PDHonline Course E335 (8 PDH)

Energy Project Measurement and Verification Procedures

Instructor: George E. Thomas, PE

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PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

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This course is for engineers, energy professionals, and facility managers to assist in evaluating the performance of energy projects. The information in this course provides a tool for developing and evaluating energy conservation measure (ECM) baselines and for validating the performance of the implemented energy conservation. The course will also discuss practical and cost effective M&V options that provide the greatest benefit to cost ratio for varying technology.

The varying technology groups include:

1) Lighting Efficiency
2) Lighting Controls
3) Constant Load Motor Retrofits
4) Variable Speed Drives
5) HVAC Systems - Boiler Replacement
6) HVAC Systems - Infrared Heating
7) Steam Trap Systems
8) Chiller Replacements
9) Cooling Tower Replacements
10) Plan Heat Exchanger Installation
11) DX Unit/Heat Pump Replacement Project
12) Energy Management & Control Systems (EM CS)
13) Cogeneration Plants
14) Building Envelope

Measurement and verification is necessary in order to:

1) Accurately establish baseline conditions;
2) Fully understand the scope and risk of the ESPC/DSM contract
3) Accurately determine the ESPC/DSM contract payment
4) Evaluate the performance of ESPC/DSM contracts
5) Identify problems and resolutions under the terms of ESPC/DSM contracts.

Measurement and Verification (M&V) is defined as the process of measuring and verifying both energy and cost savings produced as a result of the implementation of an energy conservation measure. An energy conservation measure is defined as the installation or modification of energy using equipment, or systems, for the purpose of reducing energy use and/or costs. Therefore, energy conservation measures may include fuel switching, demand side management, and energy supply agreements which may reduce the cost of energy while not actually reducing energy use.

1.1 THE NEED FOR MEASUREMENT AND VERIFICATION

The need for cost effective measurement and verification has become critical because of high energy costs and the increased funding of programs through energy savings performance contracting (ESPC) and demand side management (DSM). Effective measurement and verification is the only means of determining if the contractor is performing well, and if the ECMs are generating the expected level of cost savings. It is the measurement and verification process that will determine how much can be saved, and how much the must be paid to an ESPC/DSM contractor.

In addition, appropriate measurement and verification is required for the savings resulting from ECMs performed under the Governments FEMP and ECIP programs. Funding for these types of projects has become more and more scarce. Determining which projects should be funded to generate the best results is important if goals are to be met.

It is important to understand that the best arrangement is to direct fund projects and not use ESPC/DSM. Companies may want to fund projects that have a lower savings to investment ratio (SIR) and longer payback and leave the better projects for the ESCO to use on ESPC/DSM projects. This allows companies to manager their available funds in order to accomplish more energy work. Available funds should be applied to those projects which have proven their cost effectiveness through measurement and verification.

One more reason for the need of energy measurement and verification is the establishment of this requirement in all federal facilities by the Code of Federal Regulations (CFR). Refer to 10 CFR 435, Subpart A, Section 110, Paragraph 10, Energy Management. This section covers the minimum mandatory requirements for building energy management systems. It describes the control, testing and documentation required for managing energy in a government facility.

2.2 THE BENEFITS OF ENERGY MEASUREMENT AND VERIFICATION

There are many benefits to cost effective energy measurement and verification. The benefits apply differently to the different parties involved in consuming energy or providing energy services in today's market.

Those benefiting from cost effective energy measurement and verification include:

- building owners;
- private companies
- energy savings performance contractors;
- financial institutions;
- equipment manufacturers
- energy measurement and verification companies
- utility companies
- government agencies

The benefits to each of these parties are as follows:

1. The private companies and owner:

   - ability to direct limited funds to the most cost effective projects
   - ability to track progress toward meeting stated energy goals
   - assurance that ESPC'DSM contractors are performing as required and that payments made are consistent with savings obtained
   - avoidance of disputes with ESPC'DSM contractors
   - data to assist in negotiations with ESPC'DSM contractors and utility companies
   - assistance to the installation in documenting utility costs, including payments to ESPC'DSM contractors

2. Energy Savings Performance Contractors

   - accurate determination of payments
   - performance data which can be used in developing additional projects at the same location, or at

similar locations
- ability to identify operational or maintenance problems quickly, thus limiting the risk of lost savings
- ability to identify methods for improving the performance of the project to improve the return on investment for the project
- ability to establish an accurate and realistic baseline as well as ECM savings projections

3. Financial Institutions

- ability to evaluate performance of the contractor financed projects to determine the likelihood of additionally funded projects
- ability to predict and diagnose problems with projects for early correction.

4. Equipment Manufacturers

- identification of strengths and weaknesses in the energy performance of products
- development of products designed to allow cost effective energy measurement and verification

5. Energy Measurement and Verification Companies

- increased utilization of services offered
- development of improved methods, including engineering calculations, hardware and software
- application of existing technologies to new uses in energy measurement and verification

6. Utility Companies

- accurate determination of payments from owners
- ability to establish an accurate and realistic consumption baseline and predict future requirements

7. Government Agencies

- ability to direct limited funds to the most cost effective projects
- ability to track progress toward meeting stated energy goals
- assurance that ESPC'DSM contractors are performing as required and that payments made are consistent with savings obtained
- avoidance of disputes with ESPC'DSM contractors
- data to assist in negotiations with ESPC'DSM contractors and utility companies

An additional benefit of energy measurement and verification is the justification for metering of individual buildings and tenants, and for the compilation of data to be applied in developing more energy efficient facility designs.

3.1 MEASUREMENT AND EVALUATION OF THE EFFECTIVENESS OF ENERGY SAVINGS PERFORMANCE METHODS

Energy measurement and verification plays a primary role in assuring the success of projects performed under the ESPC or other performance methods. No one benefits from a project which is not properly defined and does not generate the anticipated savings. The first step to a successful ECM under an ESPC is establishing the baseline. Establishing a baseline that is either overestimated or underestimated can be detrimental to the project. An overstated baseline can result in savings projections not being met, thus causing problems for the contractor and financial institutions. The negative impact is that the contractor may be unable to perform additional ECMs due to the hardships resulting from not receiving payments from the overstated project. Also, financial institutions may be less willing to finance additional projects for the contractor.

A more important role that energy measurement and verification plays in developing a baseline, is assuring that the project is performing as intended and that the contractor and the project are receiving the anticipated savings. Additionally, as the ECM ages and as operation, maintenance and repair procedures are carried out on the ECM, energy measurement and verification is used to assure the efficiencies of the equipment and systems are upheld and are performing as promised. Also, energy measurement and verification data should be used to determine if an ECM has reached the end of its economic life and if it should be replaced by a new ECM.

3.2 MEASUREMENT AND EVALUATION OF THE EFFECTIVENESS OF ENERGY CONSERVATION TECHNOLOGIES, PRODUCTS, SYSTEMS, AND PROCEDURES

Energy measurement and verification procedures are used to monitor energy savings obtained by energy projects.

3.3 PRACTICAL, COST EFFECTIVE, USER FRIENDLY STRATEGIES

Energy measurement and verification should be developed for each project to obtain the most benefit from the project. It should provide a level of accuracy consistent with the needs of the project. Energy measurement and verification is a tool which adds value to the project but only to the extent that it confirms all participants are performing at an acceptable level, that savings are being generated within reasonable margins of anticipated amounts, that savings and payments are being properly credited, accounted for, and dispersed, and that it can be used to identify, predict, and project problems that require correction with the ECM.

The scope of this course is to provide practical tools to assist the energy engineer, energy professional, and facility manager in the energy measurement and verification of ECM projects. The tools will be applicable to anything on which an ECM can be performed.

4.1 FACILITIES

The information contained in this course is applicable to all building types.

4.2 CENTRAL ENERGY PLANTS

Central energy plants include a wide range of equipment and systems on which ECMs can be successfully performed. However, it is here that energy measurement and verification is generally the most difficult, costly, and labor intensive, more difficult to establish baseline data, and where risks associated with the projects can be the greatest to all parties.

4.3 DISTRIBUTION SYSTEMS

Distribution system upgrades normally involve repair/replacement of piping systems, modification of piping systems to reduce corrosion and stress due to expansion and contraction, repair and replacement of insulation and valves in manholes, shallow trenches, and accessible locations. This type of ECM can be particularly difficult for measuring and verifying savings as well as establishing a baseline.

4.4 OPERATIONS AND MAINTENANCE PROCEDURES

This type of ECM generally involves control technologies and automation systems. These ECMs involve very little capital investment and provide very large returns through energy savings.

4.5 UTILITY RATE STRUCTURES, MODEL UTILITY AGREEMENTS, DEMAND SIDE MANAGEMENT

Prior deregulation and continuing evolution of the natural gas industry as well as the deregulation of the electric utility industry, has resulted in an increasing number of alternative rate structures for building managers to consider.

Demand side management (DSM) is another strategy the utility companies are using to lock in customers for multi-year contracts and to offer savings and rebates to the customer. These programs can be beneficial but require economic evaluation.

4.6 BASELINING METHODS AND STRATEGIES

The first step to a successful ECM under an ESPC/DSM is establishing the baseline. Establishing a baseline that is either overestimated or underestimated can be detrimental to a project. An overstated baseline can result in savings projections not being met, causing problems for the contractor and financial institutions. The negative impact is that the contractor may be unable to perform additional ECMs due to hardships resulting from not receiving payments from the overstated project. Also, financial institutions may be less willing to finance additional projects for the contractor. Thus, it is important to ensure that the baseline number is realistic by comparing it against actual utility bills, sample metering/measurement, per unit consumption, or past performance of similar energy projects.

The methods and strategies for establishing the baseline are applied as necessary to meet the goals and objectives of the particular project or program. The methods and strategies applied to a project that is "point of use," such as an energy efficient motor replacement, are totally different from those used for a central energy plant. This course will provide information on these differences and establishes best case scenarios for the different applications of energy measurement and verification. In many instances, it is necessary to perform M&V at different levels of detail. For example, measurement and verification may be required for a single piece of equipment, a single system, a building with many systems, a group of buildings, a total building, or an entire campus. Also, it is feasible that multiple projects could be carried out on an campus facility by multiple contractors requiring energy measurement and verification to be segregated by contract. Multiple contractors and multiple projects should be looked at cautiously, and not overlap between ECOs or facilities which could impact the energy savings.

4.7 ENERGY SAVINGS PERFORMANCE CONTRACTS

Energy savings performance contracts are a primary element in creating the need for energy measurement and verification. Additionally, Energy Reporting, Energy Metering and Monitoring, along with ASHRAE Standard 90.1, have significantly increased the demand for better, more cost effective energy measurement and verification techniques. However, no one was really interested in the subject until it became the basis of payments made and received for performance of ESPC contracts. Many meters are available, but few are actually read on a regular basis. The responsibility for M&V development for ESPC contracts should be placed with the contractor. This assignment of responsibility assures that projects are accomplished in a timely and efficient manner to effect timely payment to the contractor. If, on the other hand, the building owner assumes this responsibility, he may unnecessarily expose himself to claims by the ESPC contractor.

Successful performance of energy measurement and verification requires that procedures be established at the point when technologies, project location and scope, and goals have been identified. The same procedures, or technically compatible procedures, must be used for both the baseline and the post ECM measurement and verification. Each energy measurement and verification procedure should establish the measurement and verification goals, establish who is responsible, and identify and deal with any contract issue, documentation, and costs.

5.1 GOALS

Energy measurement and verification goals vary significantly depending on the project type, location, funding source, project cost, anticipated savings, economic project life, and other factors. In general, the goals should accomplish the following:

- establish economic feasibility of the ECM;
- provide a method to obtain a cost effective baseline;
- establish procedures for adjusting baselines on changes in the facility use which might impact the project
- establish the physical requirements for in-line items that require installation as part of the ECM

5.2 RESPONSIBLE?

The energy measurement and verification procedures established for each ECM must clearly define the responsibilities of the parties involved in the project. Items which must be addressed include:

- equipment procurement, installation and commissioning;
- equipment maintenance and calibration
- warrantee responsibility and ownership
- performance of calculations and reporting
- auditing
- record keeping
- owners acceptance of work

For ESPC/DSM contracts, it is to the building owner’s advantage to require the contract to perform all energy measurement and verification functions with provisions for the owner’s representative to perform periodic checks or audits of the records.

5.3 CONTRACT ISSUES

In defining the energy measurement and verification procedures for each ECM, it is important that the contract or task order be reviewed by the project team to assure procedures are consistent with the contract or task order requirements. Items which should be specifically reviewed include:

- site and project access
- energy measurement and verification frequency
- baseline adjustments
- documentation
- reporting
- record keeping
- auditing
- dispute resolution

It is impossible to over emphasize the importance of teamwork for the success of Energy Savings Performance Contracts (ESPC) and demand side management (DSM) based contracts. A strong partnership and commitment to working together is to everyone's benefit. Making the right decisions for energy measurement and verification, as a team, plays a major role in assuring a successful ESPC and between performance DSM programs.

5.4 DOCUMENTATION

Documentation of energy measurement and verification procedures and results should be obtained from the Energy Engineer, ESCO, and/or Contractor and must be consistent with provisions of the contract and/or task order under which the work is performed. In many instances, the contractor may include in his proposal the documentation which will be provided. This should be separately reviewed and accepted, rejected, or negotiated prior to beginning work. It is important that the level of documentation be value-based and not be over burdensome or cumbersome to the contractor, the engineer, the building owner, or building/facility manager.

5.5 COSTS

The cost of energy measurement and verification should be reasonable and realistic considering the project economics. The resultant level of accuracy is largely a function of costs.

An incremental increase in the level of accuracy can represent an associated increase/decrease in the savings determined. If this savings is lower in value than the cost for the increased accuracy over the life of the project, the additional accuracy is of no value. In establishing energy measurement and verification procedures, it is important that the life-cycle costs of these procedures be taken into account. Again, it is emphasized that these procedures and methods be applied based on the value they add to the success of the project.

There are three categories of measurement and verification procedures: Option A, Option B, and Option C.

Option A

The role of Option A is simply to verify that there is a potential for savings. Metering is not required, but can be done on a periodic, short-term basis. The cost required is low, typically no more than five percent of the energy cost savings over the life cycle of the equipment and depends on the number of measurement points.

Accuracy depends on the quality of the baseline in determining the energy load and the estimated hours of use. If no metering is conducted, savings depends on the manufacturers' specifications and the stipulated hours of use. Actual savings are never verified with Option A. The potential is merely presented and the amount is predicted with calculations.

