cooling Load (Stated In Average Ton Hours Per Year Or Percent Time At Different Cooling Loads)	assumed equal to post-installation load which is continuously measured	not required - unless as a check, or for future baseline modifications	determined with computer simulation with possible calibration check against utility metering or end-use metering
Post-Installation Chiller And Auxiliary Equipment Power Draw (At Different Cooling Loads)	same as CH-B-01	not required - unless as a check	use of: (a) typical data, (b) manufacturer data, or (c) spot or short-term wattage/cooling load measurements to determine performance curve
Post-Installation Cooling Load (Stated In Average Ton Hours Per Year Or Percent Time At Different Cooling Loads)	post-installation cooling load is determined from measurement of water or air flows and temperatures	not required - unless as a check	determined with computer simulation with possible calibration check against utility metering or end-use metering

PART 4: OVERVIEW OF GENERAL PROCEDURAL STEPS AND SUBMITTALS

4.1 M&V ACTIVITY DETAILS

As a contract is implemented, both the customer and ESCO take certain steps with respect to the M&V of each project. Table 7 presents a flow chart of the steps.

Table 7: Overall Project Procedures



The roles of each party in these steps will be specified in their contract depending on type of specific business agreements, risk allocation and accuracy of desired verification. In general, the

ESCO will provide documentation on equipment and demonstrated savings. The customer will verify submittals for accuracy and provide approval before the project can proceed to the next step. The submittals include a: i) Project Pre-Installation Report, ii) Project Post-Installation Report, and iii) Regular Interval Reports. As part of the review of the submittals, the customer may conduct site inspections to confirm submittal data.

It should be noted that these steps should be applicable to most projects, however, some M&V activities (outlined below) might not be necessary if certain variables in estimating savings are stipulated in the contract. The steps identified above are briefly described in the following paragraphs.

4.1.1 Site-Specific M&V Plan. A site-specific M&V plan that is based on the guidelines must be defined. The approach will also be based on the type of ECM and the desired confidence and accuracy of verification. In some cases, that plan will be included by the agency as part of the solicitation, in other cases the ESCO will propose a site-specific plan to be finalized after the awarding of the contract. The decision as to whether the agency will specify the site-specific plan or the contractor will be asked to provide one may be based on resources available to the agency when constructing the solicitation.

4.1.2 Project Pre-Installation Report. A Project Pre-Installation Report is generated for each project selected for installation. The report is generated by the ESCO. The customer must review and approve the report before the ESCO can proceed with the project. At its sole discretion, the customer may conduct site inspections to confirm submittal data. This report should include a project description, facility equipment inventories with recommended ECMs, energy and cost-savings estimates, cost-effectiveness calculations, a site-specific M&V plan, budget documentation (construction and M&V budgets) and proposed construction and M&V schedules.

4.1.3 Initial M&V Activities and Meter Installation. Once the customer accepts the Project Pre-Installation Report, metering (if necessary) and/or project installation may proceed. Pre-installation metering is conducted in accordance with the approved, site-specific M&V plan in the contract and/or the Project Pre-Installation Report. Metering is commissioned, and the customer may witness the calibration. When required pre-installation metering has been completed and accepted by the customer, the project can be installed. During metering and project installation by the ESCO, the customer may request progress reports or conduct inspections. Major tasks associated with M&V work prior to measure installation are as follows[8]:

- Pre-installation M&V activities are conducted, and the customer and the ESCO agree on an M&V plan, an inspection and an installation schedule based on contract terms.
- As identified in the contract and/or Project Pre-Installation Report, pre-installation metering is conducted for a period of time required to capture all operating conditions of affected systems and/or processes. If the ESCO is responsible for metering, the customer will conduct progress inspections (and/or reports), as required.
- The customer notifies the ESCO that project installation may begin. If no pre-installation M&V activities are required, project installation approval may be given upon acceptance of the Project Pre-Installation Report.

[8]If M&V work is not required prior to installation, the first two tasks are not required.

- Project installation begins.
- The ESCO notifies the customer that project installation is complete.

4.1.4 Project Post-Installation Report. When the measures are installed, the ESCO notifies the customer that project installation is complete by submitting the Project Post-Installation Report. This report includes baseline and post-installation calculations with energy and cost-savings estimates. Post-installation M&V work may be conducted prior to submitting a Project Post-Installation Report. The customer, as required, inspects the installed project and any post-installation metering. Major post-installation tasks associated with this submittal are as follows[9]:

- Post-installation M&V activities are scheduled to begin and, if conducted by the ESCO, coordinated with customer facility personnel.
- As identified in the contract and/or Project Pre-Installation Report, post-installation metering may be conducted by the ESCO for the period of time required to capture all operating conditions of the measure and/or impacted process. If applicable, customer facility personnel will conduct progress inspections of metering.
- Metering documentation for verification is included in the Project Pre-installation Report.
- A Project Post-Installation Report is generated. The customer may either approve if the project and documentation are acceptable or disapprove if the project and documentation are unacceptable or issues exist that prevent a review decision.
- Upon customer acceptance of the Project Post-Installation Report, ESCOs may submit invoices for first-year payment based on savings estimates in the accepted Project Post-Installation Report.

4.1.5 Regular Interval Reporting. Regular true-up M&V activities are conducted periodically based on contract terms between the customer and ESCO.

Periodic reports are generated that present energy and cost-savings. If the ESCO is responsible for metering, it analyzes current M&V data and submits periodic reports for customer review and approval. The periodic reports include measurement-based kWh savings data. Periodic report data is used for correcting, if necessary, the previous payments by the customer to the ESCO. These same data is also used for projecting energy savings for subsequent contract periods, and is the basis for contract payments in the following period. Major tasks associated with periodic reports are as follows:

- If the ESCO is responsible for metering, it notifies the customer that periodic true-up activities are scheduled to begin. Periodic true-up metering may be conducted for the period of time required to capture all operating conditions of the projects(s) and/or affected processes. The customer can conduct progress inspections of metering as required.
- M&V documentation is presented in Regular Interval Reports. Customer facility personnel review and approve these reports.
- Customer facility personnel ensure that the report and verification documentation are complete, accurate, and in compliance with the contract and approved site-specific M&V plan. Based on the results, payments during the previous period are reconciled and adjusted in subsequent

[9]If M&V work is not required prior to submittal of the Project Post-Installation Report, then the first three tasks are not required.

contract payments. This payment reconciliation would not apply if fixed payments are specified in the contract.

4.1.6 Payments. The project payment process is described below:

- The customer accepts both the Project Pre-Installation Report and Project Post-Installation Report.
- The terms and conditions of the customer-issued purchase order covers information which must be in the invoice. The amount of the invoice is also specified.
- The customer pays the ESCO upon approval of the invoice in accordance with contract terms and conditions.
- Some projects may be set up so that payments are based on results in the Regular Interval Report, which indicates verified energy and cost-savings results of the previous period.

Based on the contract, the customer may use the report to reconcile payments made to the ESCO for the previous billing periods, since previous payments were made based on estimated savings that now need to be reconciled to reflect actual savings. This payment reconciliation would not apply if fixed payments are specified in the contract. The estimates in the report may also be used as the basis for subsequent payments.