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

1) To obtain the NEMVP:
    A) As a book, call the “Efficiency and Renewable Energy Clearinghouse (EREC)” at:
    1 (800) DOE-EREC (363-3732)
    or fax your name, address & telephone number to EREC at **(703) 893-0400,** ask for the “North American Energy Measurement and Verification Protocol,” and include the code “NEMVP”
    B) Electronic access via EREC’s e-mail: at **doe.erec@nciinc.com**
    C) Electronic access via the Energy Efficiency and Renewable Energy Network (EREN) home page on the World Wide Web at:
    http://www.eren.doe.gov
    The Protocol is cited on EREN’s Alphabetical Listing under **North American Energy Measurement and Verification Protocol**.
2) To obtain the Federal Energy Management Program’s Guidelines and the NEMVP together:
    A) In hard copy, call EREC at: **1 (800) DOE-EREC (363-3732)**
    B) Electronically via e-mail at: **M+V_info@lbl.gov**
    C) Electronically via the World Wide Web at:
    http://www.eren.doe.gov/femp/new_fed.html
3) For information about ASHRAE Guideline 14 via the World Wide Web:
    http://www.ashrae.org/g1-s58.htm
    Search for “Guideline 14. Measurement of Energy and Demand Savings.”
4) To access reference documents via Internet:
    Access Energy Systems Laboratory at Texas A&M server at:
    ftp://info.tamu.edu/doe

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SECTION 1.0: PURPOSE AND SCOPE OF DOCUMENT

INTRODUCTION

In 1995, North Americans installed $5 billion in efficiency equipment in their buildings in order to save money and conserve energy and water. But this covers only a small fraction of the existing cost-effective opportunities for energy savings investments. If all cost-effective efficiency investments were made in public and commercial buildings, the United States would save $20 billion per year on energy bills, create over 100,000 jobs, and significantly cut pollution.

When firms invest in energy efficiency, they 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, measurements would be trivial - install a meter. But to measure savings is a challenge, and requires both metering and a methodology, known as a measurement and verification protocol.

To determine energy savings, the parties (the building owner, the installer and perhaps the financier) must first agree on the “base case” (what the building used before retrofit), and then must measure energy use after retrofit. They may want to adjust the savings for variations in the weather or changes in occupancy or work schedules. And they should keep up the measurements to ensure that their savings persist.

In early 1994, our financial advisors complained that existing protocols (and those under-development) create a patchwork of inconsistent, sometimes unreliable efficiency installation and measurement practices that prevent development of new forms of lower cost financing. We believe that the North-American Energy Measurement and Verification Protocol (NEMVP) will help overcome these impediments to the growth of the efficiency industry.

The NEMVP Protocol is the result of a remarkable collaborative effort between federal and state agencies and experts in the energy and efficiency industries in America, Canada, and Mexico. This year-long effort, initiated by the US Department of Energy, has been largely driven by industry and reflects a broad industry consensus. The work was drafted by the NEMVP Technical Subcommittee and reviewed and guided by the NEMVP Policy Committee with financial guidance from the NEMVP financial Advisory Committee. In addition, comments were received from over 250 corresponding members.

It is our hope that this Protocol will be adopted throughout North America and internationally. Our expectation is that, by providing greater and more reliable savings and a common approach to efficiency installation and measurements, the financial markets will respond with financial products allowing the securitization of energy and water efficiency projects. Ultimately, we hope this will lead to the development of a secondary market for efficiency investments, with increased availability of low cost and off-balance sheet financing, allowing the efficiency industry to grow much more rapidly resulting in widespread benefits in the form of increased employment, lower energy and water bills and reduced damage to the environment.

1.1 PURPOSE

The long-term success of energy management projects has been hampered by the ability 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 projects to quantify energy conservation measure (ECM) performance and energy savings. By using one of the different M&V options discussed in this document, readers can allocate various risks associated with achieving energy cost savings to either the buyer or seller of the project. Additionally, this protocol:

- is designed to be consistent with EPA Acid Rain Program verification protocols for conservation and renewable energy reserve allowances,
- gives buyers, sellers and financiers a basis to discuss key M&V project-related issues,
- helps ensure the accurate verification of projects, with respect to anticipated versus achieved savings, and
- uses procedures which i) are consistently applicable to similar projects throughout all geographic regions, and ii) are nationally accepted, impartial and reliable.

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.

This M&V protocol is not intended to prescribe contractual terms between buyers and sellers. 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.

The protocol provides an overview of current techniques available for verifying aspects of third-party financed energy projects. It may also be used by building operators to assess and improve facility performance.

Coordinated with the efforts of the ASHRAE GPC 14P Committee, this document will be maintained and revised under the sponsorship of the Department of Energy on a bi-annual basis, based on recommendations developed by a consensus group of facility owners/operators, financiers, contractors or energy service companies (ESCOs) and other stakeholders. As the document is updated, it will incorporate new measurement techniques as they become available. Changes, modifications and additions will be reviewed on a regular basis and, if approved, will be incorporated directly into this document, so that buyers, sellers and financiers of energy projects are kept abreast of the latest options.

1.2 SCOPE

The scope of this M&V protocol includes:

- Addressing the energy and cost savings verification needs of participants in third-party financed energy projects - financiers, sellers, buyers and technical consultants.
- Defining the role of verification in third-party financed energy 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 savings performance.
- Creating a *living* document that includes a set of methodologies and procedures that enable the document to evolve over time.
- Designing M&V procedures for a variety of facilities including residential, commercial, institutional and industrial buildings.
- Providing techniques for calculating “whole-facility” savings, individual technology savings and stipulated savings.
- Looking at a variety of ECMs including gas and electric, fuel switching, load shifting and other measures which involve the installation of equipment and result in energy cost savings.
- Reviewing methods of measuring energy savings for retrofit as well as new construction.
- Providing procedures for the investigation and resolution of ECM performance issues.
- Designed to verify the installation of renewable energy technologies in a way that best optimizes their system benefits.

1.3 TARGET AUDIENCE

The target audience for this M&V protocol includes:

- Facility Energy Managers
- Consultants
- Researchers
- Government Agencies
- Utilities
- ESCOs
- Financiers
- Any Other Party Needing To Determine The Value Of Energy Improvements

1.4 RELATIONSHIP TO ASHRAE GPC 14P

This document is designed to be complementary to the work of the ASHRAE GPC 14P Committee, currently writing *Measurement of Energy and Demand Savings*. In contrast to the ASHRAE document, which focuses on the relationship of the measurement to the equipment being verified, this M&V protocol discusses a variety of M&V topics as they relate to actual contracts for energy services. By design, portions of these documents overlap. It is advised that the reader use both documents, as well as others referenced herein, to formulate a successful M&V plan.

1.5 RELATIONSHIP TO EPA'S CONSERVATION VERIFICATION PROTOCOL

This M&V protocol has been written to be compatible with Environmental Protection Agency (EPA) protocols. EPA's Conservation Verification Protocols (CVPs) 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. EPA's protocols are designed to verify energy savings, and not specific environmental savings, although the latter could be easily accomplished with additional calculations.

To this end, the CVPs are designed to provide EPA with sufficient confidence that the savings from utility DSM programs are real, without placing an undue burden on the utility. The CVPs are intended mainly for utility-run DSM programs, as opposed to performance contracting. The CVPs emphasize actual measurement of savings over engineering estimates. However, discounted stipulated savings are permitted for certain measures and procedures.

Energy savings verified from performance contracting is potentially eligible for bonus allowances under EPA's Acid Rain Program, provided the measures are paid for in part by an electric utility. This M&V protocol could also be used in that context to verify performance contracting energy savings, in conjunction with the CVPs or other verification procedures used by state utility commissions.

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

1.6 RELATIONSHIP TO FEDERAL ENERGY MANAGEMENT PROGRAM GUIDELINES

The Department of Energy's Federal Energy Management Program (FEMP) was established, in part, to reduce energy costs to the government to operate federal facilities more efficiently. FEMP assists federal energy managers by identifying and procuring energy-saving projects. Part of this assistance includes preparing a document called the "Standard Procedures and Guidelines for Verification of Energy Savings Obtained Under Federal Energy Savings Performance Contracting Programs."

The FEMP M&V Guidelines are an application of the NEMVP Protocol for Federal sector projects only and are intended to be fully compatible and consistent with the NEMVP Protocol. The FEMP Guideline is intended to be used by Federal procurement teams consisting of contracting and technical specialists. The content of the FEMP Guidelines includes those items necessary to draft an RFP and evaluate responses. The focus of the FEMP Guidelines are on choosing the M&V option and method most appropriate for specific projects. Contractors responding to RFP's may refer to the FEMP Guidelines for more information on specific procedures referenced in Federal RFP's. Although the FEMP Guidelines strive for compatibility, discrepancies may exist between the FEMP Guidelines and the NEMVP Protocol. In these cases, please send email to **MVinfo@lbl.gov**.

SECTION 2.0: PERFORMANCE CONTRACTING: WHY MEASUREMENT AND VERIFICATION

2.1 DEFINITION AND ROLE OF PERFORMANCE CONTRACTS

The term "Energy Savings Performance Contract" (ESPC) covers a broad range of contracts where the cost of ECM implementation is recovered through savings created by the ECMs. An ESPC can be used to accomplish any or all of the following objectives: upgrade capital equipment, provide for maintenance of existing facilities, save energy and/or save money. These contracts range in complexity from simple projects such as lighting upgrades, to more detailed projects involving all aspects of energy consumption.

Because the basis for ESPCs is the performance of the ECMs, contracts must include a clear method of: i) assessing project performance, and ii) determining savings distribution. The role of M&V is to provide that method - a means of quantifying installed ECM performance, and calculating the savings that accrue as a result of increased efficiency.

This M&V protocol formalizes the language and techniques of M&V used in many existing contracts and provides several options for assessing energy savings. This protocol is not meant to prescribe an M&V option for every type of retrofit, but to state options available and help clarify the relationship of various M&V options to the associated risks assumed under an ESPC.

Typically, a number of performance risk issues are addressed in the ESPC. Many are listed below. In the interest of brevity, some contractual issues, such as maintenance and operation of the ECMs, are not covered by this document.

2.2 PARTICIPANTS IN PERFORMANCE CONTRACTS

An ESPC usually requires the participation of several parties. While energy projects that are directly financed typically involve only an owner and a contractor (or ESCO), ESPC projects may also include financiers and third party M&V professionals.

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

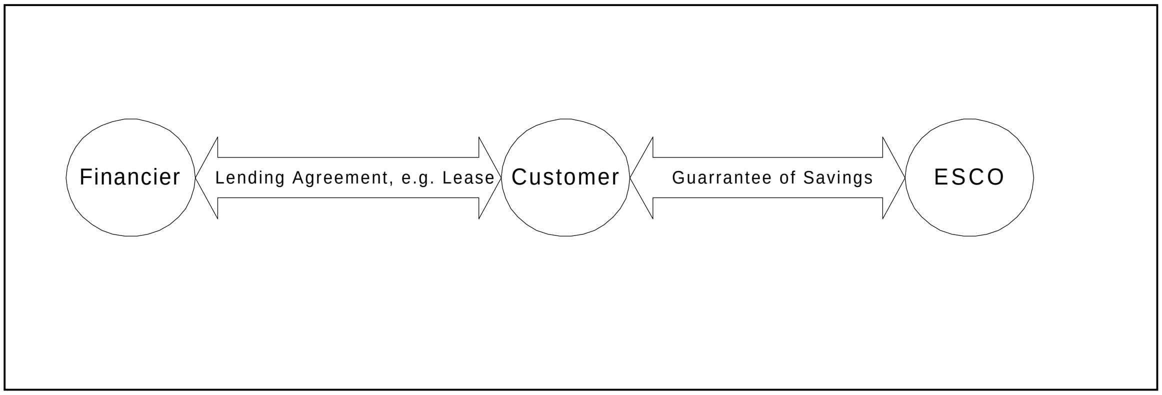
2.2.2 Contractor/Energy Services Company. The role of the contractor is to provide assistance in identifying and capitalizing on energy-saving opportunities and/or to implement the ECMs that are specified in the contract. Contractors with the resources to package engineering, financing and construction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

2.2.3 Financiers - Banks, Utilities, Etc. ESPCs require that one party be responsible for paying the initial cost of the ECMs to be installed. There are several financing options. The optimal source of financing is dictated by how risks are shared in the contract.

2.2.4 Independent M&V Professionals. The application of concepts and procedures presented in this protocol 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.

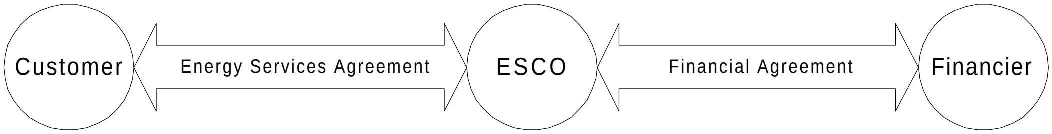
In order to adequately understand the implications of various measurement strategies, the M&V professional should have a thorough understanding of the ECMs being installed.

2.2.5 ESCO/Owner/Financier Relationship. The relationship between the parties is directly related to the different contract types and risks. When the owner is at risk for project payments, the relationship between the owner and the financier is as shown below.