Option A, more than any of the other measurement and verification option, depends on the estimated baseline data. There are two ways to determine this baseline:

- short-term metering
- stipulation of energy load and hours of use by both the contractor and the owner

The best option for accurate baselines involves short-term metering. If a system is old, was incorrectly installed, or is being used improperly, the manufacturers' specifications for the system will not be correct and should not be used to determine the baseline. These conditions usually require metering. Short-term metering can be conducted in one of two ways:

- a one-time 'snapshot' of the system showing typical usage
- periodic metering over time, demonstrating typical usage

When metering is performed only once, it is imperative that it is done during a time that represents typical usage, such as a weekday during normal operating hours. This type of metering is useful for simple systems with constant loads and constant patterns of usage. Periodic metering can determine either hours of use or variable loads. Metering should be conducted in 14-minute or one-hour intervals where the load varies by no more than five percent. If the load inexplicably varies by more than five percent, metering should be conducted over a longer span of time.

There are times when the estimated cost savings do not justify the extra expense of metering. A loss of accuracy will occur by merely stipulating run-time and energy usage, but this loss of accuracy will not be significant for simple constant systems. Examples of these kinds of systems include lighting efficiency projects and constant load motors because the amount of energy usage before and after the retrofit are well known, and the hours of use follows a typical easy-to-determine pattern.

Regardless of how the baseline is determined, it must be as accurate as possible. Incorrect baseline data can dramatically affect post-installation energy savings, regardless of how carefully the energy savings are calculated. It is imperative that the contractor and owner agree that the estimated baseline represents actual usage and load. Post-installation results are only as good as the baseline estimates.

<u>Option B</u>

Option B goes beyond Option A and verifies the savings in energy after the new systems have been installed. Therefore, it not only verifies the potential for energy savings exists, but it also verifies energy savings are being realized. Since accuracy is more crucial with Option B, metering is always conducted on a system level. The metering is periodic, or continuous, for a specified period of time during post-installation. Periodic metering was discussed in the description for Option A.

Since the level of measurement and verification is more detailed, the cost is higher. Typical costs for Option B range from 3 percent to 10 percent of the energy cost savings over the life cycle of the equipment and depends on the number of systems being measured and the complexity of the metering being conducted. Due to the longer period of measurement, the variations of the system from changing run-time or variable loads will be averaged out over time. The calculated savings will more closely resemble the actual savings than if the variables had been estimated in the baseline.

The level of accuracy depends on baseline assumptions and the amount of metering. Since usage is closely monitored over a longer period of time, actual load will more closely approximate the baseline load. Unfortunately, this does not inherently lead to more precise data. Accuracy is not guaranteed to be higher with Option B, despite the increased metering, since the systems tend to be more complex.

Baseline data for Option B requires some metering. The metering can be conducted at pre-installation to determine performance savings, or run-time can be extrapolated from post-installation data.

Option C

Both performance potential and actual performance are verified with Option C, and the analysis is conducted over the whole building. Option C is similar to Option B but involves whole building analysis, whereas Option B verifies energy savings only on a system level. Metering for Option C is done on a continuous basis for the entire facility. The cost is typically between one percent and ten percent of the energy cost savings over the life cycle of the equipment and depends on the number of relative parameters. Option C has the potential to cost comparably less than Option B because the cost of a single system is less than that of a whole building, but the cost to measure and verify savings for a single system is not less than it is for a building. Numerous buildings have a utility meter dedicated to the building, but few single systems can claim the same. The accuracy of the energy savings is dependent on baseline assumptions and selection of relevant variables.

Option B and Option C use essentially the same measurement and verification method. They differ only in the scope of energy conservation they recommend. Option C is inherently more complex. Performance is typically verified with either a whole building utility meter, or a computer simulation. Baseline data is usually obtained from utility bills that can accurately reflect energy usage through the seasons. Option C is particularly useful when energy retrofits are closely interrelated and when it is difficult to separate the ECMs into individual systems. This method is also useful if the result of the ECM is itself difficult to distinguish on a system level. Long-term contracts tend to employ Option C.

6.1 ENGINEERING CALCULATIONS

Engineering calculations are performed when extensive metering is not necessary, or cannot be justified given the level of savings. Calculation should be based on sound principles and accepted engineering standards and practices. The calculations can be extremely accurate if all required data for the calculations is available. Unfortunately, this is generally not the case and missing data must be estimated, or assumed. Thus, accuracy in the calculations is dependent upon the availability and accuracy of the required data and the ability of the system's evaluator.

6.2 ENGINEERING MODELS

Engineering models are similar to engineering calculations and vary only in the complexity of calculations. Engineering models are used when there are many interactions between the systems' operating parameters and variables. The accuracy of the models' results depends on the input given to the models and the completeness of the required input data. It is crucial that the models be completely understood before they are used. A model of an ECM baseline typically requires calibration in order to adjust the baseline result to reflect the actual building energy consumption. The building energy consumption can be obtained from utility bill information.

6.3 CONTINUOUS MEASUREMENT AND MONITORING

Continuous monitoring is characteristic of Option B and Option C. Continuous monitoring is applied when energy usage of the system cannot be easily determined or needs to be very accurate to establish a good baseline. Some systems have easily determined loads but run-time is more difficult to estimate. For other systems it is the other way around. If both the system's run-time and energy usage vary, continuous monitoring is best used to determine an accurate baseline. Continuous monitoring can also be used on systems that are not very complex but requires a high degree of accuracy to correctly determine post-installation savings.

6.4 PERIODIC MEASUREMENT AND MONITORING

Periodic measurements are characteristic of Option A and Option B. This level of measurement and verification is useful when the run-time, or energy consumed, is constant but unknown. This particularly applies to ECMs involving lighting efficiency, lighting controls, and constant load motors. Periodic measurement can help validate the expected performance of systems, estimated actual run-time, or energy consumption. This helps the contractor and owner agree on a baseline and aids in determining actual post-installation savings.

The frequency of measurement and monitoring should be stipulated in the contract. Some sites may require only a one-time baseline measurement. The frequency of monitoring should be determined by the constancy of the measured results. Any load that does not vary by more than five percent is considered to be constant and requires a one-time baseline measurement to determine a characteristic load.

7.0 SPECIFIC M&V PROCEDURES

The specific measurement and verification procedures are divided into fourteen categories and are presented in the following sequence:

7.1 Lighting Efficiency
7.2 Lighting Controls
7.3 Constant Load Motor Retrofits
7.4 Variable Speed Drives
7.5 HVAC Systems - Boiler Replacement
7.6 HVAC Systems - Infrared Heating
7.7 Steam Trap Systems
7.8 Chiller Replacements
7.9 Cooling Tower Replacements
7.10 Plan Heat Exchanger Installation
7.11 DX Unit/Heat Pump Replacement Project
7.12 Energy Management & Control Systems (EM CS)
7.13 Cogeneration Plants
7.14 Building Envelope

7.1.0 LIGHTING EFFICIENCY

7.1.1 Description

The strategy for energy conservation measures (ECMs) for lighting systems involves the following factors:

- use of more efficient equipment, including lamps, lighting fixtures, and ballasts
- use of electricity reducing technologies, including lighting controls, reflectors, natural lighting, increasing the reflectivity of space surfaces, and delamping

7.1.2 Energy Analysis Parameters

- fixture kW
- quantities
- hours of operation
- lighting levels
- energy rates
- demand rates

7.1.3 Data Gathering

- perform fixture count
- obtain fixture nameplate data
- document hours of operation
- obtain light level readings
- measurement and verification
- obtain electric rate schedules

7.1.4 Measurement And Verification Options

The following tables define how energy saving parameter values for the baseline and post-installation are obtained for each of the M&V options.

Table 7.1.1

PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
fixture kW	name plate data / table values/ sample metering	name plate data / table values/ sample metering	continuous metering
quantity	actual count	actual count	actual count
hours of operation	stipulated	stipulated	continuous metering
lighting level	measured value	measured value	measured value
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.1.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
fixture kW	name plate data / table values sample metering	sample metering or continuous metering	continuous metering
quantity	actual count	actual count	actual count
hours of operation	stipulated	sample metering or continuous metering	continuous metering
lighting level	measured value	measured value	measured value
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.1.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view as well as the contractor's point of view.

Table 7.1.3

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V Option Advantages			M&V Option Disadvantages		
Option A	Option B	Option C	Option A	Option B	Option C
lowest development cost	lower development cost				high development cost
short development period	short development period			sample or continuous metering is required	long development period
simplified verification process	ensure long term system performance and savings	ensure long term system performance and savings	no guarantee of long term system performance and savings	continual savings validation process	continuous metering is required
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	continual savings validation process
low probability of dispute		low probability of dispute		higher probability of dispute	

Table 7.1.4

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	lower development cost				high development cost
short development period	short development period	ensure long term system performance and savings		sample or continuous metering is required	long development period
no metering simplified verification process	ensure long term system performance and savings			continual savings validation process	continuous metering and validation process
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	
low probability of dispute		low probability of dispute		higher probability of dispute	
guarantee of long term shared savings					

7.1.6 Option A: Energy Savings Analysis

The baseline is fixed on stipulated parameters--no metering is required.
The energy savings analysis for the post-installation is based on stipulated parameters--no metering is required.

7.1.6.1 Baseline

The field data along with stipulated variables and parameters for each existing fixture type and usage group are compiled using spreadsheet analysis tools. The following formulas are used in performing the baseline energy savings calculations.

$$kW_{BASE} = Sum\ [kW / Fixture_{BASE}]$$

$$kWh_{BASE} = Sum\ [kW / Fixture_{BASE} \times Quantity_{BASE} \times Hours\ Of\ Operation_{BASE}]$$

7.1.6.2 Post-Installation Verification

The replacement fixture data along with stipulated variables and parameters for each fixture type and usage group are compiled using spreadsheet analysis tools. The following formulas are used in performing the post-installation energy savings calculations.

$$kW_{POST} = Sum\ [kW / Fixture_{POST}]$$

$$kWh_{POST} = Sum\ [kW / Fixture_{POST} \times Quantity_{POST} \times Hours\ Of\ Operation_{POST}]$$

7.1.6.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

$$\text{Demand Savings} = \text{kW}_{\text{POST}} - \text{kW}_{\text{BASE}}$$

$$\text{Energy Savings} = \text{kWh}_{\text{POST}} - \text{kWh}_{\text{BASE}}$$

7.1.6.4 Energy Dollar Savings

When calculating energy dollar savings**,** it is important to examine how rate structures are applied. Many rate structures use a tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. The reduction in energy consumption should be reduced from the top tier which has the lowest energy rate. If the average rate is use to calculate the savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on the time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. The savings are realized when the ECM reduces demand (kW) during the peak electric demand period when the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

$$\text{Demand Dollar Savings} = [\text{kW}_{\text{POST}} - \text{kW}_{\text{BASE}}] \text{ x Affected Rate}$$

$$\text{Energy Dollar Savings} = [\text{kWh}_{\text{POST}} - \text{kWh}_{\text{BASE}}] \text{ x Affected Rate}$$

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.1.6.5 Performance Assurance

- validate installed lighting fixtures and control schemes meet specifications;
- validate installed lighting fixtures and control schemes operate and perform as specified;
- ensure lighting systems still perform as predetermined by periodic instantaneous measurement of lighting loads;
- validate load (kW) of the facility's lighting systems by taking an instantaneous meter reading with all light fixtures on and another reading with all light fixtures off (if metering [kWh / kW] already exists at the building). The differential is the building's lighting load. The meter readings should be taken during a period when the HVAC and other equipment loads are fairly constant and at a minimum.
- initiate steps to educate building operators in the stipulated hours of operation and how lighting systems operate.

7.1.6.6 Range Of Accuracy

The fixture performance and the utility rate are well defined variables. The accuracy of Option A is primarily dependent on the estimate of stipulated operating hours. The accuracy for this measurement and verification method should normally be within ten percent depending on the accuracy of the estimate of stipulated operating hours.

7.1.6.7 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.1.6.8 Overall Advantages

Option A is most advantageous for the contractor since the savings performance is guaranteed based on stipulation. Additionally, it does not require as much time, money, and personnel to measure and verify the savings. Option A offers the same time and cost savings advantages to the owner but does not guarantee the long term system performance of the ECMs.

7.1.7 Option B: Energy Savings Analysis

The baseline is based on stipulated parameters--no metering required.
The energy savings analysis of the post-installation is based on stipulated parameters--system level sample metering or continuous metering required.

7.1.7.1 Baseline

Field data and stipulated variables and parameters for each existing fixture type and usage group are compiled using spreadsheet analysis tools. The following formulas are used in performing the baseline energy savings calculations.

$$kW_{BASE} = \text{Sum } [kW / Fixture_{BASE}]$$

$$kWh_{BASE} = \text{Sum } [kW / Fixture_{BASE} \times Quantity_{BASE} \times \text{Hours Of } Operation_{BASE}]$$

7.1.7.2 Post-Installation Verification

Energy performance is based on consumption readings of sample metering or continuous metering. The following formulas are used in performing the post-installation’s energy savings calculations.

$$kW_{POST} = \text{Sum } [kW / Fixture_{POST}]_{\text{METERING DATA}}$$

$$kWh_{POST} = \text{Sum } [kW / Fixture_{POST} \times Quantity_{POST} \times \text{Hours Of } Operation_{POST}]_{\text{METERING DATA}}$$

7.1.7.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

$$\text{Demand Savings} = kW_{POST} - kW_{BASE}$$

$$\text{Energy Savings} = kWh_{POST} - kWh_{BASE}$$

7.1.7.4 Energy Dollar Savings

When calculating energy dollar savings**,** it is important to examine how rate structures are applied. Many rate structures use the tier bracket approach where cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier which has the lowest rate. If the average rate is use to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, energy dollar savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period when the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some of the available demand structures include contract demand, on-peak/off-peak demand, ratchets demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \text{ x Affected Rate}$$

$$\text{Energy Dollar Savings} = [kW - kWh_{BASE}] \text{ x Affected Rate}$$

When calculating energy dollar savings for energy performance contracts, its is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.1.7.5 Performance Assurance

- validate installed lighting fixtures and control schemes meet specifications
- validate installed lighting fixtures and control schemes operate and perform as specified
- ensure meters function properly by periodically checking performance
- initiate steps to educate building operators to know stipulated hours of operation and how lighting systems operate

7.1.7.6 Range Of Accuracy

Performance of the ECM is based on metering data and the utility rate, which are well defined variables. Accuracy for Option B is primarily dependent on the accuracy of the estimate of stipulated factors in the baseline and should be within ten percent for this measurement and verification method.

7.1.7.7 Range Of Cost As A Percent Of Savings

The cost of Option B should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification process.

7.1.7.8 Overall Advantages

Option B is most advantageous for the owner since savings performance is ensured through continuous metering. Option B offers the same time and cost savings advantages to the contractor in the baseline development. However, it will require more time, money, and personnel to maintain the ECM's system performance and metering equipment as well as tracking and documenting the energy savings.

7.1.8 Option C: Energy Savings Analysis

The baseline energy performance is based on continuous metering of the entire facility.
The post-installation's energy performance is based on continuous metering of the entire facility.