Facility owners often erroneously believe that in a “guaranteed savings arrangement,” the ESCO guarantees the financial obligation assumed by the owner. In fact, the ESCO guarantees *a level of savings which is generally adequate to cover the financial obligation*. Hence, the owner still bears the financial risk associated with performance if, for example, the ESCO is unable to deliver on the guarantee, e.g., in the case of bankruptcy.

Shared savings, pay from savings or chauffage contracts use an arrangement shown in the figure on the following page.



Clearly this group of contracts requires additional services be provided by the ESCO. And the services, consequently, are more costly to provide. Not addressing the operations and maintenance (O&M) services normally attendant to these ESPCs could cause the ESCO to assume the risk of project performance and/or arrange for the equity aspect of the project. In these projects, financing must be obtained solely on either the project's ability to perform, or the strength of the ESCO's guarantee. In a guaranteed savings arrangement, money is raised solely on the strength of the owner’s credit.

2.3 M&V OPTIONS

The purpose of defining several M&V options is to allow the reader flexibility in the cost and method of assessing savings. Therefore, the M&V options, described briefly below and in more detail in Section 4.0, vary in accuracy and in cost of implementation. The reader should first review and understand the three general approaches (Options A, B and C) and then define a specific measurement plan based on the option that makes the most sense for the intended project.

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 that the reader understand the limitations as well as the strengths of each method presented.

2.3.1 Option A: Performance Verification, End-Use Retrofits - Measured Capacity, Stipulated Consumption Approach. The verification techniques for Option A determine savings by measuring the performance of a system before and after a retrofit, and multiplying the difference by an agreed-upon or “stipulated” factor, such as hours of operation. 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 relies on the direct measurement of affected end uses. For projects where the baseline is well understood, and operating hours are not expected to change, only the "change in equipment performance" is needed in order to calculate savings.

2.3.2 Option B: Savings Verification, End-Use Retrofits - Measured Capacity, Measured Consumption Approach. 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 the operation and performance of the ECMs. 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.

2.3.3 Option C: Whole Building or Main-Meter Measurement Approach. 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.

2.4 PROCURING PERFORMANCE CONTRACTS

This section is intended to help readers of this protocol understand the forms of performance contracts that exist and to relate the most appropriate measurement needs to each form or type of contract. ESPC types are typically designed to deal with certain contracting problems or to capitalize on specific owner opportunities. Most owners are understandably skeptical of performance financing of energy projects. This skepticism usually stems from a lack of familiarity with the contract types, as well as a natural distrust of financially complex deals.

There are several different types of contracts used for project financing within the performance contracting industry. Some of these require M&V, while others do not. In cases where M&V is not contractually required, it may still provide valuable information to the owner.

To a significant degree, different types of financing contracts can be organized by determining whether the project financing is on the owner's balance sheet[1] or not, and whether the owner's payment for services or amortization of the financing is contingent on project performance. This organization is shown in the table on the following page.

---

[1] On balance sheet means that the entire financial obligation is on the owner's balance sheet. The current portion of the obligation would be listed as a current liability, while the long-term portion would be listed as a long-term liability. If the financial obligation is "off balance sheet," only the current portion (i.e., the portion paid during the designated accounting period, usually one year) appears on the balance sheet of the owner. This distinction is important to owners, and is almost always important to their lenders.

	On Owner's Balance Sheet	**Not On Owner's Balance Sheet**
Net Owner Payment Contingent On Performance	Guaranteed Savings (Long Term)	Shared Savings Pay from Savings Chauffage
Net Owner Payment Not Contingent On Performance	Guaranteed Savings Loans (Short Term) Capital Leases	Certain Municipal Leases Operating Leases

When Owner Payment Is Not Contingent On Project Performance.

When the owner takes the long-term project risk, which occurs in most guaranteed savings contracts, the most cost-effective way to finance the project is through the use of leases or loans. When the owner needs further assurances, which may be required by law (e.g., in some states, a third-party guarantee of savings is a prerequisite for a local government agency to enter a performance contract relationship), a savings guarantee creates a guaranteed savings contract.

In essence, the project finance portion of the transaction is supported by a debt-like vehicle (loan, capital lease, municipal lease, operating lease) which is fully backed by the owner. The owner is willing to provide the capital, even though it may be arranged by the performance contractor, because the owner receives a guarantee from the performance contractor that the savings level will meet or exceed a specified minimum, which is generally greater than the amount required to service the assumed debt. With this approach, the financier does not rely on the savings guarantee, and the guarantee's presence or absence has little effect on the cost of funds.

These types of arrangements may result in an "on balance sheet" transaction in the case of capital leases or loans, or an "off balance sheet" transaction in the case of operating leases and municipal leases.

Guaranteed savings contracts are useful in some particular market niches. In the local public sector, i.e., cities, towns and counties, interest paid is generally tax exempt for most investors.[2] Since the interest spread between tax exempt and taxable interest is generally 250 to 300 basis points, using tax exempt financing can be of considerable advantage, often amounting to a present value benefit of ten-to-twenty percent (10-20%) of the amount financed. On $1,000,000 project, the benefit may be as much as $150,000. Since these projects are often multi-million dollar projects, all parties have a significant incentive to use tax exempt financing wherever possible.

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[2] If the investor is a bank, the local entity must also be "bank qualified." This requirement simply sets a limit on long-term tax exempt financing issued by the local entity in the year of the financing.

When The Owner Payment Is Contingent On Project Performance.

This type of financing arrangement is typically how most owners view performance contracts. It includes such contracts as shared savings, pay from savings and chauffage. These contracts are more easily explained than guaranteed savings contracts, but are generally much more complex in structure. Shared savings contracts are arrangements where one party provides the capital (and generally the technically expertise), while the other party provides the facility. The parties measure savings in accordance with a defined protocol, like this one, and share the project savings on a defined basis. The basis can be as simple as fifty/fifty, or perhaps variable or stepped percentages.

Pay from savings contracts are similar to a loan with a variable term based on the level of savings, i.e., more savings reduce the financial obligation more quickly. In this instance, the contractor/ESCO may loan the owner the money to build the project, while charging an elevated interest rate (to recognize the increased risk). The owner then pays the contractor/ESCO from the savings generated by the ECMs installed. Moreover, the contractor/ESCO guarantees that the savings will be adequate to pay off the obligation within a specified time period, typically five-to-ten years.

Chauffage contracts provide for a radically different structure. In essence, end uses, themselves, are sold. For example, a contractor might offer lighting from a specified fixture type on a dollars-per-hundred-hours-of-usage basis. Or, chilled water might be sold on a MMBTU basis (gallons delivered at a specified temperature). These contracts are different from others discussed above in two respects: i) they typically involve lengthy contract periods (20-30 years), and ii) the contractor provides all associated O&M support during the contract.

Why Contract Differences?

Each type of contract solves certain problems or capitalizes on specific owner advantages. Guaranteed savings contracts are most useful in the local public sector, since they provide the assurance needed for this market niche to be comfortable securing financing. This approach also offers great ease in using tax exempt financing vehicles. The reader should be advised that these types of transactions are often required to meet exacting internal investment criteria of the target company, and often they do not.

Shared savings contracts are useful where the owner cannot or does not want to use borrowing capacity. For example, many subsidiaries of large companies do not generally secure debt independently. For them, shared savings is a useful approach since the transaction structure ensures that the owner will never pay more than the savings, and the obligation will likely be off balance sheet. Hence, this structure guarantees that, absent a contract breach, the obligation can be retired from current funds. This is not true in the case of a guaranteed savings contract (e.g., suppose the guarantor refuses to pay or goes bankrupt).

Shared savings contracts are also useful because they are most often regarded as new equity and may not be required to meet internal investment criteria. For example, if the internal hurdle rate of the target company is thirty percent (30%), and the expected APR of a shared savings contract is eighteen percent (18%), the shared savings contract becomes attractive, since it is much less expensive than internal funds. By contrast, a guaranteed savings approach would likely not be acceptable for this transaction. As well, shared savings contracts generally provide the owner O&M responsibilities if the owner desires.

Pay from savings contracts would appear to have the same risk characteristic for the owner as shared savings, but these contracts lend themselves to a much more “open book” approach. This is one reason they have historically been popular in situations where cost-based construction is desired (e.g., public sector, not tax exempt and institutional).

Chauffage contracts are useful where the owner wishes to “outsource” facility services and investment.

The contract types discussed in this section are listed in the table below in order of cost. To the extent cost reflects value, i.e., each form is used in its most appropriate application, this table also represents the relative value to the owner, from the least valuable to the most valuable.

Contract Type	**Order of Cost** **1 = least** **4 = most**
Guaranteed Savings	1
Pay from Savings	2
Shared Savings	3
Chauffage	4

2.5 SELECTING THE BEST M&V OPTION

M&V is used for a variety of reasons:

1. To define how much an owner pays a contractor/ESCO.
2. To help operate a facility more efficiently.
3. To assess, by the owner and where no third party guarantees are present, whether a particular investment is performing.

If the owner chooses an M&V plan to define how much the owner will pay a contractor/ESCO, then:

- Depending on the size of the project, an independent third party is sometimes useful in providing an M&V framework for a project. Among the reasons for using a third party should be independence and objectivity, although in many projects the contracting parties can perform these tasks themselves.

- The type of measurement described in this protocol in its current form is appropriate primarily for guaranteed savings contracts, pay from savings contracts and shared savings contracts.

Chauffage contracts, by contrast, usually define payment in terms of a positive utilization rather than a negative utilization (e.g., pounds of steam used instead of savings). The measurement professional can use concepts developed in this protocol as a basis for developing payment formulae under chauffage contracts.

- Cost-effective measurement approaches and contract types generally match up as follows:

Short-Term Guaranteed Savings	Option A
Long-Term Guaranteed Savings	Option B
Shared Savings	Option B, C
Pay From Savings	Option B, C

- An M&V plan should be selected so that M&V costs do not consume the savings. In general, M&V costs should be approximately less than twenty percent (20%) of the anticipated net savings benefit to the owner.

SECTION 3.0: OVERVIEW OF MEASUREMENT AND VERIFICATION

3.1 GENERAL APPROACH TO M&V

The basic approach to determining energy savings involves comparing energy use associated with a facility, or certain systems within a facility, both before and after ECM installation. The "before" case is called the baseline. The "after" case is called post-installation. In general:

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

Exceptions to this simple equation are:

- New construction projects where baseline energy use has to be determined by methods other than pre-installation inspections or measurements.

- Projects where the baseline is determined from other similar facilities, not from the facility where the retrofit actually occurred.

Baseline and post-installation energy use can either be constant during the term of a contract, or one (or both) can vary with time. The following are three examples.

- **Baseline and post-installation energy use constant 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.

- **Baseline and post-installation energy use vary during term of agreement**:
  Example: HVAC project where new chillers are installed, and the occupancy of the building changes during the term of the agreement.

- **Baseline energy use remains constant, and post-installation energy use varies during term of agreement:**
  Example: Lighting controls project where occupancy sensors are installed, and the operating hours of the lights with occupancy sensors change during term of agreement.

Verifying baseline and post-installation conditions involves inspections, spot measurement tests and/or commissioning activities. Commissioning activities include:

- Documentation design assumptions for the ECM design.
- Documentation of the design intent for use by contractors, owners and operators.
- Functional performance testing and documentation necessary for evaluating the ECM for acceptance.
- Adjusting the ECM to meet actual needs within the capability of the system.

For projects based on "pay for performance," each ECM or site will have a separate verification process to determine its savings. 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 simulation). In addition, values for certain factors which affect energy use and savings, and which are beyond the control of the contractor/ESCO, may be stipulated by the owner.

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

For the remaining years of the contract, the contractor/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 results of the periodic report, and future year payments would be calculated based on information in the periodic report. This true-up and payment reconciliation would not apply if the contract specifies fixed payments.

3.2 VERIFYING ECM PERFORMANCE POTENTIAL

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

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.

3.2.2 Post-Installation Verification. One aspect of post-installation M&V is verification by the ESCO and the owner that the proper equipment/systems were installed, are operating correctly and have the potential to generate the 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 contractor/ESCO. Current editions of ASHRAE's GPC-13 can be the basis for commissioning activities.[3]

3.2.3 Regular Interval Post-Installation Verification. The contractor/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.

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[3] Guidelines for Commissioning of HVAC Systems, ASHRAE Guideline 1-1989.

3.3 VERIFYING ECM PERFORMANCE (ACTUAL SAVINGS)

Either once after the ECM is installed, continuously or at regular intervals, the contractor/ESCO and owner determine energy savings in accordance with an agreed-upon M&V approach 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 Billing Analysis
- Computer Simulations, e.g., DOE-2 Analysis
- Agreed-Upon Stipulations By The Owner And The Contractor/ESCO

3.3.2 Energy Use 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 ton-hours and heat exchanger fouling for chiller replacement projects. In general, but not always, one contract objective may be to adjust the baseline energy use up or down for factors beyond the control of the contractor/ESCO (e.g. building occupancy, weather) and adjust the post-installation energy use for contractor/ESCO controlled factors (e.g. maintenance of equipment efficiency).

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

However, for other projects, continuous or regular interval measurements throughout the term of the contract will be compared against baseline energy measurements to determine energy savings. For example, 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.

If any values are stipulated, a "reality check" is suggested, such as comparing total predicted savings against utility bills.

3.4 M&V IMPLEMENTATION PROCEDURES

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

- Define a general M&V approach for inclusion in the agreement between buyer and seller of energy services (the owner, and the contractor/ESCO).
- Define a site-specific plan for the particular project being installed once the project has been fully defined, usually after the agreement is signed.
- 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; spot, short-term or long-term metering; and/or analysis of billing data.
- 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.
- Calculate energy savings for the first year or all of the remaining years of a contract.
- Calculate first year payments.
- 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).
- Calculate annual payments.

3.5 M&V ISSUES

3.5.1 Independent Reviewer. Often the contractor/ESCO has more expertise and experience than the owner in dealing with performance contracts and ECM savings. Therefore, it is almost always more cost-effective and beneficial for the owner to utilize ESCO’s or, where appropriate, independent 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.

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

- 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.

- Completely defining the baseline conditions.

- Defining the analysis equations and required confidence in the savings calculations in order to determine: i) the 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).

    - ♦ Calculating 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.
    - ♦ Have an appreciation for Murphy's Law.

A note regarding Murphy's Law: Because performance contracts require a multitude of tasks be completed simultaneously, Murphy's Law applies. In other words, "if something can go wrong, it will." Performance contracts require skilled project management. Attention to detail is important for successful execution of a performance contract.

3.5.3 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, with what meter, when, and by whom. Calibration of sensors and meters to known standards is required to ensure that data collected is valid. Project information and metered data must be maintained in usable formats. Both "raw" and "compiled" data should be submitted to the owner with the post-installation and regular interval reports.

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 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 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 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.

- 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, a discussion is required between the project parties to determine the appropriate measurement period for the ECM under consideration.

If energy consumption varies by more than ten percent (10%) from one month to the next, sufficient measurements must be taken to document these variances. Any major energy consumption variances due to seasonal activity increases or periodic fluctuations must 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.

Extrapolation can be used by measuring and normalizing energy consumption as a function of some independent parameter, such as temperature, humidity, product type or production quantity. Once the relationship between the energy consumption of the equipment and the parameter(s) are established, then extrapolation can be done 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 extrapolation. Additionally, assumptions and mathematical formulas 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.

3.5.4 Energy Costs. For some projects, contract payments will be based on energy savings, e.g. kWh, kW, therms, etc. For other projects payments will be based on energy *cost* savings. When required, energy cost savings will 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. The 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 energy cost savings 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 energy usage of the new equipment and minimum standard equipment. In these situations the 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. 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 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, or
- be calculated based on Option C type analyses.

3.6 DEFINING THE APPROPRIATE LEVEL OF M&V

The level of certainty required for verifying an ECM's performance potential and actual performance will vary from project to project. The confidence which is appropriate for establishing savings is a function of the value of the project and the cost-effectiveness of increasing or decreasing confidence in savings. Factors which will affect the level of effort, i.e. 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 the contractor/ESCO and the owner for achieving savings
- Other uses for M&V data and systems

With respect to value of ECM, suppose a project has an expected savings of $100,000 per year, and that it was believed that this estimate was good plus or minus twenty percent (20%) or $20,000 per year. Thus, it may be reasonable to spend $10,000 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 as the value of the results would not be worth the price paid.

Factors which will 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 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 only possible to define a subjective accuracy range or percent of payment budget for M&V.

- *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 so that the value of information provided by M&V activity is appropriate to the project value. “Rule of thumb” estimates put M&V costs at one-to-ten percent (1-10%) of typical project construction cost.

- *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 of savings isolation 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.

  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):

  - ♦ Constant load, constant operating hours
  - ♦ Constant load, variable operating hours
    - ∗ Variable hours with a fixed pattern
    - ∗ Variable hours without a fixed pattern, i.e., weather dependent
  - ♦ 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

- *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, the 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 Option C is almost always required.

  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 is familiar may require less M&V than other, more 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. If the ESCO specifies the baseline, it may be more appropriate to use M&V Options B or C to verify savings.

- *Risk Allocation Between The Contractor/ESCO And The Owner.* If a contractor/ESCO’s payments are not tied to actual savings, M&V is not typically required. Likewise if a contractor/ESCO is not held responsible for certain aspects of project performance, these “aspects” do not need 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 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.

- *Other Uses for M&V Data and Systems*. Often the array of instrumentation installed and the 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 become more cost-effective if combined with the objectives of the M&V activities. In addition, there is the possible interest in quantifying savings beyond the requirements of the performance contract. Information may be desired for cost allocation between facility tenants, for future projects or for research purposes.

3.7 MEASUREMENT AND VERIFICATION OPTIONS

Three M&V options (A, B and C) are defined in this protocol for use with performance-based projects. Any one option is not necessarily better or more/less expensive than another. Each M&V option is applicable to different types of performance contracts. The three options are described below. The owner and contractor/ESCO 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. The table below provides a quick overview of the options.

M & V Option	Metering	Cost	Accuracy
Option A: Verifying ECM has potential to perform & generate savings	None or short-term periodic	Dependent on no. of measurement points. Approx. 1-5% of construction cost	Performance accuracy dependent on metering. Energy savings accuracy dependent on estimate of stipulated hours
Option B: Verifying ECM has potential to perform; verifying actual performance by end use	Continuous in post-installation at system level	Dependent on no. of systems measured. Typically 3-10% of construction cost	Performance accuracy dependent on metering. Energy savings accuracy dependent on baseline assumptions and metering
Option C: Verifying ECM has potential to perform; verifying actual performance (whole bldg. analysis)	Continuous in post-installation at whole-facility level	Dependent on no. of relative parameters. Typically 1-10% of construction cost	Energy savings accuracy dependent on baseline assumptions and selection of relevant variables

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 of the people conducting verification

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

3.7.1 Option A. Option A is a verification approach designed for projects where the potential to perform needs to be verified, but the actual performance (savings) can be stipulated based on the results of the "potential to perform and generate savings" verification and engineering calculations. Option A involves procedures for verifying that:

- Baseline conditions have been properly defined.
- The equipment and/or systems that were contracted to be installed have been installed.
- The installed equipment/systems meet the specifications of the contract in terms of quantity, quality and rating.
- The installed equipment is operating and performing in accordance with the specifications in the contract and meeting all functional tests.
- The installed equipment/systems continue, during the term of the contract, to meet the specifications of the contract 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. For example, baseline and post-installation conditions (e.g. equipment quantities and ratings such as lamp wattages, chiller kW/ton, motor kW, or boiler efficiency) represent a significant portion of the uncertainty associated with many projects.

The potential to perform may be verified through inspections and/or spot or 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 perform and generate savings.

With Option A, actual achieved energy or cost savings are not verified; they are predicted using engineering or statistical methods that do not involve long-term measurements. All end use technologies can be verified using Option A. Within Option A various methods and levels of accuracy in verifying performance are available. The level of accuracy involves moving from an inventory method of ensuring nameplate data and quantity of installed equipment to short-term measurements for verifying equipment ratings, capacity and/or efficiency.

Performance can be quantified using any number of methods, each depending on the accuracy requirements of the contract. Performance of equipment can be obtained either directly, i.e., through actual measurement, or indirectly, i.e., 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 be 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.

3.7.2 Option B. Option B is for projects where: i) the potential to perform and generate savings needs to be verified, and ii) actual performance during the term of the contract needs to be measured (verified). Option B involves procedures for verifying the same items as Option A plus actual achieved energy savings during the term of the contract. Performance verification techniques involve engineering calculations with metering and monitoring. Option B:

- confirms that the proper equipment/systems were installed and that they have the potential to generate the predicted savings

- determines an energy (and cost) savings value using measured data taken throughout the term of the contract

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 value accuracy is defined by the owner or negotiated with the contractor/ESCO. The task of measuring or determining energy savings using Option B can be more difficult and costly than with Option A. However, the results will typically be more precise.

Methods employed in this option will involve the use of long-term measurement of one or more variables. The use of 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, under certain circumstances there is 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 motors which have been predetermined to operate in a similar manner.

3.7.3 Option C. Option C may be employed for projects where: i) the potential to perform needs to be verified, and ii) actual performance during the term of the contract needs to be verified. Option C involves procedures for verifying the same items as Option A plus actual achieved energy savings during the term of the contract.

Performance verification techniques involve utility whole-facility meter analysis and/or computer simulation calibrated with utility billing data. Option C:

- 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

All end use technologies can be verified with Option C. 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.

SECTION 4.0: THREE 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. Many reports, papers and text books address the specific information that needs to be gathered, and provide procedures and methods for accomplishing this task. The following are sources of additional information: ASHRAE (1990), 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; 1992), 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 the 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.

- Take photographs and/or videotapes of 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.

- Obtain an accurate count of the systems to be replaced if the retrofit involves multiple units of one type of equipment. This should also be accompanied by a location diagram that indicates where new/different equipment is to be located.

- If a lighting retrofit is being considered, measure baseline and post-installation lighting conditions 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 energy conservation retrofits where end use capacity, demand or power level can be measured or estimated with manufacturer's measurements, and energy consumption, or hours of operation are known in advance, stipulated or agreed upon by both parties. Option A usually involves a one-time measurement of the instantaneous energy use before the retrofit (baseline), and a one-time measurement of the instantaneous energy use after the retrofit (post-installation). 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 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 by multiplying the representative energy capacity by the hours of operation. The capacity, demand or power level, i.e., kW, Btu/hr or kJ/hr, needs to be measured using one-time, in-situ end use measurements. This 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 Measurements. 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. One-time, in-situ 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%). Types of one-time, in-situ energy measurements that can be taken include: electrical energy use measurements (i.e., watt measurements using a RMS Wattmeter), thermal product energy use measurements (i.e., Btu-thermal - Btu-t, or Joule-thermal - Joule-t) and thermal fuel input energy use (i.e., Btu-f or Joule-f).

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. This can be accomplished at the electrical distribution panel or at the plug with a specially modified extension plug that allows access to individual wires in the branch circuit. Section 5.3.1 of this document discusses this issue in depth.

Thermal product 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 product energy use measurements usually require a volumetric flow rate per unit time (m), a specific heat value (cp) and a temperature difference (delta-T). Steam measurements require a steam flow rate (m), temperature (T) and pressure (P) of the steam, and temperature of the boiler feedwater. Section 5.3.6 of this document discusses this issue in depth.

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.

In general, estimates of energy savings using the Options A approach may be adversely affected by the following factors:

- Measured capacity, stipulated consumption savings estimates may vary if there are changes to the equipment during the course of the retrofit that affect equipment operating efficiency.

- Measured capacity, stipulated consumption savings estimates may vary if operational settings that affect facility system performance are changed after measurements are taken.

- Measured capacity, stipulated consumption savings estimates of chillers will vary if the chiller evaporator or condenser temperature operates at different temperatures than those which occurred during the in-situ tests. Measured capacity, stipulated consumption estimates of chiller retrofits should only be used in cases where the owner and contractor/ESCO accept the uncertainty due to the large variation that occurs in chiller performance, given varying operating conditions.

- Measured capacity, stipulated consumption savings estimates of boilers may vary if the boiler operates at different temperatures, loads or combustion settings than those which occurred during the in-situ tests. Tests will, therefore, need to be conducted over a range of operation to characterize performance. Measured capacity, stipulated consumption estimates for boiler retrofits should only be used in cases where the owner and contractor/ESCO accept the uncertainty due to the large variation that occurs in boiler performance, given varying conditions.

- Measured capacity, stipulated consumption savings estimates of pumps and blowers may vary if the pump or blower operates at different pressure settings, or flow rates than occurred during the in-situ tests. Tests will, therefore, need to be made over a range of operation to characterize the performance.

- Measured capacity, stipulated consumption savings estimates of lighting retrofits may vary if there is a significant number of lamp outages, or if the actual operating schedule varies significantly from the stipulated operating schedule.

- Measured capacity, stipulated consumption savings estimates of air conditioners may vary if the air conditioner operates at different condenser temperatures, or evaporator temperatures than those which occurred during the in-situ tests. Air conditioner efficiency may also be adversely affected by compressor degradation, low/high refrigerant charge, and/or insufficient evaporator or condenser air flow. Measured capacity, stipulated consumption estimates for air conditioner retrofits should only be used in cases where the owner and contractor/ESCO accept the uncertainty due to the large variation that occurs in air conditioner performance, given varying conditions.

All of these operating conditions and should be noted carefully during both the baseline and post-installation periods.

Representative Sample Measurements. Representative sample measurements are measurements that are 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, i.e., by more than plus or minus five percent (+-5%) and must be taken on similar equipment model types. Types of representative sample measurements that may be taken include: electrical energy use measurements (i.e., watt measurements using a RMS Wattmeter), thermal product energy use measurements (i.e., Btu-t or Joule-t) and thermal fuel input energy use (i.e., Btu-f or Joule-f).

Estimates using representative sample measurements and stipulated consumption may be adversely affected by the same factors as Option A: one-time, in-situ measurements as listed previously.

Representative Manufacturer's Measurements. Representative manufacturer's measurements are measurements taken and published by the manufacturer. In order for such measurements to be valid, they should be taken with calibrated instrumentation 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, i.e., by more than plus or minus five percent (+-5%) and must be taken on similar equipment model types. Types of representative sample measurements that may be taken include: electrical energy use measurements (i.e., watt measurements using a RMS Wattmeter), thermal product energy use measurements (i.e., Btu-t or Joule-t) and thermal fuel input energy use (i.e., Btu-f or Joule-f).