7.1.8.1 Baseline

Baseline energy performance is based on establishing energy consumption by continuous metering of the entire facility over a specified period--usually one year.

$$kW_{BASE} = kW_{METERED\ BASELINE} \text{ (for the whole facility)}$$

$$kWh_{BASE} = kWh_{METERED\ BASELINE} \text{ (for the whole facility)}$$

7.1.8.2 Post-Installation Verification

The post-installation's energy performance is based on actual energy consumption obtained through continuous metering of the entire facility over the performance period.

$$kW_{POST} = kW_{METERED\ POST} \text{ (for the whole facility)}$$

$$kWh_{POST} = kWh_{METERED\ POST} \text{ (for the whole facility)}$$

7.1.8.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

$$\text{Demand Savings} = kW_{POST} – kW_{BASE}$$

$$\text{Energy Savings} = kWh_{POST} – kWh_{BASE}$$

7.1.8.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier which has the lowest rate. If the average rate is use to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is also important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \times \text{Affected Rate}$$

$$\text{Energy Dollar Savings} = [kWh_{POST} - kWh_{BASE}] \times \text{Affected Rate}$$

When calculating savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.1.8.5 Performance Assurance

- validate installed lighting fixtures and control schemes meet specifications
- validate installed lighting fixtures and control schemes operate and perform as specified
- ensure meters function properly by periodically checking metering performance
- initiate steps to educate building operators to know the stipulated hours of operation and how lighting systems operate

7.1.8.6 Range Of Accuracy

Option C will offer maximum accuracy if the majority of loads are lighting, or if there are no other loads outside the ECM. The accuracy for this M&V method should be within five percent depending on the accuracy of the meter readings.

7.1.8.7 Range Of Cost As A Percent Of Savings

The cost for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in the savings resulting from the measurement and verification process.

7.1.8.8 Overall Advantages

Option C offers the same advantages for both the owner and the contractor since savings performance is ensured through continuous metering. However, it is more costly in terms of time, money, and personnel to read the meters and validate the savings. Since Option C is only practical for lighting when the majority of loads in the facility are lighting loads, it is generally not recommended for use in the measurement and verification of lighting efficiency technologies in the ECM category.

7.1.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The diagrams specific to lighting efficiency are: 1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads; and 2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads.

7.2 LIGHTING CONTROLS

7.2.1 Description

Lighting controls are generally used to decrease lighting levels and/or hours of use for the lighting system. Lighting control strategies and technologies include:

- multi-level switching
- dimmer switches
- timers
- occupancy sensors
- daylight sensing devices
- lighting controls systems

7.2.2 Energy Analysis Parameters

- fixture kW
- quantity
- hours of operation
- lighting levels
- energy rates
- demand rates

7.2.3 Data Gathering

- perform fixture count
- obtain fixture nameplate data
- document hours of operation
- obtain readings of lighting levels
- obtain electric rate schedules

7.2.4 Measurement and Verification

The following tables define how energy savings parameter values for the baseline and post-installation are obtained for each of the maintenance and verification (M&V) options.

Table 7.2.1
PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
fixture kW	name plate data / table values/ sample metering	name plate data / table values/ sample metering	continuous metering
quantity	actual count	actual count	actual count
hours of operation	stipulated	stipulated (sample metering)	continuous metering
lighting levels	measured value	measured value	measured value
energy rates	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.2.2
PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
fixture kW	name plate data / table values sample metering	sample metering or continuous metering	continuous metering
quantity	actual count	actual count	actual count
hours of operation	stipulated	sample metering or continuous metering	continuous metering
lighting level	measured value	measured value	measured value
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.2.5 Advantages and Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view as well as the contractor's point of view.

Table 7.2.3

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	low development cost				high development cost
short development period	short development period			sample or continuous metering is required	long development period
simplified verification process	ensure long term system performance and savings	ensure long term system performance and savings	no guarantee of long term system performance and savings	continual savings validation process	continuous metering is required
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	continual savings validation process
low probability of dispute		low probability of dispute		higher probability of dispute	

Table 7.2.4

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	low development cost				high development cost
short development period	short development period	ensure long term system performance and savings		sample or continuous metering is required	long development period
no metering simplified verification process	ensure long term system performance and savings			continual savings validation process	continuous metering and validation process
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	
low probability of dispute		low probability of dispute		higher probability of dispute	
guarantee of long term shared savings				no guarantee	no guarantee

7.2.6 Option A: Energy Savings Analysis

The baseline is fixed on stipulated parameters–no metering is required.

The energy savings analysis for the post-installation is based on stipulated parameters–no metering is required.

7.2.6.1 Baseline

The field data and stipulated variables and parameters for all existing fixture types, usage groups, and control schemes are compiled using spreadsheet analysis tools. Accurate baselines are critical in lighting control projects. Baseline data should encompass the same items that are included for interior lighting, which involves the number of existing light fixtures, kinds of lamps, ballasts, and fixtures as well as hours of usage. In addition, the kinds of existing lighting controls, if any, should be determined.

The primary variable for determining baseline is hours of use. If this is not estimated correctly, the post-installation's calculations could be extremely inaccurate. The number of operating hours, both baseline and for the post-installation, must be agreed to by both groups and can be determined in several ways:

- occupancy hours of building
- use of a simple photocell and data recorder
- pre-metering of affected areas to accurately determine lighting usage
- models of similar projects within similar buildings
- surveys of actual lighting usage

If retrofits to lighting efficiency and lighting controls are being made at the same time, the amount of connected load should be calculated after the lighting efficiency retrofits have been implemented so that energy savings from lighting controls are not overestimated. When two interrelated improvements are being controlled at the same time, it is imperative not to overestimate the actual savings.
The following formulas are used in performing baseline energy savings calculations.

$$kW_{BASE} = Sum\ [kW / Fixture_{BASE}]$$

$$kWh_{BASE} = Sum\ [kW / Fixture_{BASE} \times Quantity_{BASE} \times Hours\ of\ Operation_{BASE}]$$

7.2.6.2 Post-Installation Verification

Replacement fixture data along with stipulated variables and parameters for all fixture types, usage groups, and control schemes are compiled using spreadsheet analysis tools. The following formulas are used in performing the post-installation's energy savings calculations.

$$kW_{POST} = Sum\ [k\ W / Fixture_{POST}]$$

$$kWh_{POST} = Sum\ [kW / Fixture_{POST} \times Quantity_{POST} \times Hours\ Of\ Operation_{POST}]$$

7.2.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

$$Demand\ Savings = kW_{POST} – kW_{BASE}$$

$$Energy\ Savings = kWh_{POST} – kWh_{BASE}$$

7.2.6.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use a tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. Reduction in energy consumption should originate from the top tier which has the lowest energy rate. If the average rate is used to calculate the dollar savings achieved, the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings, whereas reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} – kW_{BASE}] \text{ x Affected Rate Energy}$$

$$\text{Dollar Savings} = [kWh_{POST} – kWh_{BASE}] \text{ x Affected Rate}$$

When calculating savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of he implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.2.6.5 Performance Assurance

- validate installed control schemes and/or lighting fixtures meet specifications
- validate installed control schemes and/or lighting fixtures operate and perform as specified
- initiate steps to educate building operators of stipulated hours of operation and how lighting systems operate
- awareness that long term continuous metering is not necessary

7.2.6.6 Range Of Accuracy

Fixture performance and utility rates are well defined variables. Accuracy for Option A is primarily dependent on the estimate of stipulated operating hours. Measurement and verification by this method should be within ten percent depending on the accuracy of the estimate of stipulated operating hours.

7.2.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.2.6.8 Overall Advantages

Option A is most advantageous for the contractor since savings performance is guaranteed based on stipulation. Additionally, it does not require as much time, money, and personnel to measure and verify the savings. Option A offers the same time and cost savings advantages to the owner but does not guarantee long term system performance of the ECMs.

7.2.7 Option B: Energy Savings Analysis

The baseline is fixed on stipulated parameters–no metering is required.
The energy savings of the post-installation are based on stipulated parameters–system level sample metering or continuous metering required.

7.2.7.1 Baseline

Field data and stipulated variables and parameters for all existing fixture types, usage groups, and control schemes are compiled using spreadsheet analysis tools. Accurate baselines are critical in lighting control projects. Baseline data for lighting controls should comprise the same items as interior lighting. Included are the number of existing light fixtures, types of lamps, ballasts, and fixtures, as well as hours of use. Additionally, the kinds of existing lighting controls, if any, should be determined.
The primary variable for determining the baseline is hours of use. If this is not estimated correctly, the post-installation calculations could be extremely inaccurate. The number of operating hours for the baseline and post-installation must be agreed to by both groups and can be determined in several ways:

- occupancy hours in building
- use of simple photocell and data recorder
- pre-metering of affected areas to accurately determine lighting usage
- models of similar projects within similar buildings
- surveys of actual lighting usage

If retrofits to lighting efficiency and lighting controls are being made at the same time, the amount of connected load should be calculated after the lighting efficiency retrofit has been implemented so that energy savings from lighting controls are not overestimated. When two interrelated improvements are being controlled at the same time, it is imperative not to overestimate the actual savings.

The following formulas are used in performing the baseline energy savings calculations.

$$kW_{BASE} = \text{Sum } [kW / Fixture_{BASE}]$$

$$kWh_{BASE} = \text{Sum } [kW / Fixture_{BASE} \times Quantity_{BASE} \times \text{Hours Of } Operation_{BASE}]$$

7.2.7.2 Post-Installation Verification

Energy performance is based on the consumption readings of either sample metering or continuous metering. The following formulas are used in performing the post-installation’s energy savings calculations.

kW_{POST} = Sum [kW / $Fixture_{POST}]_{METERING\ DATA}$

kWh_{POST} = Sum [kW / $Fixture_{POST}$ x $Quantity_{POST}$ x Hours Of $Operation_{POST}]_{METERING\ DATA}$

7.2.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = $kW_{POST} - kW_{BASE}$

Energy Savings = $kWh_{POST} - kWh_{BASE}$

7.2.7.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket form where the cost at the bottom tier is higher than the tiers above it. The greatest savings are generated at the top tier which has the lowest energy rate. If the average rate is use to calculate savings, the savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, energy dollar savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing savings calculations.

Demand Dollar Savings = [$kW_{POST} - kW_{BASE}$] x Affected Rate

Energy Dollar Savings = [$kWh_{POST} - kWh_{BASE}$] x Affected Rate

When calculating savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.2.7.5 Performance Assurance

- validate installed lighting fixtures and control schemes meet specifications
- validate installed lighting fixtures and control schemes operate and perform as specified
- check metering performance periodically to ensure meters function properly
- initiate steps for educating building operators to know stipulated hours of operation and how

lighting systems operate

7.2.7.6 Range Of Accuracy

Performance of the ECM will be based on metering data and the utility rate, which are well defined variables. The accuracy of Option B is primarily dependent on the accuracy of the estimate of stipulated factors in the baseline. Accuracy for this measurement and verification method should be within ten percent.

7.2.7.7 Range Of Cost As A Percent Of Savings

Cost for Option B should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification process.

7.2.7.8 Overall Advantages

Option B is most advantageous since savings performance is ensured through continuous metering. It requires slightly more time, money, and personnel to read the meters and validate the savings. Option B offers the same time and cost savings advantages to the contractor in the baseline development. However, it will require more time, money, and personnel to maintain system performance and metering equipment as well as to track and document energy savings.

7.2.8 Option C: Energy Savings Analysis

The baseline energy performance is fixed on continuous metering of the entire facility.
The post-installation's energy performance is fixed on continuous metering of the entire facility.

7.2.8.1 Baseline

The baseline energy performance is based on establishing energy consumption by continuous metering of the entire facility over a specific period–usually one year.

$kW_{BASE} = kW_{METERED\ BASELINE}$ (for the whole facility)

$kWh_{BASE} = kWh_{METERED\ BASELINE}$ (for the whole facility)

7.2.8.2 Post-Installation Verification

The post-installation's energy performance is based on actual energy consumption obtained by continuous metering of the entire facility over the performance period.

$kW_{POST} = kW_{METERED\ POST}$ (for the whole facility)

$kWh_{POST} = kWh_{METEREDPOST}$ (for the whole facility)

7.2.8.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = $kW_{POST} - kW_{BASE}$

Energy Savings = $kWh_{POST} - kWh_{BASE}$

7.2.8.4 Energy Dollar Savings

When calculating **energy dollar savings,** it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where cost at the bottom tier is higher than the tiers above it. Energy savings are usually generated at the top tier which has the lowest rate. If the average rate is used to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, energy dollar savings will depend on the usage pattern of ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will produce demand savings. However, reducing demand (kW) for light fixtures operating only at night will not generate demand savings. Demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.
Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing savings calculations.

Demand Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

Energy Dollar Savings = $[kWh_{POST} - kWh_{BASE}]$ x Affected Rate

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.2.8.5 Performance Assurance

- validate installed lighting fixtures and control schemes meet specifications
- validate installed lighting fixtures and control schemes operate and perform as specified
- check metering performance periodically to ensure meters function properly
- initiate steps to educate building operators to know stipulated hours of operation and how lighting systems operate

7.2.8.6 Range Of Accuracy

Option C will offer the most accuracy if the majority of loads are lighting loads, or if there are no other loads outside the ECM. Accuracy for this measurement and verification method should be within five percent depending on the accuracy of meter readings.

7.2.8.7 Range Of Cost As A Percent Of Savings

The cost for Option C should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification process.

7.2.8.8 Overall Advantages

Option C offers the same advantages owner and the contractor since savings performance is ensured through continuous metering. However, it is more costly in terms of time, money, and personnel to read the meters and validate the savings. Since Option C is only practical for lighting projects when the majority of loads in the facility are lighting loads, it is generally not recommended for use in the measurement and verification of lighting control technologies in the ECM category.

7.2.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The diagrams specific to lighting controls are:

1) Figure 1, Electrical Power Metering/Monitoring – Single Phase Loads; and
2) Figure 2, Electrical Power Metering/Monitoring – Three Phase Loads.

7.3 CONSTANT LOAD MOTOR RETROFITS

7.3.1 Description

The constant load motor retrofit project involves direct replacement of a constant speed, constant load motor for another motor that has a higher performance efficiency and is sized to match the same load. The strategy for energy conservation measures (ECMs) for motor retrofit involves:

- use of higher performance efficiency motors
- proper sizing of the motor to match the load (oversized motors waste energy and have low power factors)

7.3.2 Energy Analysis Parameters

- percentage of efficiency of existing motor: $\%\mathbf{E_{LO}}$
- percentage of efficiency of high efficiency motor: $\%\mathbf{E_{HI}}$
- rated full load horsepower of motor: **HP**
- percentage of full load when motor actually operates (load factor): **LF**
- voltage measured between supply conductor: **V**
- amperage, measured current flowing in supply conductor: **A**
- power factor: **PF**
- active power in kW: $\mathbf{P_{ACT}}$
- operating hour: **Hr**
- quantity: **Q**
- utility energy rate in $/kWh

- utility demand rate in $/kW

7.3.3 Data Gathering

- perform motor survey
- obtain motor nameplate data
- perform electrical measurements on motor: voltage, current, PF, kW
- make sure motors being used have the appropriate design characteristics for their application
- document hours of operation
- obtain electric rate schedules

7.3.4 Measurement And Verification

The following tables define how energy savings parameter values for both baseline and post-installation are obtained for each M&V option.