Estimates using manufacturer's sample measurements and stipulated consumption may be adversely affected by the same factors as Option A: one-time, in-situ measurements as listed previously.

Representative Baseline Power Level Profiles. 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 from day to day by more than plus or minus ten percent (+-10%).

Examples include: weekday/weekend whole-facility lighting loads 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 weather-dependent day-type profiling can be found in Katipamula and Haberl (1991), Akbari et al. (1988), Hadley and Tomich (1988) and Bou Saada and Haberl (1995a).

These types of measurements include: continuous 15-minute electrical energy use measurements (i.e., watt measurements using a RMS Wattmeter), thermal product energy use measurements (i.e., Btu-t/hr, or kJ-t/h), and thermal fuel input energy use (i.e., Btu-f/h or kJ/h).

In general, estimates of energy savings using Option A: representative baseline power level profiles can be adversely affected by the same factors as Option A: one-time, in-situ measurements as listed previously.

4.1.2 Examples.

Lighting Efficiency and/or Controls Project. Savings resulting from lighting efficiency and/or lighting controls retrofits can be estimated using the Option A approach provided both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies stipulated consumption. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

Lighting projects require the capacity, demand or power level (i.e., kW, Btu/hr or kJ/hr) be measured using one-time, in-situ end use measurements, 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.

Electricity savings, due to reduced lighting energy, are calculated by multiplying the difference between baseline and post-installation measured capacity, by the stipulated consumption or hours of operation. Electric demand reductions can also be analyzed provided representative baseline and post-installation measurements have been taken.

Electricity savings, due to reduced cooling load, are not included in Option A estimates. As well, negative savings, which account for heating increases due to reductions in internal heating load, are not included.

> *Calculating Electricity Savings*. Electricity savings resulting from lighting retrofits can be estimated in the following fashion. First, measure the baseline capacity of the facility's lighting load using one-time, in-situ end use measurements, representative sample measurements, representative manufacturer's measurements, or representative baseline power levels. Second, estimate energy savings by multiplying the difference between baseline and post-installation measurements by the stipulated hours-of-use or hourly profiles. Both the owner and contractor/ESCO should understand that this analysis provides an energy savings estimate which may or may not represent actual energy savings from the lighting project.
>
> *Calculating Electric Demand Reductions*. Electric demand reductions resulting from a lighting retrofit can be estimated in the following fashion. First, develop a baseline demand measurement using the methods previously described. Second, calculate retrofit electric demand savings by comparing baseline demand to measured post-installation demand, where the demand is measured using one-time, in-situ end use measurements, representative sample measurements, representative manufacturer's measurements or representative baseline power levels. Both the owner and contractor/ESCO should

understand that this analysis provides a demand savings estimate which may or may not represent actual demand savings from the lighting project.

Calculating Interactive Cooling Savings. An estimate of interactive cooling savings is not included in the Option A approach. Estimates of interactive cooling savings may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive cooling savings from a particular retrofit.

Calculating Interactive Heating Increases. An estimate of interactive heating increases is not included in the Option A approach. Estimates of interactive heating increases may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive heating increases from a particular retrofit.

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 estimates may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.
- Savings estimates may vary if operating settings that affect facility system performance are changed after measurements are taken.
- 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.
- Savings estimates calculated using the Option A approach do not measure cooling interaction or increases in heating load due to reductions in internal heating caused by improved lighting system efficiency.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Constant Load Motor Replacement Project. Savings resulting from constant load motor replacement projects can be estimated using the Option A approach provided both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies stipulated consumption or hours of operation of the motor. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

Load motor replacement projects require the capacity, demand or power level, i.e., kW, Btu/hr or kJ/hr be measured using one-time, in-situ end use measurements 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.

Electricity savings, due to reduced motor load, are calculated by multiplying the difference between baseline and post-installation measured capacity, by the stipulated consumption or hours of operation. Electric demand reductions can also be analyzed provided representative baseline and post-installation demand measurements have been taken.

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 a reduction in cooling or heating. Savings resulting from reduced cooling or heating load are not included in Option A estimates because only baseline and post-installation motor electrical loads are being multiplied by the run-time.

> *Calculating Electricity Savings*. Electricity savings resulting from a constant load motor replacement can be estimated in the following fashion. First, measure the baseline capacity of the motor(s) to be replaced using one-time, in-situ end use measurements, representative sample measurements, representative manufacturer's measurements or representative baseline power levels. Second, estimate the energy savings by multiplying the difference between baseline and post-installation capacity measurements by the stipulated hours-of-use or hourly profiles. Both the owner and contractor/ESCO should understand that this analysis provides an energy savings estimate which may or may not represent actual energy savings from the constant load motor replacement project.
>
> *Calculating Electric Demand Reductions*. Electric demand reductions resulting from a constant load motor replacement can be estimated by using the same method described for lighting projects in this Section 4.0.
>
> *Calculating Cooling Or Heating Savings*. Estimate of cooling or heating savings due to the downsizing of a motor used to deliver thermal energy is not included in the Option A approach. Cooling or heating savings may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive cooling or heating savings from a particular retrofit.
>
> *Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Option A*. Savings from a constant load motor replacement that are calculated using Option A can be adversely affected by the following:
>
> - Savings estimates may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.
> - Savings estimates may vary if operating settings that affect facility system performance are changed after measurements are taken.
> - Savings estimates 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.
> - Savings estimates using Option A do not measure cooling/heating savings due to downsizing in the pump that may be delivering thermal energy to a facility.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

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 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 the savings estimates. In the worst case, errors of one-hundred to two-hundred percent (100-200%) have been observed.

4.1.4 Expected Cost. Option A costs will generally all between one and five percent (1-5%) of 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.

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

Option B is intended for energy conservation retrofits where the end use capacity, demand or power level can be measured before the retrofit (baseline), and the continuous energy consumption of the equipment or sub-system can be measured after the retrofit (post-installation) for a selected period of 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 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). As with Section 4.1, this section includes information regarding installed equipment performance confirmation and includes examples, expected accuracy and cost information.

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" measurements, whereas Option B involves portable monitoring equipment installed in a facility for a *period of time* 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 a few days before the retrofit 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 B does not include measurement of whole-facility heating or cooling loads which would be necessary to calculate heating-cooling interaction of a lighting retrofit.

Specific tests may need to be performed on the equipment to force it through all possible operating modes while input-output efficiency measurements are being taken. Examples of this type of testing include chiller efficiency tests (Gordon and Ng 1994; Anderson and Breene 1995; Phelan et al. 1995), boiler efficiency tests (CEUE 1995; Dyer and Maples 1981; Dukelow 1991) and tests regarding pumps and fans (Phelan et al. 1996).

4.2.2 Examples.

Lighting Efficiency and/or Controls Project. Savings resulting from efficiency and/or lighting controls projects can be measured using Option B provided both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies estimates made to extrapolate sample measurements, so that one year of lighting consumption is represented. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

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. After the retrofit, the measurements are repeated to develop post-installation 24-hour profiles of lighting system energy consumption. Continuous post-installation measurements can also be taken.

Electricity savings due to reduced lighting energy consumption are calculated by analyzing the difference between measured 24-hour consumption profiles for the baseline period and the post-installation period. Electric demand reductions can also be analyzed provided representative baseline and post-installation demand measurements have been taken.

Electricity savings due to reduced cooling load are not included in Option B estimates. As well, negative savings, which account for increased heating due to reduced internal heating load, are not included.

> *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. 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, in educational facilities there is often a significant difference between school year and summer vacation period loads. In some instances baseline, weekday/weekend profile measurements may be necessary during both school year and summer vacation periods. 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 statistical projections.

Calculating Electric Demand Reductions. Electric demand reductions resulting from a lighting retrofit can be calculated in the following fashion. First, develop an hourly baseline demand measurement profile using the methods previously described. Second, calculate retrofit electric demand savings by comparing baseline demand to measured post-installation demand. Both the owner and contractor/ESCO should understand that this analysis provides an estimate of the demand savings which may or may not represent actual demand savings from the lighting project

Calculating Interactive Cooling Savings. Interactive cooling savings estimates are not included for Option B because whole-facility cooling measurements that correspond to the baseline and post-installation periods are not normally taken. Estimates of interactive cooling savings may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive cooling savings from a particular retrofit.

Calculating Interactive Heating Increases. Interactive heating savings estimates are not included for Option B. Estimates of interactive heating increases may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive heating increases from a particular retrofit.

Limitations Of Calculating Retrofit Savings From Lighting And/Or Lighting Controls Projects Using Option B. Savings resulting from lighting efficiency and/or lighting controls projects that are calculated using Option B can be adversely affected by the following factors:

- Savings calculated using Option B 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.

- Savings estimates may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.

- Savings estimates may vary if operating settings that affect facility system performance are changed after measurements are taken.

- 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.

- Savings estimates calculated using the Option B approach do not measure cooling interaction or increases in heating load due to reductions in internal heating caused by improved lighting system efficiency.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Constant Load Motor Replacement Project. Savings resulting from constant load motor replacement projects can be using the Option B approach provided both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies short-term measurements. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

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 estimated with representative sample measurements (Biesemeyer and Jowett 1994; Phelan 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).

Electricity savings due to reduced motor load are calculated by analyzing the difference between baseline and post-installation measured capacity multiplied by the estimated hours of operation. Electric demand reductions can also be analyzed provided representative baseline and post-installation demand measurements have been taken.

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. Electricity savings resulting from constant load motor replacement can be estimated in the following fashion. 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 the post-installation period. 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 load profiles. Both the owner and contractor/ESCO should understand that this analysis provides an energy savings estimate which may or may not represent actual energy savings from the constant load motor replacement project.

Calculating Electric Demand Reductions. Electric demand reductions resulting from constant load motor replacement can be calculated in the following fashion. 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 the baseline demand to the measured post-installation demand. Both the owner and contractor/ESCO should understand that this analysis provides a demand savings estimate which may or may not represent actual demand savings from the constant load motor replacement project.

Calculating Cooling Or Heating Savings. An estimate of cooling or heating savings due to downsizing a motor delivers thermal energy is not included in Option B. Estimates of cooling or heating savings may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive cooling or heating savings from a particular retrofit.

Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Option B. Savings resulting from a constant load motor retrofit calculated using the Option B approach can be adversely affected by the following:

- 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 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.

- Savings estimates may vary if there are equipment changes during the retrofit that affect equipment operating efficiency.

- Savings estimates may vary if operating settings that affect facility system performance are changed after measurements are taken.

- Savings estimates may vary if there is a change in load being placed on the motor, e.g., there is a significant increase in the pressure drop across the motor due to a valve closure in the piping system.

- Savings estimates calculated using Option B do not measure cooling or heating savings due to downsizing in the pump delivering thermal energy to a facility.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Variable Speed Drive Motor Project. Savings resulting from variable speed drive motor replacement projects can be estimated using the Option B approach provided both the owner and contractor/ESCO are willing to accept the uncertainty that accompanies short-term measurements. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1.

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 estimated with representative sample measurements (Biesemeyer et al. 1993; Phelan et al. 1996). 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. A statistical model can be used to extrapolate this variable electricity use over an entire year.

Electricity savings due to reduced motor load are calculated by analyzing the difference between the motor's measured constant baseline electricity use and either: i) actual measured electricity use in the post-installation period, or ii) electricity use predicted by the statistical model of the post-installation electricity use. Electric demand reductions can also be analyzed provided representative baseline and post-installation demand measurements have been taken.

If the motor(s) being replaced is used to deliver chilled or hot water, downsizing the motor may reduce thermal flows to the facility, which may cause reduced cooling or heating. Savings due to any cooling or heating load reduction are not included in Option B estimates because only measured baseline and post-installation motor electrical loads are used in the calculation.

Calculating Electricity Savings. Electricity savings resulting from variable speed motor replacement can be estimated in the following fashion. First, measure the baseline capacity 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, in the post-installation period, take either continuous measurements or short-term measurements to characterize the variable electricity use (Phelan et al. 1995). In cases where short-term measurements are used, electricity use variability should be analyzed and correlated to a predictor variable (such as ambient temperature), so that an hourly statistical model can be developed to extrapolate variable electricity use for an entire year. 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 5.13 Uncertainty equations for measuring in-situ performance can be found in Phelan et al., 1996.

Calculating 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. Both the owner and contractor/ESCO should understand that this analysis provides a demand savings estimate which may or may not represent actual demand savings from the motor replacement project

Calculating The Cooling Or Heating Savings. Cooling or heating savings estimates due to downsizing a motor used to deliver thermal energy are included in Option B. Estimates of cooling or heating savings may be stipulated as part of the contract, however, both the owner and contractor/ESCO should understand that these estimates may or may not reflect actual interactive cooling or heating savings from a particular retrofit.

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 load motor replacement projects, with the exception of the following:

- 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.

HVAC and/or EMCS Project. Savings resulting from HVAC systems and/or Energy Management Control System (EMCS) projects can be analyzed using Option B 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 (Knebel 1983; Katipamula and Claridge et al. 1991; 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. Such models are capable of determining electricity and thermal savings, as well as 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 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 (Phelan et al. 1996, Balcomb et al 1993 and Liu et. al. 1994). In the post-installation period, either continuous energy use is measured or 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 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.

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

Calculating Cooling Savings. Cooling energy savings can also be calculated if calibrated baseline and post-installation simulation models are used. Cooling savings are estimated by comparing the 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.