Table 7.3.1

PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
motor efficiency	name plate data manufacturer performance curve	name plate data manufacturer performance curve	name plate data manufacturer performance curve
rated motor full load HP	name plate data	name plate data	name plate data
load factor, LF	measured value	measured value	measured value
voltage, V	measured value	measured value	measured value
amperage, A	measured value	measured value	measured value
power factor, PF	measured value	measured value	measured value
active power, P_{ACT}	measured value	measured value	continuous metering
quantity, Q	actual count	actual count	actual count
hour of operation, Hr	stipulated	stipulated	continuous metering
energy consumption	calculated	calculated	continuous metering
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.3.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
motor efficiency	name plate data manufacturer performance curve	name plate data manufacturer performance curve	name plate data manufacturer performance curve
rated motor full load hp	name plate data	name plate data	name plate data
load factor, LF	measured value	measured value	measured value
voltage, V	measured value	measured value	measured value
amperage, A	measured value	measured value	measured value
power factor, PF	measured value	measured value	measured value
active power, P_{ACT}	measured value	measured value	continuous metering
quantity, Q	actual count	actual count	actual count
hour of operation, Hr	stipulated	continuous metering	continuous metering
energy consumption	calculated	continuous metering	continuous metering
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.3.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view as well as the contractor's point of view.

Table 7.3.3

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V Option Advantages			M&V Option Disadvantages		
Option A	Option B	Option C	Option A	Option B	Option C
lowest development cost	lower development cost				high development cost
short development period	short development period			sample or continuous metering is required	long development period
simplified verification process	ensure long term system performance and savings	ensure long term system performance and savings	no guarantee of long term system performance and savings	continual savings validation process	continuous metering is required
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	continual savings validation process
low probability of dispute		low probability of dispute		higher probability of dispute	

Table 7.3.4

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	lower development cost				high development cost
short development period	short development period	ensure long term system performance and savings		sample or continuous metering is required	long development period
no metering simplified verification process	ensure long term system performance and savings			continual savings validation process	continuous metering and validation process
reasonable accuracy	improved accuracy	best accuracy possible	accuracy dependent on stipulated values	accuracy dependent on stipulated values	
low probability of dispute		low probability of dispute		higher probability of dispute	
guarantee of long term shared savings					

7.3.6 Option A: Energy Savings Analysis

The baseline is based on stipulated parameters--no metering required.

The energy savings analysis for the post-installation is based on stipulated parameters--no metering required.

7.3.6.1 Baseline

Field data and stipulated variables and parameters for each existing motor type, usage group, and control scheme are compiled using spreadsheet analysis tools. The primary variables for determining baseline are efficiency of the motor, the operating load factor, and the hours of use.

A motor observed during the field survey may operate at a constant speed but that does not guarantee the motor's load is constant. The operating load of the motor must be measured to ensure it meets constant load criteria as well as to determine the operating load factor. The performance of a constant speed motor can be determined by taking power measurements of a representative sampling of typical motors in an application group and/or by using the manufacturer's specifications and performance curves.

If the motor cycles on and off during operation; document the cycle period so hours of operation can be estimated more accurately. The hours of operation must be precisely estimated to ensure an accurate baseline. The number of operating hours is not continuously measured, but an estimate is made and agreed to by both groups. As specified below, operating hours can be estimated in several ways.

- surveys of actual motor usage
- operation logs from energy management systems
- modeling of energy usage patterns of the applied load

The following formulas are used in performing the baseline energy savings calculations.

Measured $P_{ACT} = 1.732 \times V \times I \times PF \times 1/1000$ (kW)

$$\text{Calculated LF} = [\text{Measured } P_{ACT} \times \%E_{LO}] / [0.746 \times HP]$$

or

$$\text{Estimated } P_{ACT} = [0.746 \times HP \times LF\ (\text{Estimated})] / \%E_{LO}\ (kW)$$

$$kW_{BASE} = \text{Sum } [\text{Measured } P_{ACT} \times \text{Quantity}_{BASE}]$$

or

$$KW_{BASE} = \text{Sum } [\text{Estimated } P_{ACT} \times \text{Quantity}_{BASE}]$$

$$kWh_{BASE} = \text{Sum } [kW_{BASE} \times \text{Quantity}_{BASE} \times Hr_{STIPULATED}]$$

7.3.6.2 Post-Installation Verification

Replacement motor data and stipulated variables and parameters for each motor type, application, and usage group are compiled using spreadsheet analysis tools. The following formulas are used in performing the post-installation's energy savings calculations.

$$\text{Measured } P_{ACT} = 1.732 \times V \times I \times PF \times 1/1000\ (kW)$$

$$\text{Calculated LF} = [\text{Measured } P_{ACT} \times \%E_{HI}] / [0.746 \times HP]$$

or

$$\text{Estimated } P_{ACT} = [0.746 \times HP \times LF\ (\text{estimated})] / \%E_{HI}\ (kW)$$

$$kW_{POST} = \text{Sum } [\text{Measured } P_{ACT} \times \text{Quantity}_{POST}]$$

or

$$KW_{BASE} = \text{Sum } [\text{Estimated } P_{ACT} \times \text{Quantity}_{POST}]$$

$$kWh_{POST} = \text{Sum } [kW_{POST} \times \text{Quantity}_{POST} \times Hr_{STIPULATED}]$$

7.3.6.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

$$\text{Demand Savings} = kW_{POST} - kW_{BASE}$$

$$\text{Energy Savings} = kWh_{POST} - kWh_{BASE}$$

or

$$\text{Demand Savings} = LF \times HP \times (1\ 00/\%E_{LO} - 1\ 00/\%E_{HI}) \times 0.746$$

$$\text{Energy Savings} = LF \times HP \times (1\,00/\%E_{LO} - 1\,00/\%E_{HI}) \times 0.746 \times Hr$$

7.3.6.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where cost at the bottom tier is higher than the tiers above it. Reduction in energy consumption should be reduced from the top tier which has the lowest energy rate. If the average rate is used to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \times \text{Affected Rate}$$

$$\text{Energy Dollar Savings} = [kWh_{POST} - kWh_{BASE}] \times \text{Affected Rate}$$

When calculating savings for energy performance contracts, its is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.3.6.5 Performance Assurance

- validate installed motors meet specifications
- validate installed motors operate and perform as specified
- long term continuous metering not necessary

7.3.6.6 Range Of Accuracy

The motor's performance and the utility rate are well defined variables. The accuracy of Option A is primarily dependent on the estimate of the stipulated operating hours. Accuracy for this M&V method should be within ten percent.

7.3.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.3.6.8 Overall Advantages

Option A is most advantageous for the contractor since savings performance is guaranteed based on stipulation and does not require as much time, money, and personnel to measure and verify savings. Option A offers the same time and cost savings advantages to the owner but does not guarantee the long term system performance of the ECMs.

7.3.7 Option B: Energy Savings Analysis

The baseline is fixed on stipulated parameters--no metering required.
The post-installation's energy savings analysis is based on stipulated parameters--system level sample metering or continuous metering required.

7.3.7.1 Baseline

Field data and stipulated variables and parameters for each existing motor type, usage group, and control scheme are compiled using spreadsheet analysis tools. The primary variables for determining baseline are efficiency of the motor, operating load factor, and hours of use.

A motor observed during the field survey may operate at a constant speed but that does not guarantee the motor's load is constant. The operating load of the motor must be measured to ensure it meets constant load criteria and to determine the operating load factor. The performance of a constant speed motor can be determined by taking power measurements of a representative sampling of typical motors in an application group and/or by using the manufacturer's specifications and performance curves.
If the motor cycles on and off during operation; document the cycle period so that hours of operation can be estimated more accurately. The hours of operation must be precisely estimated to ensure an accurate baseline. The number of operating hours is not continuously measured but is estimated and greed to by both groups. Operating hours can be estimated in several ways.

- surveys of actual motor usage
- operation logs from energy management systems
- modeling of energy use patterns of applied loads

The following formulas are used in performing baseline energy savings calculations.

Measured $P_{ACT} = 1.732 \text{ x } V \text{ x } I \text{ x } PF \text{ x } 1/1000$ (kW)

Calculated $LF = [\text{Measured } P_{ACT} \text{ x } \%E_{LO}] / [0.746 \text{ x } HP]$

or

Estimated $P_{ACT} = [0.746 \text{ x } HP \text{ x } LF(\text{estimated})] / \%E_{LO}$ (kW)

$kW_{BASE} = \text{Sum } [\text{Measured } P_{ACT} \text{ x Quantity}_{BASE}]$

or

$KW_{BASE} = \text{Sum } [\text{Estimated } P_{ACT} \text{ x Quantity}_{BASE}]$

kWh_{BASE} = Sum [kW_{BASE} x $Quantity_{BASE}$ x $Hr_{STIPULATED}$]

7.3.7.2 Post-Installation Verification

Energy performance is based on consumption readings of sample metering or continuous metering. The following formulas are used in performing the post-installation's energy savings calculations.

kW_{POST} = Sum [P_{ACT}] METERING DATA

kWh_{POST} = Sum [P_{ACT} x $Quantity_{POST}$ x $Hr_{METERED}$] METERING DATA

7.3.7.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

7.3.7.4 Energy Dollar Savings

When calculating **energy dollar savings,** it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier which has the lowest rate. If the average rate is used to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use where the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

When calculating **demand dollar savings,** it is important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

Demand Dollar Savings = [kW_{POST} - KW_{BASE}] x Affected Rate

Energy Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.3.7.5 Performance Assurance

- validate installed motors meet specifications
- validate installed motors operate and perform as specified
- periodically check metering performance to ensure meter functions properly

7.3.7.6 Range Of Accuracy

Performance of the ECM will be based on metering data and the utility rate, which are generally well defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline. Accuracy for this M&V method should be within ten percent.

7.3.7.7 Range Of Cost As A Percent Of Savings

The cost of Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.3.7.8 Overall Advantages

Option B is most advantageous for the owner since savings performance is ensured through continuous metering. Option B offers the same time and cost savings advantages to the contractor in baseline development. However, it will require more time, money, and personnel to maintain the system performance and metering equipment as well as tracking and documenting energy savings.

7.3.8 Option C: Energy Savings Analysis

Baseline energy performance is based on continuous metering of the entire facility.
The post-installation's energy performance is based on continuous metering of the entire facility.

7.3.8.1 Baseline

Baseline energy performance is based on establishing energy consumption by continuous metering of the entire facility over a specific period--usually one year.

$kW_{BASE} = kW_{METERED\ BASELINE}$ (for the whole facility)

$kWh_{BASE} = kWh_{METERED\ BASELINE}$ (for the whole facility)

7.3.8.2 Post-Installation Verification

The post-installation's energy performance is based on actual energy consumption obtained by continuous metering of the entire facility over the performance period.

$kW_{POST} = kW_{METERED\ POST}$ (for the whole facility)

$kWh_{POST} = kWh_{METERED\ POST}$ (for the whole facility)

7.3.8.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

7.3.8.4 Energy Dollar Savings

When calculating **energy dollar savings,** it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier which has the lowest rate. If the average rate is used to calculate savings, actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use where the energy rate is higher during the on-peak period and lower during the off-peak period. For this kind of rate structure, savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. Demand dollar savings are realized when ECMs reduce demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

Energy Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating savings for energy performance contracts, its is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.3.8.5 Performance Assurance

- validate installed motors meet specifications
- validate installed motors operate and perform as specified
- periodically check metering performance to ensure meter functions properly

7.3.8.6 Range Of Accuracy

Option C will offer the best possible accuracy if most (>90%) facility loads are constant load motors;

otherwise, this method should not be used. Accuracy for this M&V method should be within five percent depending on the accuracy of the meter readings.

7.3.8.7 Range Of Cost As A Percent Of Savings

The cost of Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.3.8.8 Overall Advantages

Option C offers the same advantages for the owner and the contractor since savings performance is assured through continuous metering. However, it is more costly in terms of time, money, and personnel to read meters and validate the savings. Option C is only applicable to constant motor load retrofit projects when the majority of facility loads are constant load motors. Thus, it is generally **not recommended** for use in the measurement and verification process.

7.3.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The two diagrams specific to constant load motor retrofits are: 1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads; and 2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads.

7.4. VARIABLE SPEED DRIVES

7.4.1 Description

Variable speed drives save energy by providing the capability to modulate the output of the motor to satisfy changing system requirements rather than wasting a portion of the mechanical energy provided by the motor while operating at full output. The output of the equipment is typically adjusted by various means (clutches, breaks, valves, dampers) to satisfy dynamic system requirements. The means of system output adjustments are not efficient compared to varying the speed of the motor. The strategy for energy conservation measures (ECMs) for variable speed drive applications involves the following two aspects:

- use of more efficient equipment, including drives, motors, pumps and fans;
- use of energy reducing technologies, including the use of proper equipment load controlling strategies.

7.4.2 Energy Analysis Parameters

- percentage of efficiency of existing motor: **$\%E_{LO}$**
- percentage of efficiency of new motor (if applicable): **$\%E_{HI}$**
- percentage of efficiency of adjustable speed drive: **$\%E_{ASD}$**
- rated full load horsepower of motor: **HP**
- motor speed data: **RPM**
- percentage of full load with the motor operating (load factor): **LF**
- voltage measured between supply conductor: **V**

- amperage, measured current flowing in supply conductor: **A**
- power factor: **PF**
- active power in kW: $\mathbf{P_{ACT}}$
- operating hour: **Hr**
- determine system output performance at various load conditions (GPM, CFM, etc.)
- utility energy rate in $/kWh
- utility demand rate in $/kW

7.4.3 Data Gathering

- perform motor survey
- obtain motor nameplate data
- perform electrical measurements on motor: voltage, current, PF, kW
- verify motors being used have appropriate design characteristics for their applications
- determine existing control method
- determine existing operating characteristics: variable torque, constant torque, constant horsepower, and operating speed
- determine system performance based on system output values (cfm, gpm, etc.)
- document hours of operation for various load conditions
- acquire electric rate schedules

7.4.4 Measurement And Verification

The following tables define how energy saving parameter values for both baseline and post-installation are obtained for each M&V option.

Table 7.4.1
PAMAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
motor efficiency and drive efficiency	name plate data manufacturer performance curve	name plate data manufacturer performance curve	name plate data manufacturer performance curve
rated motor full load hp	name plate data	name plate data	name plate data
motor speed	name plate data	name plate data	name plate data
load factor, LF	measured value	measured value	measured value
voltage, V	measured value	measured value	measured value
amperage, A	measured value	measured value	measured value
power factor, PF	measured value	measured value	measured value
active power, P_{ACT}	measured value	measured value	energy simulation modeling
hour of operation, Hr	stipulated	stipulated	energy simulation modeling
system performance	stipulated based on measured values	stipulated based on measured values	energy simulation modeling
energy consumption	calculated	calculated	energy simulation modeling
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.4.2

PARAMETER VALUES FOR THE POST-INSTALLATIOIN

M&V Option Parameters	Option A	Option B	Option C
motor efficiency	name plate data manufacturer performance curve	name plate data manufacturer performance curve	name plate data manufacturer performance curve
rated motor full-load hp	name plate data	name plate data	name plate data
motor speed		measured value	measured value
load factor, LF	measured value	measured value	measured value
voltage, V	measured value	measured value	measured value
amperage, A	measured value	measured value	measured value
power factor, PF	measured value	measured value	measured value
active power, P_{ACT}	measured value	measured value	energy simulation modeling
hour of operation, Hr	Stipulated	continuous metering	energy simulation modeling
system performance	stipulated based on measured values	continuous metering	energy simulation modeling
energy consumption	Calculated	continuous metering	energy simulation modeling
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.4.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view and the contractor's point of view.

Table 4.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	lower development cost				higher development cost
short development period	short development period			sample or continuous metering is required	longer development period
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	
reasonable accuracy	improved accuracy		accuracy dependent on stipulated values	accuracy dependent on stipulated values	accuracy dependent on stipulated values and modeling
low probability of dispute					higher probability of dispute

Table 4.5.2

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost	lower development cost				higher development cost
short development period	short development period			sample or continuous metering is required	lower development period
no metering simplified verification process	ensure long term system performance and savings			continual savings validation process	
reasonable accuracy	improved accuracy		accuracy dependent on stipulated values	accuracy dependent on stipulated values	accuracy dependent on stipulated values
low probability of dispute					higher probability of dispute
guarantee of long term shared savings					

7.4.6 Option A: Energy Savings Analysis

The baseline is based on stipulated parameters--short term sample metering required.
The energy savings analysis for the post-installation is based on stipulated parameters--short term sample metering required.

7.4.6.1

The baseline is established by determining the existing motor characteristics, system's method of control (none, clutches, breaks, dampers, guide vanes, valves, pitch, etc.), the controlling parameters, and the operating load profile (number of hours and power input requirements at a specific percentage of system output). Determine the energy usage by calculation using the determined method of control and current operating load profile. The operating load profile can be determined by extrapolation of short term metering. The hours of operation must be precisely estimated to ensure an accurate baseline. The number of operating hours at various load conditions is not continuously measured, but an estimate is made and agreed to by both groups. The operating hours can be estimated in several ways:

- actual motor usage sampling of metered measurement
- operation logs from energy management systems
- modeling of load profiles and energy usage patterns of the applied load

The following formulas are used in performing the baseline energy savings calculations for various load conditions.

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

Calculated LF = [Measured P_{ACT} x $\%E_{LO}$] / [0.746 x HP]

or

Estimated P_{ACT} = [0.746 x HP x LF (Estimated)] / [$\%E_{LO}$] (kW)

kW_{BASE} = Measured P_{ACT} @ Various Baseline Load Conditions

or

= Estimated P_{ACT} @ Various Baseline Load Conditions

kWh_{BASE} = Sum [kW_{BASE} x $Hr_{STIPULATED}$] @ Various Baseline Load Conditions

7.4.6.2 Post-Installation Verification

The post-installation's measurement and verification is accomplished by conducting system performance measurement at various load conditions. The new system's performance profile can be developed and compared with the baseline system's performance profile at various load conditions. The differential in the maximum input power requirement is the demand savings. Energy savings can be calculated by applying the required operating hours at various system operating points in the system's performance profile. The following formulas are used in performing the calculations.

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

Calculated LF = [Measured P_{ACT} x % E_{HI} x $\%E_{ASD}$] / [0.746 x HP]

or

Estimated P_{ACT} = [0.746 x HP x LF (Estimated)] / [$\%E_{HI}$ x $\%E_{ASD}$] (kW)

kW_{POST} = Measured P_{ACT} @ Various Baseline Load Conditions

or

= Estimated P_{ACT} @ Various Baseline Load Conditions

kWh_{POST} = Sum [kW_{BASE} x $Hr_{STIPULATED}$] @ Various Baseline Load Conditions

7.4.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

7.4.6.4 Energy Dollar Savings

When calculating **energy dollar savings,** it is important to examine how rate structures are applied. Many rate structures use a tier brackets structure where the cost at the bottom tier is higher than the tiers above it. Reduction in energy consumption should be reduced from the top tier which has the lowest energy rate. If the average rate is use to calculate savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

When calculating **demand dollar savings,** it is important to examine how rate structures are applied. Savings are generally realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings, whereas reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.

Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the energy conservation measure. The following formulas are used in performing energy dollar savings calculations.

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

Energy Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating energy dollars savings for energy performance contracts, its is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share benefits as well as the risk of possible changes in utility rates.

7.4.6.5 Performance Assurance

- validate that installed drives and motors meet specifications
- validate that installed drives and motors operate and perform as specified

7.4.6.6 Range Of Accuracy

The accuracy for Option A is primarily dependent on the estimate of stipulated operating hours; however, for variable speed drive applications, the hours of operation at various load conditions are difficult to estimate because the system has many interdependent variables, such as demand conditions on the system, equipment (pump, fan, etc.) operating characteristics, control schemes, and environmental operating conditions (i.e. weather). Accuracy for this M&V method could be off by a wide margin if sample operating load profiles are not representative of the actual operating conditions.

7.4.6.7 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.4.6.8 Overall Advantages

Option A is most advantageous for the contractor since savings performance is guaranteed based on stipulation. Also, it does not require as much time, money, and personnel to measure and verify the savings. Option A offers the same time and cost savings advantages to the owner but does not guarantee the short term or long term system performance of the ECMs.

7.4.7 Option B: Energy Savings Analysis

The baseline is based on stipulated parameters--short term sample metering required.
The post-installation's energy savings analysis is based on stipulated parameters--system level continuous metering required.

7.4.7.1 Baseline

The baseline is established by determining the existing motor's characteristics, system method of control (none, clutches, breaks, dampers, guide vanes, valves, pitch, etc.), controlling parameters, and operating load profiles (number of hours and power input requirements at a specific percentage of system output). Determine the energy usage by calculation utilizing the determined method of control and the present operating load profiles. The operating load profile can be determined by extrapolation of short term metering. The hours of operation must be precisely estimated to ensure an accurate baseline. The number of operating hours at various load condition is not continuously measured, but an estimate is made and agreed to by both groups. Operating hours can be estimated in several ways.

- metered measurement sampling of actual motor usage
- operation logs from energy management systems
- modeling load profiles and energy usage patterns of the applied load

The following formulas are used in performing the baseline energy savings calculations for various load conditions.

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

Calculated LF =[Measured P_{ACT} x %E_{LO}] / [0.746 x HP]

or

Estimated P_{ACT} = [0.746 x HP x LF(Estimated)] / [%E_{LO}] (kW)

kW_{BASE} = Measured P_{ACT} @ Various Baseline Load Conditions

or

= Estimated P_{ACT} @ Various Baseline Load Conditions

kWh_{BASE} = Sum [kW_{BASE} x $Hr_{STIPULATED}$] @ Various Baseline Load Conditions

7.4.7.2 Post-Installation Verification

Energy performance is based on continuous metering of system performance and energy usage. The following formulas are used in performing the post-installation's energy savings calculations.

kW_{POST} = Sum [P_{ACT}] METERING DATA

kWh_{POST} = Sum [P_{ACT} x $Quantity_{POST}$ x $Hr_{METERED}$] METERING DATA

7.4.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

7.4.7.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use tier bracket structures where the cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier where has the lowest rate. If the average rate is use to calculate energy dollar savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is important to examine how rate structures are applied. The savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings, while reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \times \text{Affected Rate}$$

$$\text{Energy Dollar Savings} = [kWh_{POST} - kWh_{BASE}] \times \text{Affected Rate}$$

When calculating savings for energy performance contracts, its is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits and the risk of possible changes in utility rates.

7.4.7.5 Performance Assurance

- validate installed drives and motors meet specifications
- validate installed drives and motors operate and perform as specified
- ensure meter functions properly by periodically checking performance

7.4.7.6 Range Of Accuracy

Performance for the ECM will be based on metering data and the utility rate, which are well defined variables. The accuracy of Option B is primarily dependent on the estimate of stipulated factors in the baseline. Accuracy for this M&V method should be within ten percent depending on the accuracy of the estimate of stipulated factors in the baseline.

7.4.7.7 Range Of Cost As A Percent Of Savings

Cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in the savings resulting from the measurement and verification.

7.4.7.8 Overall Advantages

Option B is most advantageous for the owner since savings performance is ensured through continuous metering. Option B offers the same time and cost savings advantages to the contractor in baseline development; however, it will require more time, money, and personnel to maintain the system's performance and metering equipment of the ECM, as well as tracking and documenting the energy savings.

7.4.8 Option C: Energy Savings Analysis

The baseline is based on computer simulation modeling calibrated with utility billing data.
The post-installation is based on computer simulation modeling calibrated with utility billing data.

7.4.8.1 Baseline

The data collected during the initial site survey is used as input data to the simulation program to build the baseline model. The process of simulation calibration then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the output electric (i.e. kWh and kW) and gas (i.e. therms and therms/hr.) use closely match that of the measured data.

For programs that output hourly kWh and therm consumption, and with availability of actual hourly kWh and therm consumption, the mean bias error (MBE), and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model. These statistical concepts are defined below.

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption, and by what percentage. A small value of the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because the possibility exists for cancellation of under-prediction and over-prediction errors from one hour to the next.

The CV(RMSE) is an indication of variability in the data. If the CV(RMSE) is larger, the degree of variability is higher. Comparing monthly measured and simulated data with a low MBE and a low CV(RMSE) means the simulated results match well with the measured results. In general, the absolute value of the MBE should be less than 7 percent, and the absolute value of the CV(MBSE) should be less than 25 percent. These specifications are guidelines only, the owner and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values of measured and simulated values along with the MBE and CV(RMSE) for each month in the year will yield a more comprehensive basis for simulation calibration. For the months where the MBE, the CV(RMSE), or both, are large, model adjustments can be performed. The agency and ESCO should both agree to acceptable levels for the MBE and CV(RMSE).

7.4.8.2 Post-Installation Verification

As with other M&V methods described here in, installation of the ECMs should be verified and the equipment/systems commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). At times spot-metering of the new equipment may be necessary to verify the performance data.
Once the baseline model is calibrated, the baseline input file is saved and the new ECM’s description replaces data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration. This is primarily dependent on the number of changes required to model the new ECMs.

7.4.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit shall consist of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills, and/or submetered data.

Successive annually recalibrated models can be used to calculate savings using either:

- typical meteorological year (TMY) weather and/or average building occupancies (which is the most common option), etc., or
- actual post-installation values for the weather and/or building occupancies, etc.

7.4.8.4 Energy Dollar Savings

To ensure that the simulation model accurately calculates the energy dollar savings, it is important to examine how utility rate structures are applied. Many rate structures use the tier bracket arrangement where the cost at the bottom tier is higher than the tiers above it. The greatest energy savings are generated at the top tier where the rate is lowest. If the average rate is used to calculate the energy dollar savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

For electric demand dollar savings, it is also important to examine how rate structures are applied. Demand dollar savings are generated when the ECM reduces demand (kW) during the peak electric demand period, at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings; however, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Be sure the utility rate structures are entered correctly into the simulation modeling program.

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the baseline. By using this approach, the owner and the contractor share the benefits as well as the risk of changes in utility rates.

7.4.8.5 Performance Assurance

- ensure simulation models account for any field changes in implementation phase
- validate installed equipment and control schemes meet specifications
- validate installed equipment and control schemes operate and perform as specified
- perform annual energy audit consisting of recalibration of the simulation model based on the post-installation ECM data, the previous year's weather, utility bills, and/or submetered data

7.4.8.6 Range Of Accuracy

To accurately model building energy performance and cost, detailed data is required concerning the facility and its energy systems. The data includes the physical layout of a building, its physical properties, intended use, installed equipment, and interaction between energy systems. Additionally, computer simulations of building energy performance and cost will largely depend on the experience of the modeling analyst. In order to obtain accurate results using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is required. If simulation results do not agree with measured whole-building energy data, at times only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, and occupancy schedules, etc., enable the discovery and rectification of discrepancies much more rapidly. Thus, the accuracy of Option C depends on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. The accuracy for this measurement and verification method should normally be less than ten percent of the actual utility bills.

7.4.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in the savings resulting from the measurement and verification.

7.4.8.8 Overall Advantages

Option C is more advantageous to the contractor than to the owner because the contractor develops the building energy simulation model and is considered to be the expert. The contractor has the advantage of manipulating the baseline and the post-installation results since modeling is more of an art form than exact science. The savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate. The owner will need knowledgeable engineers to review the simulation model and validate the model input and assumptions. Utility bills are the best tool the owner has for validating the energy performance results of the model. Option C is more costly to develop for the contractor than it is for the owner, but it can be equally costly to the owner to validate and ensure the performance of the energy project.

7.4.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system’s performance. Two diagrams are specific to variable speed drives and include: 1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads; and 2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads,

7.5 HVAC SYSTEMS - BOILER REPLACEMENT

7.5.1 Description

The measurement and verification process for boiler replacement projects involves calculating or metering the fuel input rate, the heat output rate, and hours of operation at various load conditions. In many cases this will involve a different fuel and/or heating media for the baseline, as opposed to the post-installation case; many performance contracts are justified by fuel-switching or changeout of heat transfer media. For example, an electric boiler may be switched out for a natural gas boiler, or a steam boiler may be switched out for a hot water boiler. Thus, the parameters required are the same in both cases, but the methods for measuring them are different. The discussion in this section can also be applied to domestic water heaters and indirect-fired heating sources, such as heat exchangers, or converters. Unless the system is large enough to warrant a full-time operator who monitors and logs the pertinent data, annual hours of operation must be estimated. This can be accomplished based on interviews with maintenance personnel responsible for the equipment along with a survey of the existing control system and local weather bin data. Simple projects, which merely achieve savings by replacing the heating source, could utilize Option A or Option B, depending on the level of detail and available data.