Calculating Heating Savings. As with cooling savings calculations, heating energy savings can be calculated if calibrated baseline and post-installation simulation models are used. Heating savings are estimated by comparing post-installation projections of the baseline HVAC heating 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 heating system efficiency, i.e., Btu/lb.-steam or input/output boiler efficiency 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:

- 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 match actual HVAC electricity and thermal consumption over an annual period.

- Estimated savings using Option B may be affected if HVAC system operating characteristics do not complement representative schedules used to drive the models.

- 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.

- Changes in cooling savings 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 overall electricity consumption.

- Changes in heating savings 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.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Chiller Project. Savings resulting from chiller retrofit projects can be estimated using Option B if calibrated baseline and post-installation chiller models are developed (Phelan et al. 1995; Gordon and Ng 1994; Anderson and Breene 1995). Such models are 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, chilled water supply temperatures and condenser temperatures, and comparing the differences predicted.

> *Limitations Of Calculating Retrofit Savings From Chiller Retrofits Using Option B.* Estimated chiller retrofit savings calculated using the Option B approach can be adversely affected by the following factors:
>
> - Savings calculations are intended to be estimates of electricity savings which utilize representative baseline and post-installation, one-time measurements or short-term measurements of installed chiller performance over varying conditions. Therefore, the accuracy of the measurements is completely dependent on how well representative chiller measurements match actual chiller performance over an annual period.
>
> - Estimated savings using Option B may be affected if chiller operating characteristics do not complement the representative schedules used to drive the models.
>
> All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Boiler Project. Boiler retrofit savings can be estimated using Option B 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 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 the annual boiler performance. Retrofit savings are then calculated by comparing the differences between baseline annual boiler performance and post-installation annual boiler performance. Continuous post-installation measurements can also be taken. 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 the following factors:
>
> - Savings calculated using Option B are intended to be estimates of electricity and/or fuel savings which utilize representative baseline and post-installation, one-time measurements or short-term measurements of installed boiler performance over varying conditions. Therefore, the accuracy of the measurements is completely

dependent on how well representative boiler measurements match actual boiler performance over an annual period.

- Estimated savings from Option B may be affected if boiler operating characteristics do not complement the representative schedules used to drive the models.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

4.2.3 Expected Accuracy. As previously stated, retrofit savings calculated using the Option B approach are intended to be estimates of electricity and/or thermal energy savings which utilize representative short-term, baseline measurements and either representative short-term or continuous post-installation measurements of the installed equipment over varying conditions. Measurement accuracy is completely dependent on how well representative one-time measurements and agreed-upon hours-of-operation match actual equipment performance over an annual period.

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 one-hundred to two-hundred (100-200%) have been observed.

4.2.4 Expected Cost. The expected cost of Option B 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 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 (1%) of the cost of the retrofit each year.

The use of continuous post-installation monitoring may help identify O&M problems in a facility. Results from several studies have shown that O&M savings as high as five-to-fifteen percent (5-15%) of annual energy costs can be identified using data from hourly data loggers (Claridge et al. 1994; 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 energy use before the retrofit (baseline), and a continuous measurement of the whole-facility energy use after the retrofit (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., the kWh, Btu or kJ. This section contains information concerning M&V using utility billing data methods, and methods that use hourly whole-facility baseline and post-installation analysis. As with previous Option discussions, this section includes examples, expected accuracy and cost information.

4.3.1 Utility Billing Methods. Utility billing methods calculate the savings from an energy conservation retrofits by establishing a baseline or baseline model using twelve or more months of whole-facility utility billing data. In general, this type of savings calculation procedure is intended for projects where savings are expected to be twenty percent (20%) 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.

Data Requirements. Normally, twelve months or more of monthly baseline data is required to establish baseline energy consumption (Fels 1986). This includes the following information: i) the date of the meter readings, ii) daily average temperature data from a nearby airport (i.e., NWS min/max data), and iii) the amount of energy consumed during the utility billing period (i.e., the period between the current and previous month's reading).

For each billing period, the average temperature should be calculated. The appropriate statistical model is determined by regressing the billed utility data against the average billing period temperature. If several different meters are read on separate days, then a separate analysis will need to be performed on each meter having a unique billing period. The results will then need to be combined after the analysis.

Differences in billing period length can be accounted for by calculating average daily energy use in the billing period, and multiplying by the number of days in the post-installation utility billing period. A small amount of error can occur due to differences between the number of weekdays and weekends in the baseline and post-installation periods, and/or differences in holiday schedules.

Developing A Baseline Energy Use Using An Inverse (Regression) Model. This procedure 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 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). The simplest form of an inverse model is a steady-state inverse model of a facility's energy use. 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 accurate methods use sophisticated 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 point or points at which the model switches from weather-dependent to non-weather-dependent behavior. 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. Examples include the three and five parameter Princeton Scorekeeping Method - PRISM (i.e., where the three parameters include: weather-independent base-level use, change point temperature and a slope of the line fitted to the points above or below the change point) (Fels 1986), and a four parameter model (4P) developed by Ruch and Claridge (1991), i.e., where the four parameters include a change point, a slope above the change point, a slope below the change point and the energy use associated with the change point.

Figure 1 on the following page shows steady-state, single variable models appropriate for commercial facility energy use as follows:

- (a) One-Parameter Model
- (b) Two-Parameter Model Shown For Cooling Energy Use
- (c) Three-Parameter Heating Energy Use Model (Heating)
- (d) Three-Parameter Cooling Energy Use Model (Cooling)
- (e) Four-Parameter Heating Energy Use Model (Heating)
- (f) Four-Parameter Cooling Energy Use Model (Cooling)
- (g) Five-Parameter Heating And Cooling Energy Use Model
  (With Distinct Heating And Cooling Modes)

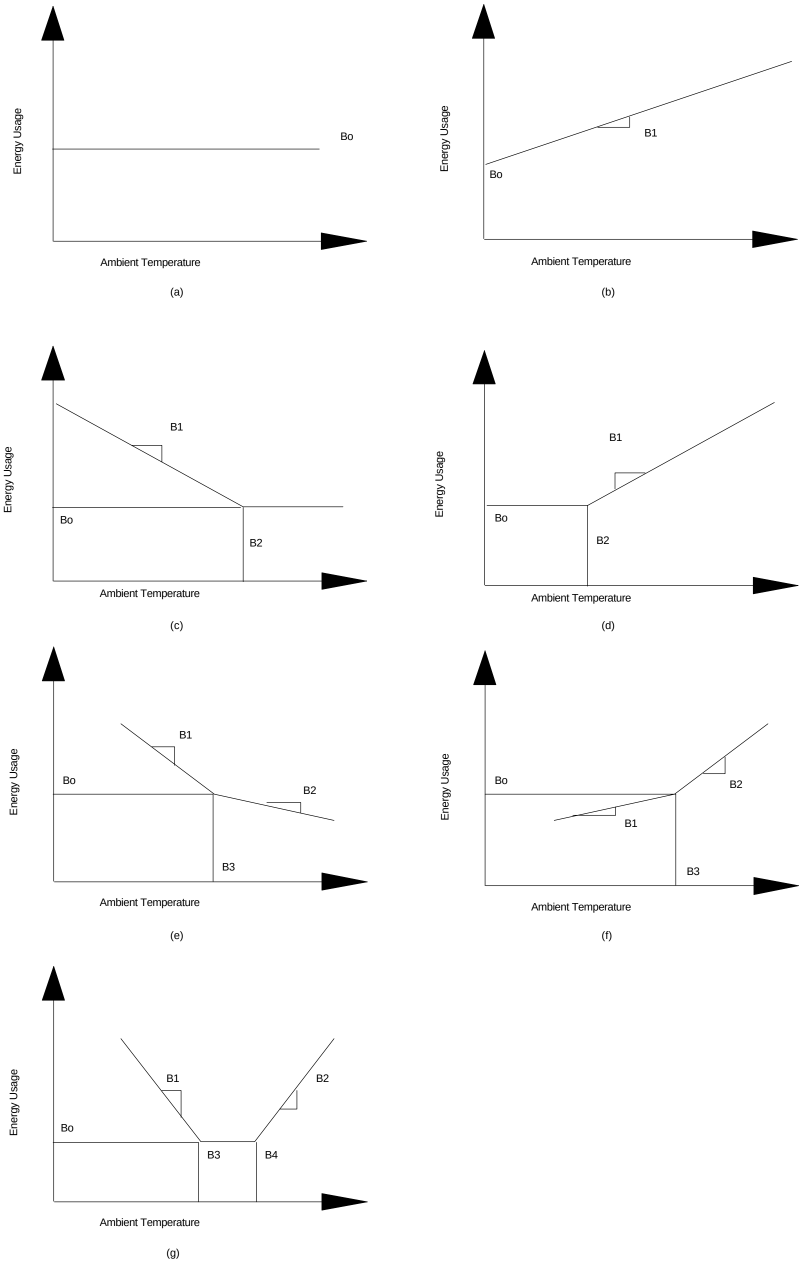

Figure 1 shows several types of steady-state, single variable inverse models. Figure 1.a. shows a simple one-parameter, or constant model, and equation (4.3.1) gives the equivalent notation for calculating the constant energy use using this model. Figure 1.b. shows a steady-state two-parameter model where Bo is the y-axis intercept and B1 is the slope of the regression line for positive values of x, where x represents the ambient air temperature. Figure 1.c. shows a three-parameter, change point model. This is typical of natural gas energy use in a single family residence that utilizes gas for space heating and domestic water heating. In equation (4.3..3), which is given for the three-parameter model, Bo represents the baseline energy use, B1 is the slope of the regression line for values of ambient temperature less than the change point B2. In this type of notation, the exponent (+) indicates that only positive values of the parenthetical expression are considered. Figure 1.d. shows a three-parameter model for cooling energy use, and equation (4.3.4) gives the appropriate expression for analyzing cooling energy use with a three-parameter model.

Figures 1.e. and 1.f. illustrate four parameters for heating and cooling, respectively. Equations (4.3.5) and (4..3.6) indicate the respective expressions for calculating heating (Figure 1.e.) and cooling (Figure 1.f.) energy use using a four-parameter model. In a four-parameter model, Bo represents the baseline energy exactly at the change point B3. B1 and B2 are the lower and upper region regression slopes for ambient air temperature below and above the change point B3.

Equation (4.3.7) gives the expression for calculating a five-parameter model where there are separate change points for heating and cooling energy use as might be expected in an all-electric heat pump facility for cases where the change point B3 < B4. For cases where there is simultaneous heating and cooling, i.e., B3 > B4, the base-level Bo will be artificially high, and sub-metering is recommended to differentiate between heating and cooling.

$$\text{Eperiod} = \text{Bo} \tag{4.3.1}$$

$$\text{Eperiod} = \text{Bo} + \text{B1}(T) \tag{4.3.2}$$

$$\text{Eperiod} = \text{Bo} + \text{B1}(\text{B2} - T)+ \tag{4.3.3}$$

$$\text{Eperiod} = \text{Bo} + \text{B1}(T - \text{B2})+ \tag{4.3.4}$$

$$\text{Eperiod} = \text{Bo} + \text{B1}(\text{B3} - T)+ - \text{B2}(T - \text{B3})+ \tag{4.3.5}$$

$$\text{Eperiod} = \text{Bo} - \text{B1}(\text{B3} - T)+ + \text{B2}(T - \text{B3})+ \tag{4.3.6}$$

$$\text{Eperiod} = \text{Bo} + \text{B1}(\text{B3} - T)+ + \text{B2}(T - \text{B4})+ \tag{4.3.7}$$

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, Rabl and Riahle 1992, Claridge et al. 1994 and Rabl 1988).

Disadvantages of the steady state inverse monthly models include:

- Insensitivity to dynamic effects, e.g., thermal mass.

- Insensitivity to variables other than temperature, e.g., humidity and solar.
- 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 will need to be developed such as hourly or daily models.

Selecting The Best Monthly 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 several regression models and select the best model depending on the match as measured by the R^2, coefficient of variation of the normalized annual consumption, i.e., CV(NAC)), or coefficient of variation of the RMSE.

Additional information concerning these selection procedures can be found in Reynolds and Fels (1986) and Kissock (1994). Public domain 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 1995).

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 1995).

Calculating Energy Savings Using The Baseline Model. Once the appropriate baseline model has been determined for the facility, energy savings are calculated by comparing energy 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 general the following steps are used to calculate the savings:

1. Determine the appropriate baseline or baseline model.
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 the savings by comparing the difference between energy use predicted by the post-installation model and actual energy use. 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

   (Esave,i) = energy savings from the energy conservation retrofit during period (i).

   E(baseline,i) = the baseline or baseline energy use projected into the post-installation period by multiplying the parameters of the baseline model by weather and operating parameters from the post-installation period.

E(post) = 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 the 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 the baseline and post-installation energy use is greater than model error as determined by the RMSE.

Examples Of Projects Analyzed With Monthly Energy Use. The example projects that follow can be analyzed with monthly utility billing data provided that the change in baseline and post-installation energy use is larger than the inherent uncertainty in the statistical model as calculated by the RMSE. For those retrofits where the change in monthly baseline and post-installation consumption is *less* than the uncertainty in the statistical model, alternative methods of measuring the retrofits savings should be considered, i.e., Option B, or baseline and post-installation hourly or daily analysis.