A more extensive project may include changeout of the secondary components of the heating system in conjunction with the boiler, such as heating coils, radiators, and distribution piping. If the effects of replacing these components must be considered in the project, Option C is the best method. Assumptions must be made regarding the overall system efficiency from fuel-input to end-use device heat output. Also, assumptions must be made on a case-by-case basis, taking into account system leaks, age, and the overall condition. Some qualitative measurements can be made to bring the assumptions more in line with actual conditions, such as thermographic imaging of equipment and piping; conditioned space and secondary equipment temperature and flow measurements; and visual inspection of heating system components. However, no economically effective way of absolutely quantifying the overall system efficiency is available; all assumptions must be reviewed with respect to their impact and validity so that all parties to a performance contract can accept them.

7.5.2 Energy Analysis Parameters

- fuel input rate (MBtu/hr or kW): $\mathbf{P_{ACT}}$
- steam flow : $\mathbf{Flow_S}$ (lb/hr)
- steam pressure: $\mathbf{P_S}$ (psia)
- steam temperature (if superheated steam): $\mathbf{T_S}$ (F)
- feed water flow: $\mathbf{Flow_{FW}}$ (lb/hr)
- feed water temperature: $\mathbf{_{TFW}}$ (F)
- percentage blowdown: **%BD**
- blowdown flow: $\mathbf{Flow_{BD}}$ (lb/hr)
- enthalpy of steam: $\mathbf{h_S}$ (BTU/lb)
- enthalpy of feed water: $\mathbf{h_{FW}}$ (BTU/lb)
- enthalpy of blowdown: $\mathbf{h_{BD}}$ (BTU/lb)
- fuel higher heating value (Btu), specific gravity, pressure base
- boiler part-load efficiency profile
- utility energy rate

7.5.3 Data Gathering

- obtain boiler nameplate data
- perform boiler efficiency tests
- determine existing control method
- obtain boiler part-load efficiency performance profile (from manufacturer’s data or sample metering of boiler’s part-load efficiency performance)
- obtain boiler parameters listed above (from historical logs, sample metering, and/or operator interviews)
- document hours of operation for various load conditions (through observation and/or operator interviews)
- obtain utility rate schedules

7.5.4 Measurement And Verification

The following tables define how energy parameters for the baseline and post-installation are obtained for each of the maintenance and verification options:

Table 5.4.1

PARAMETER VALUES FOR THE BASELINE

M&V OPTION PARAMETERS	OPTION A	OPTION B	OPTION C
fuel input rate, P_{AIT}	nameplate data logs or sample metering	nameplate data; logs or metering	nameplate data; logs or sample metering
steam flow, $flow_s$	nameplate data logs or sample metering	nameplate data; logs or metering	nameplate data, logs or sample metering
steam pressure, P_s	nameplate data logs or sample metering	nameplate data or sample metering	nameplate data or sample metering
steam temperature, T_s	nameplate data logs or sample metering	nameplate data or sample metering	nameplate data or sample metering
feed water flow, $flow_{FW}$	estimated from logs or measured values	estimated from logs or measured values	estimated from logs or measured values
feed water temperature, t_s	estimated from logs or measured values	estimated from logs or measured values	estimated from logs or measured values
blowdown flow, $flow_{BD}$	estimated from logs or measured values	estimated from logs or measured values	estimated from logs or measured values
enthalpy of steam, h_s	steam table	steam table	steam table
enthalpy of feed water, h_{FW}	steam table	steam table	steam table
enthalpy of blowdown, h_{BD}	steam table	steam table	steam table
operating hours profile	stipulated from logs or sample observations	stipulated from logs or sample observations	stipulated from logs, sample observations or modeled data
part-load performance	stipulated based on manufacturer data or measured values	stipulated based on manufacturer data or measured values	stipulated based on manufacturer data or measured values
energy consumption (larger plants may be metered so that energy consumption will be known)	simplified calculations based on parameter data	simplified calculations based on parameter data	calculate using hourly computer simulation modeling based on parameter data
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 5.4.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
fuel input rate, $\mathbf{P_{ACT}}$	nameplate data or sample metering	continuous or periodic metering	nameplate data or sample metering in conjunction with modeling a utility bill analysis
steam flow, $\mathbf{flow_s}$	nameplate data or sample measurements	continuous or periodic metering	nameplate data or sample measurements
steam pressure, $\mathbf{P_s}$	measured values	measured values	measured values
steam temperature, $\mathbf{T_s}$	measured values	measured values	measured values
feed water flow, $\mathbf{flow_{FW}}$	measured values	continuous or periodic metering	measured values
feed water temperature, $\mathbf{T_s}$	measured values	measured values	measured values
blowdown flow, $\mathbf{flow_{BD}}$	calculated or measured values	continuous or periodic metering	calculated or measured values
enthalpy of steam, $\mathbf{h_s}$	steam table	steam table	steam table
enthalpy of feed water, $\mathbf{h_{FW}}$	steam table	steam table	steam table
enthalpy of blowdown, $\mathbf{h_{BD}}$	steam table	steam table	steam table
operating hours profile	stipulated	continuous or periodic metering	facility energy modeling calculations/utility bill analysis
part-load performance	stipulated based on manufacturer data or measured values	continuous or periodic metering	manufacturer data/ facility energy modeling
energy consumption	simplified calculations	continuous or periodic metering	calculated using hourly computer simulation modeling/utility bill analysis
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.5.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view and from the contractor's point of view.

Table 5.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				metering is required	longer development period
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
average probability of dispute	lower probability of dispute		Some owner risk associated with stipulation of savings		higher probability of dispute

Table 5.5.2
OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	longer development period
simplified verification process	best monitoring of long term performance	some monitoring of performance	little or no monitoring of performance	continual validation requires more accounting	continual validation requires more accounting
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
	lower probability of dispute		higher probability of dispute		higher probability of dispute
outside variables stipulated so as not to affect savings		effect of outside variables more easily accounted for in modeling		outside variables such as weather and occupancy patterns can affect savings	

7.5.6 Option A: Energy Savings Analysis

Typically, this option is only applicable in smaller systems where the heating source is being switched out and the effect of secondary heating system elements, such as distribution piping and heat exchangers, is neglected, or is the same in the baseline as in the post-installation case (i.e. a base-wide conversion of local building boilers from fuel oil to natural gas). The baseline is based on stipulated parameters and short-term sample metering is recommended, although stipulations can be based on manufacturer's data and survey observations. The post-installation performance is based on stipulated parameters. Again, short-term sample metering is recommended but not required.

7.5.6.1 Baseline

The baseline is established by determining the part-load performance of the existing boiler. The fuel input rate (in Btu/hr for fuel-fired boilers; kW for electric boilers), boiler output, and hours of operation at various load conditions are calculated using any, or all, of the methods listed in the M&V baseline options parameters table, Option A. The part-load performance curve for the baseline may be obtained directly if the existing boiler is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make an accurate estimate of baseline operating parameters. The baseline performance efficiency is used to calculate the baseline energy consumption for various load conditions. If the boiler's auxiliary equipment (pumps and fans) is also being replaced as part of the project, their energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the sections dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application). Assuming that no direct-metered data for fuel input and boiler output is available (or is suspect as to its validity), the following formulas are used in calculating the baseline energy for various load conditions:

Fuel Input Rate (Btu/hr) = Fuel Flow Rate(Unit/Hr) x Higher Heating Value (Btu/Unit) @ Various LoadConditions (preferably in a minimum of 10% increments)

Boiler Heat Output Rate (Btu/hr) = [Flow$_S$ (lbs/hr) x (h$_S$ - h$_{FW}$)(Btu/lb)] + [Flow$_{BD}$ (lbs/hr) x (h$_{BD}$ - h$_{FW}$) (Btu/lb)] @ Corresponding Load Conditions

The profile of hours of operation at various load conditions is stipulated based on bin temperature data, if applicable (generally not applicable for process loads). For process loads, sample metering, or historical data, is required to establish a credible profile.

Baseline Efficiency Curve = Boiler Output Rate @ Each Load Increment / Fuel Input Rate @ Each Load Increment

Baseline Energy Consumption @ Corresponding Load Conditions = Summation

of

(Boiler Output Rates @ Each Load Increment) x (Hours of Operation @ Each Load Increment) / Boiler Baseline Efficiency @ Each Load Increment

7.5.6.2 Post-Installation Verification

The post-installation's performance efficiency is established by determining the part-load performance of the new boiler. The fuel input rate (MBtu/hr for fuel-fired boilers; kW for electric boilers), boiler output, and hours of operation at various load conditions are calculated using the parameters listed on the post-installation M&V options parameters table, Option A. The retrofit part-load performance curve is stipulated based on the boiler manufacturer's data, or by sample measurements of boiler performance at various load conditions. The performance data is used to determine energy consumption as compared to the baseline performance for the corresponding load conditions. If boiler auxiliary equipment (pumps and fans) is also being replaced, their energy consumption must also be calculated. The methodology for calculating the new system's energy consumption is the same as described in the previous section for baseline performance calculations, but using the stipulated efficiency of the newly installed system instead of the baseline system efficiency. Again the system performance curve is established by agreement on manufacturer's performance data, post-installation sample measurements, or simplified calculations using bin data.

7.5.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. Following is the formula used in performing the energy savings calculations.

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

Keep in mind that in a situation involving an electric boiler, electric demand costs/savings must also be taken into account.

7.5.6.4 Energy Dollar Savings

To ensure the simulation model accurately calculates the energy (MBtu) savings, it is important to examine how the utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 with all usage above that level priced at $0.35. Examine the overall base utility usage to determine what the real cost of energy saved from a particular ECM will be. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings for a case like this, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels such as natural gas, the demand charge, if present, is a negotiated amount per month. Also, examine closely the effect of ECMs on "firm" energy charges vs. "interruptible" rates. Dollar savings are calculated by applying an appropriate rate structure to energy and demand savings of the ECM. The following formulas are used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefit as well as the risk of changes in utility rates.

7.5.6.5 Performance Assurance

- verify that new boiler(s) meet specifications--check submittals and nameplates
- validate performance--perform routine annual combustion efficiency testing

7.5.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on the estimate of the stipulated operating hours. However, run-hours at various load conditions are generally difficult to estimate because of the system's interdependent variables, such as the effects of occupancy, usage patterns of building plug loads, lighting on heat load, variable process or domestic hot water loads on the system, level of system maintenance, control schemes, and environmental (i.e. weather) operating conditions. Thus, accuracy for this M&V method can be off by a wide margin if the developed load profile is not representative of true operating conditions.

7.5.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the total energy dollar savings over the term of the energy performance contract.

7.5.6.8 Overall Advantages

Option A **can** be equally advantageous to the contractor and the owner because savings performance is guaranteed based on stipulations and does not require as much time, money, or personnel from either party in order to measure and verify the savings. However, if stipulations are not made to monitor equipment operating efficiencies after installation and to correct the savings if equipment performance is lower than stipulated, this option is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that the stipulated equipment performance is being met.

Option A can be helpful in simple local boiler replacement projects (boilers less than 10 MBtu/hr in size) but is not recommended for larger boilers, or central plants, where a boiler serves multiple buildings. Metering devices (Option B) are a more accurate and cost effective option for larger projects and are normally required on larger boiler systems. Option A is not recommended in complete changeout of heating systems where other system components, such as radiators or heat exchangers, are being replaced along with the boiler.

7.5.7 Option B: Energy Savings Analysis

This option is typically only applicable in systems where the heating source is being switched out and the effect of secondary heating system elements, such as distribution piping and heat exchangers, is neglected, or is the same in the baseline as in the post-installation (i.e. a base-wide conversion of local building boilers from fuel oil to natural gas), or is a one-for-one boiler replacement in a central plant. The baseline is based on stipulated parameters--short term sample metering, at a minimum, is required. Post-installation verification is achieved by system-level (boiler input and output) continuous metering.

7.5.7.1 Baseline

The baseline is established by determining the part-load performance of the existing boiler. The fuel input rate (in Btu/hr for fuel-fired boilers; kW for electric boilers), boiler output, and hours of operation at various load conditions are calculated using any, or all, of the methods listed in the M&V baseline options parameters table, Option B. The part-load performance curve for the baseline may be obtained directly if the existing boiler is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make an accurate estimate of baseline operating parameters. The baseline performance efficiency is used to calculate the baseline energy consumption for various load conditions. If the boiler auxiliary equipment (pumps and fans) is also being replaced as part of the project, their energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the sections dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application). Assuming that no direct-metered data for fuel input and boiler output is available (or is suspect as to its validity), the following formulas are used in calculating the baseline energy for various load conditions:

Fuel Input Rate (Btu/hr) = Fuel Flow Rate (Unit/Hr) x Higher Heating Value (Btu/Unit) @ Various Load Conditions (Preferably In A Minimum Of 10% Increments)

Boiler Heat Output Rate (Btu/Hr) = [$Flow_S$ (lbs/hr) x (h_S - h_{FW}) (Btu/lb)] + [FlowBD (lbs/Hr) x (h_{BD} - h_{FW}) (Btu/lb)] @ Corresponding Load Conditions

The profile of hours of operation at various load conditions is stipulated based on bin temperature data, if applicable (generally not applicable for process loads). For process loads, sample metering or historical data is required to establish a credible profile.

$$\text{Baseline Efficiency Curve} = \frac{\text{Boiler Output Rate @ Each Load Increment}}{\text{Fuel Input Rate @ Each Load Increment}}$$

Baseline Energy Consumption @ Corresponding Load Conditions = Summation of

$$\frac{\text{(Boiler Output Rates @ Each Load Increment) x (Hours of Operation @ Each Load Increment)}}{\text{Boiler Baseline Efficiency @ Each Load Increment}}$$

7.5.7.2 Post-Installation Verification

The energy performance of the new system is determined by metering continuously or for a specified period of time. At a minimum, totaling meters are required for fuel input and heat output and run-time meters are recommended. A separate meter, which serves only boiler auxiliaries (pumps and fans), is recommended if the auxiliaries are also being replaced as part of the project. However, in most cases, the auxiliary equipment will be spot-metered before and after installation to estimate energy consumption. If the boiler input and output is directly metered, no calculations are necessary; if indirect measurements (such as flow and temperature) are made, the same equations used for Option A are used to determine fuel input, heat output, and energy consumption.

7.5.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formula is used in performing energy savings calculations.

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

Keep in mind that in a situation involving an electric boiler, electric demand costs/savings must also be taken into account.

7.5.7.4 Energy Dollar Savings

To ensure that the simulation model accurately calculates the **energy** (MBtu) savings, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 with all usage above that level priced at $0.35. Examine the overall base utility usage to determine what the real cost of the energy saved with a particular ECM will be. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings for a case like this, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels, such as natural gas, the demand charge, if present, is a negotiated amount per month. Also, examine closely the effect of ECMs on "firm" energy charges vs. "interruptible" rates. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.5.7.5 Performance Assurance

- verify that new boilers meet specifications--check submittals and nameplates
- validate performance--check and calibrate meter periodically

7.5.7.6 Range Of Accuracy

The performance of the ECM will be based on metered data and the utility rate, which are generally well-defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline and should normally be within ten percent.