Lighting Efficiency and/or Controls Project. Lighting efficiency and/or lighting control retrofit savings can be analyzed using monthly baseline and post-installation utility billing data 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.

Obtaining utility billing data for twelve 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 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 energy are calculated by analyzing whole-facility electricity use. Electric demand reductions can also be analyzed using monthly utility billing data.

Electricity savings due to reduced cooling load can also be determined through the selection of the appropriate baseline and post-installation modeling strategy if the energy use of the chiller or air-conditioning equipment is considered in the whole-facility utility meter. Negative savings that account for increased heating due to reduced internal heating load can also be determined if the heating system energy use is available for analysis.

> *Calculating Electricity Savings*. Electricity savings resulting from a lighting retrofit can be determined in the following fashion. First, develop a baseline model using the methods previously described. Second, calculate the retrofit electricity savings 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 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.

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

Calculating Electric Demand Reductions. Electric demand reductions from a lighting retrofit can be determined in the following fashion. First, develop a baseline demand model using the 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. Demand savings are determined to be significant if the difference between baseline and post-installation electric demand is greater than model error as determined by the RMSE.

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 relative internal load proportions versus 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 the energy use of the cooling system is available, or ii) the cooling energy use is part of the main meter.

If separate metering data is available for the cooling system, cooling savings 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 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 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. 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.

If cooling energy use is part of the main meter, cooling savings may be combined with the electricity reduction (due to lighting fixture retrofits) in the whole-facility statistical model. A combined electricity and cooling reduction can be determined by developing a baseline model using the 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 is 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. 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.

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 of heating system and the cost of heating fuel. The additional heating energy required can be determined from monthly data if: i) separate metering data for the energy use of the heating system is available, or ii) 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 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. In situations where significant data is missing in the post-installation period, a post-installation model can be created to fill in missing data. The additional energy is then calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model. Additional heating energy requirements are determined to be significant if the difference between baseline and post-installation energy use is greater than the model error as determined by the RMSE.

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 statistical model. An evaluation of reduced lighting electricity and increased heating electricity can be determined by developing a baseline model using the 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. In situations where significant data is missing in the post-installation period, a post-installation model can be created to fill in missing data. The electricity plus additional heating energy are then calculated by comparing the energy use predicted by the baseline model to the energy use predicted by the post-installation model. Combined 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 Lighting And/Or Lighting Controls Projects Using Monthly Utility Billing Data. Lighting efficiency and/or lighting controls project savings calculated using the Option C approach should be greater than the uncertainty as calculated by the RMSE. These savings can be adversely affected by the following factors:

- Savings in the whole-facility electricity consumption can be affected by changes in electric receptacle loads.

- Savings in the whole-facility demand can be affected by additions or subtractions of major electric consuming sub-systems.

- Changes in the whole-facility interactive cooling savings 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 overall electricity consumption.

- Changes in whole-facility interactive heating savings 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.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Constant Load Motor Replacement Projects. Constant load motor replacement project savings can be analyzed using Option C 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. In particular, 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, 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 twelve 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. Constant load motor project electricity savings can be determined in the following fashion. First, develop a baseline model using the 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 RMSE.

Calculating Electric Demand Reductions. Electric demand reductions from a constant load motor retrofit can be determined in the following fashion. First, develop a baseline demand model using the 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. 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 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:

- 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 change.

- Savings in electric demand can be affected by additions or subtractions of major electric consuming sub-systems.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

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

HVAC and/or EMCS Project. HVAC system and/or EMCS savings can be analyzed using the Option C approach 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. Obtaining utility billing data for twelve 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 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. Electricity savings from an HVAC or EMCS retrofit can be determined in the following fashion. First, develop a baseline model using the methods previously described. Second, calculate post-installation electricity savings by comparing 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.

Calculating Electric Demand Reductions. Electric demand reductions from an HVAC or EMCS retrofit can be determined in the following fashion. First, develop a baseline demand model using the methods previously described. Second, calculate the post-installation electric demand savings by comparing the monthly demand predicted by the baseline model to measured post-installation demand data. Demand savings are determined to be significant if the difference between baseline and post-installation electric demand is greater than model error as determined by the RMSE.

Calculating The Cooling Savings. In most HVAC or EMCS projects there may be significant reductions in the energy required to cool the space due to improved HVAC system efficiency. The amount of cooling savings may vary by facility depending on the relative proportions of internal loads versus 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 energy savings from an HVAC retrofit can be determined from monthly data if: i) separate metering data for the energy use of the cooling system is available, or ii) the 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.

Calculating Heating Savings. In HVAC or EMCS retrofits there may also be significant reductions in the energy required to heat the space due to improved HVAC system efficiency. The amount of heating savings will vary by facility depending on the relative proportions of internal loads versus the envelope loads, the type of heating system, etc. Heating energy savings from an HVAC retrofit can be determined from monthly data if: i) separate metering data for the energy use of the heating system is available, or ii) the heating energy use is part of the main meter.

In either case, heating reductions can be determined by developing a baseline heating model using the methods previously described. Heating energy savings are calculated by comparing the energy 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:

- In facilities where simultaneous heating/cooling occurs during a significant portion of the year, savings due to HVAC system modifications may require hourly baseline and post-installation measurements or in-situ efficiency measurements of the HVAC system.

- Savings in whole-facility electricity consumption can be affected by changes in the electric receptacle loads.

- Savings in whole-facility demand can be affected by additions or subtractions of major electric consuming sub-systems.

- Changes in whole-facility cooling savings can be affected by procedures used to operate the cooling systems.

- Changes in whole-facility heating 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.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Chiller Project. Chiller project savings can be analyzed using monthly baseline and post-installation utility billing data provided the savings are greater than the uncertainty of the regression model, and that chiller operating conditions have remained the same. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1. In particular, 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).

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 Section 4.2. Hourly baseline and post-installation measurements can 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 twelve 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. Electricity savings from a chiller retrofit that has constant baseline and post-installation loading profiles and operating temperatures can be determined in the following fashion. First, develop a baseline model using the 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 RMSE.

Calculating Electric Demand Reductions. Electric demand reductions from a chiller retrofit can be determined in the following fashion. First, develop a baseline demand model using the methods previously described. Second, calculate the post-installation electric demand savings by comparing the monthly demand predicted by the baseline model to measured post-installation demand data. Demand savings are determined to be significant if the difference between baseline and post-installation electric demand is greater than model error as determined by the RMSE.

Limitations Of Calculating Savings From A Chiller Retrofit Using Utility Billing Data. In most 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.

Even in such cases where all of these variables have been held constant, savings from a chiller retrofit project can be adversely affected by the following:

- 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.

- Savings in electricity consumption can be affected if the baseline and post-installation loading on the chiller is 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 fifty percent (50%).

- Savings in electricity consumption can also be affected by flow rates through the evaporator and/or condenser.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Boiler Project. Savings resulting from upgrades to or replacements of large boilers can be analyzed with monthly baseline and post-installation utility billing data provided the savings are greater than the uncertainty of the regression model, and that the baseline and post-installation conditions under which the boiler operates has remained the same. Existing baseline conditions should be documented according to the procedures outlined in Section 4.0.1. In particular, 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 Section 4.2. Hourly baseline and post-installation measurements can be used for such retrofits if the loading and temperature have remained relatively constant, and if the boiler fuel input and thermal output are being measured.

For boiler replacement projects that have constant baseline and post-installation loading conditions and operating temperatures, obtaining utility billing data for twelve 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. Energy savings from a boiler retrofit that has constant baseline and post-installation loading profiles and operating temperatures can be determined in the following fashion. First, develop a baseline model using the methods previously described. Second, calculate the retrofit energy savings by comparing the energy 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.

Calculating Electric Demand Reductions. Electric demand reductions from an electric boiler retrofit can be determined in the following fashion. First, develop a baseline demand model using the methods previously described. Second, calculate the post-installation electric demand savings by comparing the monthly demand predicted by the baseline model to measured post-installation demand data. 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 RMSE.

Limitations Of Calculating Savings From A Boiler Retrofit Using Utility Billing Data. Boiler retrofit savings calculations can be adversely affected by the following:

- 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.

- Savings in energy consumption can be affected if the baseline and post-installation loading on the boiler is substantially different. This can be a significant problem if the new boiler is oversized and must operate under on/off cycling conditions.

- 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.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

4.3.2 Whole-Facility Or Main Meter Hourly Before/After Analysis. 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.

The equipment, where feasible, should also be installed to minimize noise 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 receptacle loads so that changes can be noted and adjustments made should there be significant change in the 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 as the local utility to bill the owner. Such meters must be equipped or modified to provide a digital pulse (or in some cases a 4-20 mA signal) 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. In some instances, such equipment may provide a 4-20 mA signal that can be recorded as an accumulated analog signal by the monitoring equipment.

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 intervals. Such data will need to be converted to interval data before it is useful for energy savings calculations (Claridge et al. 1993). In almost all cases, 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.

In most cases, hourly measurements are adequate to characterize energy and demand profiles of the equipment to be retrofitted. However, where savings changes to the electric demand plays an important factor in energy savings calculations, 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 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. In most cases 15-minute clock measurements will suffice for sliding 15-minute data. 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. 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 usually 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 (Haberl et al. 1995). Other data required includes average hourly dry bulb temperatures and humidity data. This data can be recorded on site or obtained from a nearby National Weather Service weather 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, significantly more data scatter makes the fit of the regression line less accurate (Katipamula et al. 1994). Reasons for scatter in hourly data include:

- on/off switching of HVAC systems
- schedule variations
- dynamic effects of thermal mass, etc.
- solar effects
- latent cooling loads due to dehumidification of moist air during the cooling season

In many facilities, scatter in the data can be reduced without losing significant accuracy by aggregating the data to the daily level prior to analysis.

In daily data a fair amount of this 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 the weekday and weekend (or holiday) mode, depending on the day of the week. Such daily models have been shown to be capable of accounting for ninety to ninety-five percent (90-95%) of the variation in a facility's weather-dependent energy use (Reddy 1994). Appropriate models for the analysis of daily energy use include 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, i.e., 8,760 data points for an hourly model of a facility's energy use versus 365 data points for a daily model, or twelve data points for a monthly model. 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, and more advanced models such as neural network models (Kreider and Haberl 1994).

Selecting The Best Hourly Or Daily Regression Model. The best hourly or daily regression model is selected in the same fashion as the monthly models. Several regression models are calculated, and the best model is selected based on the best match as measured by the R^2, coefficient of variation of the normalized annual consumption, i.e., CV(NAC)), or coefficient of variation of the RMSE.

Lighting Efficiency and/or Controls Project. Savings from lighting efficiency and/or lighting controls 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.

Hourly measurements for at least twelve 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 adequately 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 demand for a given month to the demand for 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 (i.e., negative savings) to make up for internal heating reductions caused by lighting retrofits.

Calculating Electricity Savings. The analysis method used to determine 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, in most situations this is not 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, electric slab heaters (for ice melting on sidewalks), etc. Assuming such channels can be monitored, a proxy lighting channel can be created by subtracting the sum of the motor control center (plus cooling and heating loads), from the whole-facility electric as indicated in equation 4.3.9.

E(lights, proxy) =
E(whole-facility) -
[E(motor control center)+
E(chiller)+
E(boiler) +
E(other, non-lighting)]..(4.3.9)

where

E(lights, proxy) = the hourly (or 15-minute) electricity use of the derived lights and receptacles load.
E(whole-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-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 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 is 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 RMSE.

In cases where only whole-facility electricity is available on a 15-minute or hourly basis, savings can be calculated if at least twelve months of data is 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 (Bou Saada and Haberl 1995b; Akbari, et al. 1988). 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. Savings are determined to be significant if the difference between baseline and post-installation profiles is greater than model error as determined by RMSE.

Calculating Electric Demand Reductions. If end use lighting loads are being monitored or if proxy lighting loads, i.e., lights and receptacles, are being measured, 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 Cooling Savings. Interactive cooling savings can be measured using hourly data if the chillers (or large cooling equipment) are being measured directly, or statistically if only whole-facility electric data is available, which includes heating, cooling and all other electrical uses.

If separate metering data is available for the cooling system, 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 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 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. Savings are determined to be significant if the difference between baseline and post-installation energy use is greater than model error as calculated by the RMSE.

If cooling energy use is part of the main meter, cooling savings will be combined with electricity reduction (due to lighting fixture retrofits) in the whole-facility statistical model. Combined electricity and cooling reductions can be determined by developing a baseline model using the methods previously described. Electricity plus cooling savings are calculated 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. 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. 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.

Calculating Interactive Heating Savings. The interactive increase in heating use can be measured using hourly data if heating equipment is being measured directly, or statistically if only whole-facility electric data is available that includes: heating, cooling and all other electrical uses.

If separate metering data is available for the heating system, heating reductions can be determined by developing a baseline heating model using the methods previously described. Additional heating energy is calculated by comparing the energy use predicted by the baseline energy use (projected into the post-installation period by multiplying by post-installation weather and operating conditions) to measured post-installation data. The additional energy is then calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model. Additional heating energy is determined to be significant if the difference between baseline and post-installation energy use is greater than model error as determined by the RMSE.

If 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 statistical model. An evaluation of reduced lighting electricity and increased heating electricity can be determined by developing a baseline model using the 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. Electricity plus additional heating energy is calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model. Combined 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 Lighting And/Or Lighting Controls Projects Using Hourly Whole-facility, Before/After Data. Savings from lighting efficiency and/or lighting controls projects that are 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:

- Savings measured with end use lighting measurements are most accurate. However, such savings can be affected by lighting fixture outages and/or changes in lighting system operational patterns.

- Savings that utilize proxy lighting measurements can also be highly accurate. However, such savings can be affected by lighting fixture outages and/or changes in operational patterns. In addition, such savings can be affected by significant additions to the plug (or receptacle loads), since such loads are typically combined with lighting loads.

- Changes in hourly whole-facility interactive cooling savings can 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 overall electricity consumption.

- Changes in the hourly whole-facility interactive heating savings may be affected by heating system operating procedures. Boilers or furnaces run at low loads can cycle excessively, which decreases fuel conversion efficiency.

All of the above operating conditions should be noted carefully during both the baseline and post-retrofit periods.

Constant Load Motor Replacement Project. Constant load motor replacement project savings 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.

Hourly measurements should be obtained for several months to adequately characterize baseline motor performance. In some cases, twelve months of data may be needed to adequately characterize performance if the facility has several occupancy schedules throughout the year. 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 the demand for that 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 the 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 following fashion. First, develop a baseline model using the methods previously described for each of the channels being monitored. Second, calculate retrofit electricity savings by comparing electricity use predicted by the 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 is missing in the post-installation period, a post-installation model can be created to fill in missing data. Electricity savings are calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model.

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.

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.

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

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 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 heating/cooling system, heating/cooling reductions can be determined by developing a baseline model using the methods previously described.

Limitations Of Calculating Retrofit Savings From Constant Load Motor Retrofits Using Hourly Before/After Data. Constant load motor retrofit savings using utility billing data can be adversely affected by the following:

- Savings calculated using whole-facility hourly data can be 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.

The above operation condition should be noted carefully during both the baseline and post-installation periods.

Variable Speed Drive Motor Project. Savings resulting from the replacement of a constant speed motor drive with a variable speed motor drive can be analyzed with 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.

Hourly measurements should be taken for several months to adequately characterize baseline motor performance. In some cases, twelve months of data may be needed to adequately characterize performance if the facility has several occupancy schedules throughout the year. If electricity savings and electric demand are being evaluated, a separate demand analysis should be performed that compares demand for a given month with the demand for that same month in the year prior to the retrofit. Total measured energy savings should include end use electricity savings from the reduced motor load where possible.

In 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 variable speed motor drive is the same method used to calculate a constant speed motor retrofit using hourly data. 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.

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.

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

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 Constant Load Motor Retrofits Using Hourly Before/After Data. Savings from a constant load motor retrofit using utility billing data can be adversely affected by the following:

- Savings calculated using whole-facility hourly data can be 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 variable speed motor drive electricity use to check for power factor changes and adverse harmonics caused by an improperly installed variable speed drive.

All of the above operating conditions should be noted carefully during both the baseline and post-installation periods.

HVAC and/or EMS Project. Savings from HVAC and/or EMCS retrofits 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.

Hourly measurements should be taken for at least twelve 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 adequately reflects all normal environmental and schedule conditions. 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 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 analysis method used to determine electricity savings from HVAC and EMCS retrofits 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 most facilities, electricity savings from HVAC and EMCS retrofits can be adequately monitored 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- HVAC" such as exterior security lighting, exterior electric slab heaters (for ice melting on sidewalks, etc.). Assuming such channels can be monitored, models for electricity, cooling and heating savings can be created.

Once these measurements have been obtained, electricity savings from HVAC or EMCS retrofits can be determined in the following fashion. First, develop a baseline model for electricity savings using measurements from the motor control center. Second, calculate the retrofit 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 is missing in the post-installation period, a post-installation model can be created to fill in missing data. Electricity savings are calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model.

In cases where only whole-facility electricity data is available on a 15-minute or hourly basis, savings can be calculated if at least twelve months of data is 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 and calibrated simulations.

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

Demand savings can also be calculated from whole-facility measurements. However, caution should be taken to verify that reductions are caused by the HVAC or EMCS retrofit, not from an unknown cause.

Calculating Heating and Cooling Savings. Heating and cooling savings can be measured using hourly data if heating and/or cooling equipment is being measured directly, or statistically if only whole-facility electric data is available.

If separate metering data is available for heating/cooling systems, heating/cooling reductions can be determined by developing a baseline model using the methods previously described. Heating/cooling energy savings are calculated by comparing energy 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 is missing in the post-installation period, a post-installation model can be created to fill in missing data. Energy savings are calculated by comparing 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 RMSE.

If heating/cooling energy use is part of the main meter, savings will be combined with other electricity reductions (due to reductions in motor loads) in the whole-facility model. A combined electricity and heating/cooling reduction can be determined by developing a baseline model using the methods previously described. Electricity plus heating/cooling savings are then calculated 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. Electricity plus heating/cooling energy savings are calculated by comparing 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 RMSE.

Limitations Of Calculating Retrofit Savings From HVAC Or EMCS Projects Using Hourly Whole-facility, Before/After Data. Savings resulting from HVAC or EMCS retrofits calculated with hourly whole-facility, 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:

- Savings measured with end use measurements are the most accurate. However, such savings can be affected by changes to the operational parameters of the HVAC or EMCS.

- 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, and boilers or furnaces run at low loads can cycle excessively, which decreases fuel conversion efficiency.

All of the above operating conditions should be noted carefully during both the baseline and post-installation periods.

Chiller Project. Savings resulting from chiller replacements can be analyzed with 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 procedures outlined in Section 4.0.1.

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 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 which involves a calibrated thermodynamic model of the chiller similar to that described by Gordon and Ng (1994) and Anderson and Breene (1995). Such a 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, thermal output, chilled water supply temperature and condenser water return temperature.

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 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 electric measurements need be obtained.

Once such measurements have been obtained, electricity savings from the chiller retrofit can be determined by developing a baseline chiller model and 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 is missing in the post-installation period, a post-installation model can be created to fill in missing data. Electricity savings are calculated by comparing energy use predicted by the baseline model to energy use predicted by the post-installation model.

In cases where only whole-facility electricity data is available on a 15-minute or hourly basis (and baseline and post-installation chiller temperatures and loading conditions are constant) savings can be calculated if at least twelve months of data is available, and the data can be statistically separated into heating, cooling and non-heating/non-cooling season data. Several methods have been developed for accomplishing this separation including weather day-types and calibrated simulations.

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

Demand savings can also be calculated from whole-facility measurements. 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. Savings resulting from chiller retrofits that are calculated with hourly whole-facility, 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:

- Savings measured with 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, etc.

- Savings measured with electricity measurements only can also be affected by changes to the facility cooling load such as changes to the facility envelope and/or changes to interior lighting loads, etc.

- Savings measured with chiller thermal and electric measurements can be adversely affected by chilled water supply temperature, condenser water return temperature and other changes to operational settings that affect chiller efficiency.

All of the above operating conditions should be noted carefully noted during both the baseline and post-installation periods.

Boiler Project. Savings resulting from boiler replacements can be analyzed with 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.

During the previous heating season, hourly measurements should be taken to adequately characterize heating season 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, etc. If electric demand savings are being evaluated, a separate demand analysis will need to be performed that 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 boiler retrofit should include electricity and thermal savings resulting from boiler replacement, as well as associated loads such as pumps, etc. that accompany the new boiler package.

Calculating Energy Savings. In a similar fashion to chillers, boiler efficiency is affected by boiler loads, 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 the 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. 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, forecasting baseline use into the post-installation period and comparing post-installation baseline use to measured post-installation data.

For cases where the post-installation boiler load is different than the baseline boiler load, fuel input and thermal output should be measured so that a baseline input/output model can be developed. Be sure to note baseline operating conditions affecting boiler operation. This baseline input/output model can then be forecast into the post-installation period. Ultimately, savings can be determined by comparing energy use forecasted by the baseline input/output model to post-installation energy use. In situations where significant data is missing in the post-installation period, a post-installation model can be created to fill in missing data.

In cases where only whole-facility energy use is available on a 15-minute or hourly basis, and baseline and post-installation boiler conditions are constant, savings can be calculated if at least twelve months of data is available, and the data can be statistically separated into heating, cooling and non-heating/non-cooling season data. Several methods have been developed for accomplishing this separation including weather day-types and calibrated simulations.

Calculating Electric Demand Reductions. If end use loads are being monitored, 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 baseline and post-installation maximum values for the appropriate demand interval. Several calculations may be required for more complex utility rate structures which include on-peak, off-peak, summer and/or winter electric demand rates.

Demand savings can also be calculated from whole-facility measurements. However, be sure that the reductions could only have been caused by the boiler retrofit, not by an unknown cause.

Limitations Of Calculating Retrofit Savings From Boiler Retrofits Using Hourly Whole-facility, Before/After Data. Savings resulting from boiler retrofits 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:

- Savings calculated with whole-facility measurements only can be adversely affected by boiler loading, boiler supply temperature, combustion settings and other changes to operational settings affecting boiler efficiency. Savings calculated with boiler thermal and fuel input measurements can be adversely affected by boiler operating settings.

The above operating condition should be noted carefully during both the baseline and post-installation periods.

4.3.3 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.

4.3.4 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 percent (1%) 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 secod 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. For most applications, whole-facility data loggers can be installed for the first year for five percent (5%) of the retrofit cost. Recording and reporting during the second and subsequent years should cost approximately one percent (1%) of the cost of the retrofit each year.

SECTION 5.0: OTHER M&V ISSUES

5.1 REPORTING FORMAT AND INVOICING

Reporting is an inherent 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.

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 both parties agreeing on 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, indepdent of the ESCO. The level of involvement of the M&V professional depends on the amount of information necessary to determine contract value.

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 substantiate 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 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 information is derived from two types of measurements: current and voltage. Numerous manufacturers have developed equipment to gather one or both of these types of measurements. Indiscriminate selection or use of voltmeters and ammeters 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," which is defined as "the ratio of the active power to the apparent power." Often this error occurs because it was assumed that the electrical load possessed a sinusoidal waveform, when in fact, the waveform was distorted due to the presence of harmonics.

The Nuances of Power Measurement. *Energy* is not the same as *power*. Power is an instantaneous quantity. Energy includes a time function, i.e., the length of time the power has been applied. Utility companies often bill customers based on "demand," which is defined as "the average value of power over a specified interval of time (typically fifteen minutes).” 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 termed "real power" or "actual power" and is the basis upon which utilities invoice their customers. Utility revenue meters record whole-facility watt-hours from voltage and current sensors, which is the measurement that forms the basis for energy savings calculations. However, watt-hour information is not usually available for specific end uses. Therefore, it is often impossible to determine project-specific energy savings without additional metered data. Obtaining that data should follow the accepted engineering practices discussed in this section.

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 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 forty percent (40%). Wattmeters on chiller equipment typically read much lower power levels than individual current and voltage measurements due to lower power factors associated with partially loaded chillers.

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. Stand-alone watt-hour transducers are available to produce pulses representative of some number of watt-hours. These pulses are typically input to a pulse-counting data logger for storage and subsequent retrieval and analysis.

An alternate technology involves combining metering and data logging functions into a single piece of hardware. This integrated metering approach incorporates virtual digital watt-hour meters into a single solid-state device capable of monitoring eight to thirty-two single-phase power channels. Whereas pulse-counting technology makes kW and kWh information available to the user, the integrated approach allows access to much more information. In addition to kW and kWh, each defined power channel can record voltage, current, apparent power in kVA, kVAh and power factor. Many integrated meter/monitors have the ability to perform waveform analysis, capturing harmonic information for both voltage and current waveforms.

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, un-interruptable power supplies and variable speed motor drives, nonlinear waveforms are more the norm. When 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. 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.

5.3.2 Measurement Of Runtime. Measurement and verification 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.” Constant load motors and lights are examples of equipment that need not be 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.

5.3.3 Measurement Of Temperature. 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: i) resistance temperature detectors (RTDs), ii) thermoelectric sensors (thermocouples), iii) semiconductor-type resistance thermometers (thermistors), and iv) junction semiconductor devices which are also called integrated circuit temperature (IC) sensors.

Resistance Temperature Detectors (RTDs). The most common method of measuring 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 the 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. 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 straight forward 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. 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 the temperature difference. The most commonly used thermocouple materials are: i) platinum-rodium (Type S or R), ii) chromel-alumel (Type K), iii) copper-constantan (Type T), and iv) 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 very large negative resistance change with temperature. Thermistors are not interchangeable, and their temperature-resistance relationship is very 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, dewpoint 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 rather measure the effect of moisture using an indirect measurement. Relative humidity measurements (indirect) include:

- 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.

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 that 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 the returning liquid condensate than to measure the live steam as it enters the facility.

Choosing a flow meter for a particular application requires a knowledge of what type of fluid is being measured, how dirty or clean that fluid is, what the lowest expected flow velocities for that fluid are and what type of budget one has available. This section discusses the most common liquid flow measurement devices that are used 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: i) differential pressure flow meters (e.g., orifice plate meter, venturi meter, pitot tube meter), ii) obstruction flow meters (e.g., variable-area meter, positive displacement meter, turbine meter, tangential paddlewheel meter, target meter, vortex meter), iii) non-interfering meters (e.g., ultrasonic meter, magnetic meter), and iv) 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 turbine meters and vortex meters. There is interest in non-interfering metering technology to defray the costs of shutting down pumps and cutting pipe. Each of these technologies will be addressed in this section.