7.5.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The additional cost of Option B should not exceed the expected increase in savings resulting from using this M & V option.

7.5.7.8 Overall Advantages

Option B is most advantageous for the owner because the savings performance is ensured through continual metering. However, Option B will require more time, money, and personnel to maintain the system's performance and metering equipment for an ECM as well as to continually track and document energy savings. Option B has the potential to put the contractor at great risk if variables beyond his control result in little or no savings for the project. Some stipulation of variables, such as occupancy and usage patterns, may be required in order to utilize Option B. Conversely, the owner should broker the savings agreement under this option so as to capture part, or all, of any windfall savings resulting from this project.

7.5.8 Option C: Energy Savings Analysis

This option is recommended only for projects which involve replacement of other heating system components, such as heat exchangers, radiators, or distribution systems, in conjunction with boiler replacement. Before using Option C, consider Option A for small-scale projects of this type involving small systems and/or very few buildings. Option C should be used only when the simplified assumptions and calculations of Option A are considered inadequate, or the project scope is too extensive to effectively meter (Option B) all the components. The baseline is fixed on computer simulated modeling calibrated with utility billing data, nameplate data, and/or spot measurements. The post-installation is based on computer simulated modeling calibrated with utility billing data, nameplate data, and/or spot measurements.

7.5.8.1 Baseline

The data collected during the initial site survey is used as input to the simulation program to build the baseline model. The process of calibrating the model then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data.

Only calibrations with utility data are described in this section. The simulation model is calibrated when the electric (i.e. - kWh and kW) and fuel (MBtu) usage for a given time period (usually a year) are within approximately 10 percent of the totals for the measured data.

Using programs that simulate hourly energy consumption along with the available actual hourly kWh and fuel consumption, the mean bias error (MBE) and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption and by what percentage. A small value for the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because the possibility exists for cancellation of under-prediction and over-prediction errors from one hour to the next.

The CV(RMSE) is an indication of variability in the data. The degree of variability is higher with a large CV (RMSE). Comparing monthly measured and simulated data with a low MBE and CV(RMSE) means the simulated results are well matched with the measured results. In general, the absolute value of the MBE should be less than 7 percent, and the absolute value of the CV(MBSE) should be less than 25 percent. The specifications are guidelines only and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values for the measured and simulated values, the MBE, and CV(RMSE) for each month in the year will yield a more comprehensive basis for simulation calibration. For the months where the MBE, the CV(RMSE), or both, are large, an indicated model adjustment can be achieved. The agency and ESCO should agree to acceptable levels for the MBE and CV(RMSE).

7.5.8.2 Post-Installation Verification

As with other M&V methods described in this document, the equipment installation for the ECMs should be verified and the system(s) commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify performance data.

Once the baseline model is calibrated, the baseline input file is saved. For the ECM simulation, the new equipment performance data replaces the same parameters that were used in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration as described in the previous section, depending primarily on the number of changes required to model the new ECMs.

7.5.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation's ECM data, the previous year's weather, utility and/or submetered data.
Successive annually recalibrated models can be used to calculate savings using the following data:

- typical meteorological year's (TMY) weather and/or average building occupancies (this is the most common option), or
- actual post-installation values for the weather and/or building occupancies (more time-consuming and costly to verify), etc.

7.5.8.4 Energy Dollar Savings

To ensure the simulation model accurately calculates the energy (MBtu) savings, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 with all usage above that level priced at $0.35. Examine the overall base utility usage to determine what the real cost of the energy saved with a particular ECM will be. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings for a case like this, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels, such as natural gas, the demand charge, if present, is a negotiated amount per month. Also, closely examine the effect of ECMs on "firm" energy charges versus "interruptible" rates. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Be sure the utility rate structures are entered correctly in the simulation modeling program. Also, consider how the demand is modeled compared to actual metering of the demand charge. Generally, demand is metered at one location for the entire base, or at several locations, which may be billed with a conjunctive demand charge. ECM modeling of demand is typically not performed on a basewide level; thus, it is sometimes difficult to determine the actual effect of a particular ECM on a basewide demand charge.

The following formulas are used in performing dollar savings calculations:

$$\text{Energy Dollar Savings} = \text{Energy Savings} \times \text{Affected Rate}$$

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \times \text{Affected Rate}$$

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.5.8.5 Performance Assurance

- ensure the simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes match with agreed-to specifications
- perform annual, or periodic, audits consisting of a new simulation model that is calibrated based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data

7.5.8.6 Range Of Accuracy

To accurately model building energy performance, a high degree of detail in data concerning the facility and its energy systems is required. Some of the data includes the physical layout of a building, its properties, usage schedules, installed equipment, and the interaction between energy systems. In addition, computer simulations of building energy performance will largely depend on the experiences of the modeling analyst. In order to obtain an accurate result using this method, calibrate the simulation model with actual utility metering data and/or short term metering of individual systems. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, and occupancy schedules, etc. enable the discovery and rectification of discrepancies much more rapidly. Accuracy for Option C depends on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this method should be within ten percent of the actual utility bills.

7.5.8.7 Range Of Cost As A Percent Of Savings

Costs for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. Additional costs for Option C should not exceed the expected increase in savings resulting from this option.

7.5.8.8 Overall Advantages

Option C is typically more advantageous to the contractor than to the owner, because the contractor is the one responsible for developing the building energy simulation model and is considered to be the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models. The savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate since energy modeling is more an art than a science. The owner will require knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tool the owner has for validating the model. Option C is more costly to develop for the contractor than it is for the owner, but it can be equally costly for the owner to validate and ensure the performance of the energy project.

7.5.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The four diagrams specific to HVAC systems are:

1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Load;
2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
3) Figure 4, Hot Water Boiler; and
4) Figure 5, Steam Boiler.

7.6 HVAC SYSTEMS - INFRARED HEATING

7.6.1 Description

The measurement and verification (M&V) process for replacement of warm-air-circulation heating systems with direct-infrared heating systems involves comparing the system's annual fuel consumption for maintaining the heated space at the same level of comfort. Since infrared heating systems are typically used to replace unit heaters in warehouses, hangars or other open, high bay areas, direct metered data at the system level is not typically available. Thus Options A or C are more frequently used for this ECM.

The infrared heating system heats objects, not the air mass, through direct and indirect radiation. Heat loss from radiant systems depends on the mass and thermal conductivity of the objects in the heated space, whereas heat loss from warm air systems depends on transmission and infiltration losses. In addition, the energy output intensity of the infrared heating system is a function of the distance from the heated object. Because of the differences in operating characteristics, M&V processes based on comparisons of the systems' part-load performance are very difficult.

7.6.2 Energy Analysis Parameters

- conditioned space heat loss: **HL**
- design temperature rise: **TDTR**
- correction factor due to radiant effects (based on ASHRAE empirical data): **K**
- empirical correction factor for heating effect vs. 65°F days: **CD**
- mounting height adjustment factor: **CFMH**
- (typically 1% per foot increase in system energy input requirement for mounting height above 20 feet, CFMH >1)
- degree days: **D**
- heating value of fuel used: **V**
- thermal efficiency of heating system: **E**
- factor for fuel unit usage per unit heat loss: **U**
- operating hours, **Hr**
- heating system's annual or monthly fuel consumption (if available)
- utility energy rate

7.6.3 Data Gathering

- perform building envelop survey
- perform building heat loss calculation or obtain building heat loss design data
- determine existing type of heating systems
- obtain existing heating equipment's performance profile (manufacturer's data or sample metering of part-load efficiency performance)
- obtain historical fuel usage information, if available
- document space conditions maintained
- document hours of operation
- obtain electric rate schedules

7.6.4 Measurement And Verification

The following tables define how the parameters for both the baseline and post-installation are obtained for each M&V option.

Table 7.6.4.1

PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
facility heat loss, H_L Btu/hr	calculated based on building design	calculated based on building design	calculated or building energy modeling
design temperature rise, T_{DTR}	stipulated based on measurements or design data	stipulated based on measurements or design data	stipulated based on measurements or design data
correction factor based on ASHRAE calculated heat loss due to radiant effects, K	ASHRAE tables	ASHRAE tables	ASHRAE tables
empirical correction factor for heating effect vs. 65 F degree days, C_D	ASHRAE tables	ASHRAE tables	ASHRAE tables
mounting height adjustment factor, CF_{MH}	site observations	site observations	site observations
degree days: D	weather data	weather data	weather data
heating value of fuel used, v Btu/unit	energy conversion/ energy value tables	energy conversion/ energy value tables	energy conversion/ energy value tables
heating system part load efficiency performance	stipulated based on manufacturer data or measured values	stipulated based on manufacturer data or measured values	stipulated through utility bill analysis or energy modeling calculations
fuel or energy consumption	stipulated calculations based on available data or measured values	stipulated calculations based on available data or measured values	stipulated through utility bill analysis or energy modeling calculations
usage profile of operating hour, hr	stipulated based on site survey and weather data	stipulated or established through post-installation metering	stipulated through utility bill analysis or energy modeling calculations
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.6.4.2

PARAMETER VALUES FOR THE POST-INSTALLATIOIN

M&V Option Parameters	Option A	Option B	Option C
facility heat loss, H_L Btu/hr	calculated based on building design	calculated based on building design	calculated or building energy modeling
design temperature rise, T_{DTR}	stipulated based on measurements or design data	stipulated based on measurements or design data	stipulated based on measurements or design data
correction factor based on ASHRAE calculated heat loss due to radiant effects, K	heating equipment/system manufacturer performance data	heating equipment/system manufacturer performance data	heating equipment/system manufacturer performance data
empirical correction factor for heating effect vs. 65°F days, C_D	ASHRAE, 1985 fundamentals reference handbook	ASHRAE, 1985 fundamentals reference handbook	ASHRAE, 1985 fundamentals reference handbook
mounting height adjustment factor, AF_{MH}	manufacturer's data, site observation	manufacturer's data, site observation	manufacturer's data, site observation
degree days: D	weather data	n/a	weather/utility data or building energy modeling
heating value of fuel used, V Btu/unit	energy conversion/ energy value tables	energy conversion/ energy value tables	energy conversion/ energy value tables
heating system part load efficiency performance	n/a	n/a	stipulated based on manufacturer data or measured values
fuel or energy consumption	stipulated based on manufacturer data or measured values	continuous or periodic metering	computer simulation/ building energy modeling
usage profile of operating hour, hr	stipulated based on observations and weather data	continuous or periodic metering	utility bill analysis/energy modeling
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.6.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view and from the contractor's point of view.

Table 7.6.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	longer development period
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
average probability of dispute	lower probability of dispute		Some government risk associated with stipulation of savings		higher probability of dispute

Table 7.6.5.2

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	longer development period
simplified verification process	best monitoring of long term performance	some monitoring of performance	little or no monitoring of performance	continual validation requires more accounting	
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
	lower probability of dispute		higher probability of dispute		higher probability of dispute
outside variables stipulated so as not to affect savings		effect of outside variables more easily accounted for in modeling		outside variables such as weather and occupancy patterns can affect savings	

7.6.6 Option A: Energy Savings Analysis

This option is used only where the project cannot bear the cost of metering or facility modeling. The baseline and the ECM energy usage calculations are based on stipulated parameters--short term sample metering is preferred, but is typically not used as it is difficult and costly to meter the ECM at the system level.

7.6.6.1 Baseline

The baseline is established by determining the existing heating system's fuel consumption over the performance interval (monthly or annually) and the space condition maintained. The baseline energy consumption data may be obtained directly if the existing heating system is equipped with metering and if historical data is available; otherwise, data must be obtained by sample measurement and/or stipulated calculations. If the existing heating system's auxiliary equipment (pumps and fans) is being replaced as part of the project, their energy performance and consumption must be calculated and included as part of the overall system baseline. (See the M&V option for constant load motor and variable speed drives for the appropriate M&V application.) Typically the existing system remains in place to serve the portion of the facility which cannot utilize infrared heating, so the use of Option A requires an assumption as to what percentage of the current energy usage is attributed to the area being retrofitted with infrared radiant heaters. The following formulae are used in performing baseline energy savings calculations.

$$\text{Baseline Energy Consumption} = \frac{H_L(\text{Btu/Hr}) \times D\ (\text{Degree*Day}) \times 24\ (\text{Hr/Day})}{\text{System Efficiency} \times T_{DTR}(\text{Degree})}$$

or

Heating System Input From Historical Log

or

Measured Fuel Input Rate = Fuel Flow Rate (Unit/Hr) x Higher Heating Value (Btu/Unit)
(Btu/Hr) @ VARIOUS BASELINE LOAD CONDITIONS

Baseline Energy Consumption = Sum [Heating System Fuel Input Rate (Btu/Hr) x Hours of Operation] @ VARIOUS BASELINE LOAD CONDITIONS

The profile for hours of operation at various load conditions is a stipulated estimate based on heating degree day temperature data.

7.6.6.2 Post-Installation Verification

The savings analysis for the post-installation is established by determining the infrared heating system's fuel consumption over the performance interval (monthly or annually) required to maintain the same level of comfort. For Option A, this is established by calculations based on parameters previously described above. If the heating system's auxiliary equipment (pumps and fans) is being replaced as part of the project, energy performance and consumption must also be calculated and included as part of overall system baseline. (See the M&V option for constant load motor and variable speed drives for the appropriate M&V application.)

The following formulae are used in performing the post-installation's energy savings calculations.

$$\text{Post-Installation Energy Consumption} = H_L(\text{Btu/Hr}) \times AF_{MH} \times D\ (\text{Degree*Day}) \times 24\ (\text{Hr/Day}) \times CD\ K \times T_{DTR}(\text{Degree})$$

or

$$\text{Sampling Measurement Of Fuel Input Rate(Btu/Hr)} = \underline{\text{Fuel Flow Rate} \times \text{Higher Heating Value}}\ _{\text{@ Various Baseline Load Conditions}}$$

Post-Installation Energy Consumption = Sum [Heating System Fuel Input Rate(Btu/Hr) x Hours Of Operation] @ VARIOUS BASELINE LOAD

CONDITIONS

The profile for hours of operation at various load conditions is a stipulated estimate based on heating degree days.

7.6.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

For cases involving demand charges, the effect of increased or reduced energy demand must be considered in calculating the savings.