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 times without the severe pressure-loss penalty that is incurred with a orifice plate or venturi meters. In general these meters place a much smaller target, weight or spinning wheel in the flow stream that then allows the velocity of the fluid to be determined by the force on the meter body (target or variable area meter), and 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 the existing pipe as the meter body. Because the insertion turbine meter only measures the 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 above 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.

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 good 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 of the previously mentioned meters, some interference with the flow stream was necessary to extract a measurement. Recently, a relatively 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 from one percent (1%) of actual flow to two percent (2%) of full scale are now possible, although this technology is still quite expensive. Recently, an ultrasound meter that uses the Doppler principle in place of transit time has been developed. In such a meter a certain amount of particles and air are necessary in order for the signal to bounce-off and be detected by the receiver. Doppler-effect meters are available with an accuracy between two and five percent (2-5%) of full scale and command prices somewhat less than the standard transit time-effect ultrasonic devices. Meter cost is independent of pipe size.

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 the facility chillers is recorded in Btu and is a calculated value determined by measuring the 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 inputs from a previously described flow meter and temperature sensors. These electronic Btu meters offer an accuracy better than one percent (1%). They are most attractive on larger or more critical installations where accuracy is a prime concern. A side 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^{o}F to 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 the 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 the specified maintenance of the Energy Conservation Measures will be performed. Independent of whether the maintenance is performed by the vendor, the purchaser or another party, the contract measurement and verification plan should include the procedure by which the implementation of the maintenance plan is verified.

5.5 SPECIAL NOTES ON NEW CONSTRUCTION

New construction by definition will not have pre-retrofit information for use in calculating energy savings. Therefore, it will be necessary for both parties to agree on how the baseline energy usage will be determined. Many contracts use the Minimum Energy Standards that are in effect for the jurisdiction where the project is to be constructed. Energy savings are calculated as the difference between the "minimum standard energy performance" and the actual performance.

5.6 MINIMUM ENERGY STANDARDS (FEDERAL, STATE AND LOCAL)

One of the difficulties in determining energy savings is defining at what level the baseline energy use should be established. Many facilities where retrofits are considered have equipment that does not meet current standards for energy efficiency. Agreement must be made between the contracting parties as to whether the baseline will be established at the actual performance level of the existing equipment or whether to ignore actual conditions and use the current standard as the baseline.

5.7 DEALING WITH DATA COLLECTION ERRORS AND LOST DATA

No data collection is without error. Methodologies for data collection differ in degrees of difficulty and therefore in the amount of data that is either in error or missing. 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 responsible party who fails to collect the minimum data requirement. Higher levels of data accuracy may have a dramatic affect on the cost of verification and should be decided as part of the overall project economics. The second concept is the methodology by which data that is missing or determined to be incorrect will be interpolated for final analysis.

5.8 COMMISSIONING PROJECTS

Project commissioning is not only preferable, but highly recommended for performance dependent projects. ASHRAE Standard 1-89, Guideline for Commissioning of HVAC Systems, should be consulted for recommendations concerning HVAC commissioning procedures. The properly chosen M&V option should reinforce the total commissioning process.

The commissioning process itself may be divided into pre-design, design, construction, acceptance, and post-acceptance phases. 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 monitoring and verification activities to proceed, possibly beyond the performance contract limit. In such cases, a qualified commissioning agent might act as the M&V agent as well. This would have three-fold benefit since it would:

1. allow for monitoring under the chosen M&V option,
2. give independent party verification of the monitoring results, and
3. allow long-term monitoring of persistence of savings extending for the useful life of a project.

5.9 INTERACTIVE EFFECTS BETWEEN MEASURES

Information not included in this version 1.0.; deferred until next version of the M&V protocol.

5.10 DISPUTE RESOLUTION

Information not included in this Version 1.0.; deferred until next version of the M&V protocol.

5.11 SPECIAL NOTES ON RESIDENTIAL PROJECTS

All three paths are applicable to residential projects, however there are some practical considerations and limitations to be aware of. The choice of an M&V protocol will be strongly influenced by the type of residence and the type of purchaser, in addition to the retrofit technology. Projects can be grouped into three categories:

1. a large multifamily facility or complex (above about 20 to 40 units),
2. an individual residence or a small multifamily facility, and
3. a large number of individual residences.

Large multifamily facilities or complexes can be treated in much the same manner as commercial facilities. It is, however, crucial 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, always on (hallways and other common areas), and unknown (private areas). Unitary HVAC equipment is more common in residential and small commercial facilities, so the M&V plan may also need to recognize that case. 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.

For individual residences, performance contracting is rare and Option A M&V is generally the only feasible path. The submetering of loads required by Option B is usually far too costly. In addition, many of the retrofit measures affect more than one energy using piece of equipment, such as insulation lowering both heating and cooling requirements. Application of either Option B or C to a single residence is also not accurate due to the high variability is energy use patterns over time for any individual home. In Option A, verification of installation and potential to perform is generally by nameplate only, without spot measurement. Stipulated values for hours use are usually gross averages, sometimes reflecting regional values.

A large number of individual residences can receive efficiency improvements under a performance contract between an ESCO and a utility or a government entity. Occasionally, a utility acts as an ESCO under an agreement with its regulator's 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 one hundred homes. All three Options can be applicable to this type program, with Option C being highly preferable for most situations.

The stipulated values in Option A are often based on prior research using Options B or C. Option B is expensive for individual residences, relative to the value of the saved energy, but with a large group of homes, sampling can be used. With a carefully stratified sample, as few as forty points can yield 90% confidence of ten percent (10%) accuracy, while two hundred points can achieve ninety-five percent (95%) confidence of five percent (5%) accuracy. Metering techniques are derived from those used by utilities for appliance load research. The Electric Power Research Institute has a large body of literature on the topic.

Option C is the preferred method to measure the energy savings from a large scale residential program. Often the conservation effort is a "whole house" retrofit, including heating, cooling, water heating and lighting improvements, so 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 production computer programs are usually needed to process the data. 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 multifamily homes, the preferred analysis tool is the Princeton Scorekeeping Method (PRISM). PRISM is an automated process that develops pre and post retrofit 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 is 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 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. (The definitive reference on PRISM is the special issue of Energy and Facilities edited by Margaret F. Fels - Volume 9, Numbers 1 & 2, February/May 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 can not readily model physical reality and is difficult to reduce to contractual language.

5.12 CALIBRATION OF INSTRUMENTATION

For the highest quality measurements it is recommended that the calibration procedures developed by the National Institute of Standards and Technology (NIST) be used. A list of calibration procedures is provided in the references and includes: Baker and Hurley (1984), Benedict (1984), Bevington and Robinson (1992), Bryant and O'Neal (1992), Cortina (1988), Doebelin (1990), EEI (1981), Haberl et al. (1992), Harding (1982), Huang (1991), Hyland and Hurley (1983), Hurley and Schooley (1984), Hurley (1985), ISA (1976), Kulwicki (1991), Lee (1988), Leider (1990), Miller (1989), Morrissey (1990), O'Neal et al. (1990), Ramboz and McAuliff (1983), Robinson et al. (1992), Ross (1990), Taylor (1981), Wiesman (1989), Wise and Soulen (1986), Wise (1976).

5.13 CALCULATING UNCERTAINTY

The issue of uncertainty effects the degree of confidence one has in the calculation of energy savings. In the most simple cases, a continuously running constant load can be measured (per Section 5.3.1) before and after an energy retrofit and the savings calculated directly. Uncertainty becomes an issue when multiple loads are sampled and the total load derived from the sample data. How certain can one be that the sample truly represents the load characteristics of the whole (the population)? The largest concerns of uncertainty occur when one develops a regression equation to represent the population load characteristics. Load data is obtained upon which a regression equation is constructed. How certain that equation represents the actual load is a great concern to all involved. Inaccuracies in the load data (from a poor instrumentation plan design or inaccuracies in load measuring equipment) can lead to uncertainties in the ability of the equation to predict true loads. A poorly constructed regression equation can provide uncertain information.

The three statistical indices 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 (which was arbitrarily assigned as 1 for all models).

The regression equation is used in the calculation of energy savings. 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. The regression equations must be sensitive to runtimes, indoor and outdoor temperatures and humidity, chilled water temperatures and possibly thermal loads removed (or added) to the system. Uncertainties in obtaining the base data upon which equation is developed or in the structure of the equation will lead to unfounded projections of savings. 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 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 effect energy use. A poorly designed metering and instrumentation plan can result in poor quality inputs to build regression equations. Equations so constructed will be poor predictors of energy consumption.

5.13.1 Effect Of Short Pre-Retrofit Data Sets. 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 also in the different operating modes of the facility and of the HVAC system. However, in many cases a full year of data are not available and one is constrained to develop models 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 were compared to the 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% 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% to 3.0% and the average annual heating prediction error decreased from 27.5% to 12.9% as the length of data sets increased from one month 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 and vice-versa. The converse seems to hold 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, are frequently better predictors of annual energy than five month data sets from winter and summer.

5.13.2 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 the day and across seasons, as with air-conditioning equipment, a much longer metering or monitoring period may be required to characterize the system. In this case, long-term data are used to determine annual and time-of-use period energy savings.

If the energy consumption of the metered equipment or systems varies by more than ten percent (10%) from month to month, 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 the regression equations for whatever reason, they must 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. The uncertainty in savings can be attributed to measurement errors (both in the 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.

SECTION 6.0: DEFINITION OF TERMS

TERM	DEFINITION
Annual Energy Audit	*A procedure established within the contract for determining the annual energy savings attributed to a project.*
Building Automation System	*An electronic computer that can be programmed to control the operations of energy consuming equipment in a facility.*
Baseline Usage (Demand & Energy)	*The calculated energy 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 data collected from invoices sent to the owner from the power supplier, i.e., an electric or gas bill.*
Chauffage	*Type of performance contract where the ESCO assumes the operating risk and provides the owner with a guaranteed amount of energy at a guaranteed price over time.*
Commissioning	*The process of documenting and verifying the performance of VAC systems so that they operate in conformity with the design intent. System/equipment commissioning is expected to be completed by the ESCO. Current editions of ASHRAE's commissioning guideline GPC-1 can be the basis for commissioning activities.*
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 reports.*
Demand Savings	*[Peak period baseline energy less peak period post-installation energy] divided by the number of hours in the peak period*
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 Audit	*Procedure to establish baseline energy use and verify achievement of energy savings.*
Energy Conservation Opportunity	*An alternation to a new or existing system or component specifically intended to reduce energy consumption.*
Energy Cost	*The actual unit cost of power, i.e., electric cost = $/kW, $/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	*Usually a computer controlled device that is capable of sensing building conditions and making pre-set logic decisions about how energy consuming equipment should operate.*
Energy Savings	*Actual reduction in energy use or demand in electrical or thermal units.*
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) *facility*	*An organization which designs, procures, finances, installs and possibly maintains one or more ECMs at an owner or facilities.*
Error Analysis	*A mathematical determination of the errors present in the representation of any savings reports.*
Investment Grade Audit	*Detailed energy survey with sufficient detail to allow for the project value with respect to financing.*
Measurements, Long-Term	*Measurements taken over a period of several years.*
Measuremenst, Short-Term	*Measurements taken for several hours, weeks or months.*

Measurements, Spot	*Measurements taken one-time; snap-shot measurements.*
Measurement & Verification (M&V)	*The act of obtaining and verifying energy efficiency equipment performance.*
Metering	*Collection of energy consumption data over time at a facility through the use of meters.*
Metered Data	*Data collected at a facility over time through a meter for a specific end-use energy using system or location.*
Models, Calibrated Engineering	*Simulation models that are forced to fit measured data.*
Models, Regression	*Inverse models that require data to extract parameters***.**
Models, Simulation	*Use algorythms that calculate energy used based on engineering equations.*
Monitoring	*The collection of data at a facility over time for the purpose of savings analysis, i.e. energy consumption,, temperature, humidity, hours of operation, etc.*
M&V Option	*One of three generic M&V approaches defined for energy performance contracts.*
M&V Method	*A generic, not-project specific, M&V approach defined which applies one of the three M&V options to a specific ECM technology category such as lighting efficiency retrofits, constant load motor retrofits, of variable load, variable operating hour project retrofits.*
M&V Technique	*An evaluation tool for determining energy and cost savings. M&V techniques discussed in this document include engineering calculations, metering, utility billing analysis and computer simulation.*
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.*
Preliminary Energy Survey	*A quick inventory of energy consuming equipment often used for the first determination of whether a potential project exists for improved energy performance. Not to be used for investment decisions.*

Project Pre-Installation Report	*The ESCO, prior to the installation of energy 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. Documentation that provides a description and inventory of existing and proposed energy efficiency equipment, estimates of energy savings and a site-specific M&V plan (if not included in contract).*
Project Post-Installation Report	*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. Documentation that provides a description and inventory of old and installed energy efficiency equipment, estimates of energy savings and M&V results.*
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 5.13 Calculating Uncertainty.*
Variable Loads - Accuracy	*Power consuming equipment that has a changing energy consumption level over time.*
Walk -Through Audit	*See "Preliminary Energy Survey."*

SECTION 7: REFERENCES AND BIBLIOGRAPHY

7.1 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 site the publication, publisher or source where the document can be obtained.*

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