7.6.6.4 Energy Dollar Savings

To ensure the simulation model accurately calculates the **energy** (MBtu) savings, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 while all usage above that level is priced at $0.35. Examine the overall base utility usage to determine what the real cost of energy saved from a particular ECM will be. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings for a case like this, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels, such as natural gas, the demand charge, if present, is a negotiated amount per month. Also, closely examine the effect of ECMs on "firm" energy charges versus "interruptible" rates. Dollar savings are calculated by applying an appropriate rate structure to both the energy and demand savings of the ECM. The following formulas are used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate

Demand Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.6.6.5 Performance Assurance

- verify installed infrared heating systems meet specifications
- verify performance by spot metering or observations

7.6.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on the estimate of the stipulated operating hours; however, the run-hours at various load conditions are generally difficult to estimate because of the system's interdependent variables, such as the effects of occupancy and usage patterns on infiltration rates; building plug loads and lighting; variable process or domestic hot water loads on the system at the baseline level; level of system maintenance; control schemes; and environmental (i.e. weather) operating conditions. Thus, accuracy for this M&V method can be off by a wide margin if the developed load profile is not representative of true operating conditions.

7.6.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.6.6.8 Overall Advantages

Option A can be equally advantageous to both the contractor and the owner because savings performance is guaranteed based on stipulations and does not require as much time, money, and personnel from either party in order to measure and verify the savings. However, if stipulations are not made to monitor equipment operating efficiencies after installation and to correct the savings if equipment performance is lower than stipulated, this option is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that the stipulated equipment performance is being met.

Option A can be helpful in simple one-for-one heating system replacement projects (less than 10 MBtu/hr in size), but it is not recommended for projects involving larger systems or central plants where a boiler serves multiple buildings. Metering devices (Option B) are a more accurate and cost effective option for larger projects. Option A is not recommended in the changeout of complete heating systems where other types of heating systems are being installed along with a radiant heating system.

7.6.7 Option B: Energy Savings Analysis

This option is only applicable in systems where the heat source is switched out and the effect of secondary heat system elements, such as distribution piping and heat exchangers, is neglected, or is the same in the baseline as in the post-installation case (i.e. a base-wide conversion of hangar heating from gas-fired heating and ventilating units to gas-fired radiant heat). The baseline is based on stipulated parameters--short term sample metering is recommended. Post-installation verification is achieved by system-level metering.

7.6.7.1 Baseline

The baseline is established by determining the existing heating system's fuel consumption over the performance interval (monthly or annually) and the space condition maintained. Energy consumption data for the baseline may be obtained directly if the existing heating system is equipped with metering and if historical data is available; otherwise, sample measurement and/or stipulated calculations are required. If the heating system's auxiliary equipment (pumps and fans) is being replaced as part of the project, energy performance and consumption must be calculated and included as part of overall system baseline. (See the M&V option for constant load motor and variable speed drives for the appropriate M&V application.) The following formulas are used in performing energy savings calculations for the baseline.

$$\text{Baseline Energy Consumption} = \frac{H_L\text{(Btu/Hr)} \times \text{D (Degree*Day)} \times \text{24 (Hr/Day)}}{\text{System Efficiency} \times T_{DTR}\text{ (Degree)}}$$

or

Heating System Input: From Historical Log

or

Measured Fuel Input Rate = Fuel Flow Rate (Unit/Hr) x Higher Heating Value (Btu/Unit) (Btu/Hr) @ Various Baseline Load Conditions

Baseline Energy Consumption = Sum [Heating System Fuel Input Rate (Btu/Hr) x Hours of Operation] @ VARIOUS BASELINE LOAD CONDITIONS

The profile for hours of operation at various load conditions is a stipulated estimate based on heating degree day temperature data, if applicable (generally not applicable for process loads).

7.6.7.2 Post-Installation Verification

Energy savings for the post-installation are established by continuous or periodic metering of the infrared heating system's fuel consumption over a specified performance interval (monthly or annually). Following is the formula used in performing the energy savings calculations for the post-installation if periodic metering is used instead of continuous metering:

Post-Installation Energy Consumption = Sum [Fuel Input Rate (Btu/Hr) x Hour of Operation]

7.6.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and post-installation energy consumption. Following is the formula used in performing energy savings calculations:

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

7.6.7.4 Energy Dollar Savings

To ensure that energy (MBtu) savings are calculated accurately, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 while all usage above that level is priced at $0.35. Examine the overall base utility usage to determine what the real cost will be for energy saved using a particular

ECM. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings for a case like this, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels, such as natural gas, the demand charge, if present, is a negotiated amount per month. Additionally, closely examine the effect of ECMs on “firm” energy charges versus “interruptible” rates. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of an ECM. Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate

Demand Dollar Savings = $[k_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.6.7.5 Performance Assurance

- validate infrared heating systems meet specifications
- validate installed infrared heating systems operate and perform as specified
- check metering performance periodically to ensure meter functions properly

7.6.7.6 Range Of Accuracy

The performance of the ECM will be based on the metering data and the utility rate, which are well defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline and should be within ten percent of actual savings.

7.6.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from Option B.

7.6.7.8 Overall Advantages

Option B is most advantageous for the owner because savings performance is ensured through continual metering; however, Option B will require more time, money, and personnel in maintaining the system’s performance and metering equipment as well as tracking and documenting the energy savings. Option B has the potential to put the contractor at great risk if variables beyond his control result in little or no savings for the project. Some stipulation of variables, such as occupancy and usage patterns, may be required in order to utilize Option B. Conversely, the owner should broker the savings agreement under this option so as to capture part, or all, of any windfall savings which result from the project.

7.6.8 Option C: Energy Savings Analysis

Before using Option C, Option A should be considered for projects of this type involving small systems and/or very few buildings. Option C should be used only where the simplified assumptions and calculations of Option A are considered inadequate. The baseline and the ECM energy analysis are based on modeling, or simplified calculations, using utility bill analysis, nameplate data and/or spot measurements.

7.6.8.1 Baseline

The data collected during the initial site survey is used as input to the simulation program to build the baseline model. The process of calibrating the model then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the electric (i.e. - kWh and kW) and fuel (MBtu) usage for a given time period (usually a year) are within approximately 10 percent of the totals for the measured data.

For programs that simulate hourly energy consumption, and with availability of actual hourly kWh and fuel consumption, the mean bias error (MBE) and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption and by what percentage. A small value for the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because the possibility exists for cancellation of under-prediction and over-prediction errors from one hour to the next.

The CV(RMSE) is an indication of variability in the data. The degree of variability is higher with a large CV (RMSE). Comparing monthly measured and simulated data with a low MBE and CV(RMSE) means the simulated results are well matched with the measured results. In general, the absolute value of the MBE should be less than 7 percent, and the absolute value of the CV(MBSE) should be less than 25 percent. The specifications are guidelines only and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values for the measured and simulated values, the MBE, and CV(RMSE) for each month in the year will yield a more comprehensive basis for simulation calibration. For the months where the MBE, the CV(RMSE), or both, are large, an indicated model adjustment can be achieved. The agency and ESCO should agree to acceptable levels for the MBE and CV(RMSE).

7.6.8.2 Post-Installation Verification

As with other M&V methods described in this document, the equipment installation of the ECMs should be verified and the system(s) commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.

Once the baseline model is calibrated, the baseline input file is saved. For the ECM simulation, the new equipment performance data replaces the same parameters that were used in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration as described in the previous section, depending primarily on the number of changes required to model the new ECMs.

7.6.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.
Successive annually recalibrated models can be used to calculate savings using the following data:

- typical meteorological year's (TMY) weather and/or average building occupancies, (the most common option); or
- actual post-installation values for the weather and/or building occupancies (more time-consuming and costly to verify), etc.

7.6.8.4 Energy Dollar Savings

To ensure the simulation model accurately calculates **energy** (MBtu) savings, examine the way utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 therms of gas used in a month may cost $0.40 with all usage above that level priced at $0.35. Examine the overall base utility usage to determine the real cost of energy saved when using a particular ECM. With this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand during peak periods. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. For fuels such as natural gas, the demand charge, if present, is a negotiated amount per month. Examine closely the effect of the ECMs on "firm" energy charges versus "interruptible" rates. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM.

Make sure utility rate structures are entered correctly in the simulation modeling program. Additionally, consider how demand is modeled compared to actual metering of demand charges. In general, demand is metered at one location for the entire base, or at several locations which may be billed with a conjunctive demand charge. However, ECM modeling of demand is typically not performed on a basewide level, which makes it difficult to determine the actual effect of a particular ECM on a basewide demand charge.

Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this approach, the owner and the contractor share the benefits as well as the risk of possible changes in utility rates.

7.6.8.5 Performance Assurance

- ensure simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes match with agreed-to specifications
- perform annual, or periodic audits, consisting of a new simulation model which is calibrated on the post-installation ECM data, the previous year’s weather, utility bills and/or submetered data

7.6.8.6 Range Of Accuracy

To accurately model building energy performance, detailed data concerning the facility and its energy systems is required. Some of the data includes the physical layout of a building, its properties, usage schedules, installed equipment, and the interaction between energy systems. Additionally, computer simulations of building energy performance will largely depend on the experience of the modeling analyst. To obtain accurate results using this method, calibrate the simulation model with actual utility metering data and/or short term metering of individual systems. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc. enable the discovery and rectification of discrepancies much more rapidly. Accuracy for Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this method should normally be within ten percent of the actual utility bills.

7.6.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. Additional costs for Option C should not exceed the expected increase in savings resulting from this option.

7.6.8.8 Overall Advantages

Option C is typically more advantageous to the contractor than the owner because the contractor is largely responsible for developing the building energy simulation model and is considered the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models The savings are often guaranteed based on results of the simulation model; however, long term energy performance is difficult to validate since energy modeling is more an art than a science. The owner will need knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tool the owner has for validating the model. Option C is more costly to the contractor to develop than it is for the owner, but it can be equally costly to the owner to validate and ensure performance of the energy project.

7.6.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The four diagrams specific to HVAC systems are: 1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads; 2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads; 3) Figure 4, Hot Water Boiler; and 4) Figure 5, Steam Boiler.

7.7 STEAM TRAP SYSTEMS

7.7.1 Description

Steam traps are designed to remove condensate and non-condensable gases from steam systems. The different types of traps include inverted bucket, thermodynamic disc, thermostatic, float and trap with thermostatic air vent (F&T), and differential controller. Most types of traps are designed to fail open so that they leak unused steam through the system. Some types of traps fail closed so that they pass neither condensate nor steam, in which case the condensate will build up and back into the coil. The failed trap quickly identifies itself by not providing the required heat. Other types of traps will fail unpredictably in a closed or opened position. The strategy for energy conservation measures (ECMs) for steam trap replacement involves:

- replacement of failed traps to minimize steam and energy losses
- properly sizing the trap to match the steam load

7.7.2 Energy Analysis Parameters

- condensate/steam loads on the traps
- steam trap orifice diameter (inches)
- steam trap inlet pressure (psi)
- steam trap back pressure (psi)
- cost of steam ($/MBtu)

7.7.3 Data Gathering

- types, sizes, and quantity of traps involved in the projects
- traps' maintenance history, including failure rate, replacement practice, cost, etc.
- steam trap orifice diameter (inches)
- steam trap inlet pressure (psi)
- steam trap back pressure (psi)
- cost of steam ($/MBtu)

7.7.4 Measurement And Verification

The steam trap replacement project is an ECM in which savings are based on steam savings from an annual replacement of identified failed steam traps. Due to the impractical cost of metering (steam/condensate flows, inlet and outlet temperatures, and inlet and outlet pressures on many traps) when compared to the cost of new steam traps, and with difficulty in determining accurate energy parameters required for modeling (types, functions, orifice sizes, control method, load conditions, and system dynamics), Option A is the only practical choice for performing measurement and verification of steam trap replacement projects.

7.7.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view and the contractor's point of view.

Table 7.7.5.1

OPTIONS FOR ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
low cost	n/a	n/a		n/a	n/a
easy to develop	n/a	n/a		n/a	n/a
	n/a	n/a	accuracy depends on stipulated values	n/a	n/a
	n/a	n/a	no guarantee of energy savings performance	n/a	n/a

Table 7.7.5.2

OPTIONS FOR ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
low cost	n/a	n/a		n/a	n/a
easy to develop	n/a	n/a		n/a	n/a
	n/a	n/a	accuracy depends on stipulated values	n/a	n/a
guaranteed shared energy savings performance	n/a	n/a		n/a	n/a

7.7.6 Option A: Energy Savings Analysis

The baseline is based on stipulated parameters.
The energy savings analysis for the post-installation is based on stipulated parameters.

7.7.6.1 Baseline

Determination of the baseline for replacement of steam traps involves acquiring data on steam equipment and system operating parameters (pressure, temperature, flow rate, and consumption). Steam trap types, sizes, quantity of traps involved in projects, failure rate, replacement practice, and costs are acquired. From the data gathered, conditions are stipulated and steam loss calculations are performed to determine the baseline steam losses. Due to the relatively small size and large quantity of existing steam traps, continuous monitoring would not be a cost effective way of measuring the steam loss. However, a combination of visual temperature differential measurement, or ultra-sonic detection devices, can periodically be used to determine the operating condition (functional or faulty) of steam traps. The cost of steam generation is applied to the calculated steam losses to determine the baseline energy cost. Figures 7.6.1.1 and 7.6.1.2 are orifice inlet pressure (psi) versus saturated steam flow (lbm/hr) graphs showing the amount of steam flow through a given orifice when the trap fails open and condensate is not present. Steam traps are generally oversized for the load because of design safety factors; thus, when the traps fail open, condensate will quickly pass through the orifice and steam will continually flow through the traps. Figures 7.6.1.1 and 7.6.1.2 can be used to estimate steam loss through a failed trap for a given size orifice. For example, a steam system with an orifice inlet pressure of 5 psig and an orifice size of 0.05 inches has a saturated steam loss of 2 lbm/hr when the trap fails open.

7.7.6.2 Post-Installation Verification

The post-installation involves validating types, sizes, and quantities of steam traps installed and ensuring steam traps meet specifications as well as verifying that steam systems operate properly. Energy savings are from elimination of steam losses resulting from failed steam traps (the baseline steam losses and costs). At the time of project implementation, an adjustment may have to be made for the actual steam traps replaced. The performance period for the replaced steam traps should only extend over the life expectancy of the installed steam traps. The life expectancy of steam traps can vary widely (1 to 14 years) depending on the type, system operating pressure and temperature, operating load, and environmental operating conditions.

7.7.6.3 Energy Dollar Savings

Energy dollars savings represent the avoided cost of steam losses resulting from failed steam traps calculated in the post-installation phase.

7.7.6.4 Performance Assurance

- validate installed steam traps are operating and performing, as specified
- perform periodic steam trap survey/audits to determine the performance of the steam trap and
- required replacement cycle

7.7.6.5 Range Of Accuracy

The range of accuracy for maintenance and verification of steam trap projects will vary widely depending on the accuracy of stipulated values.

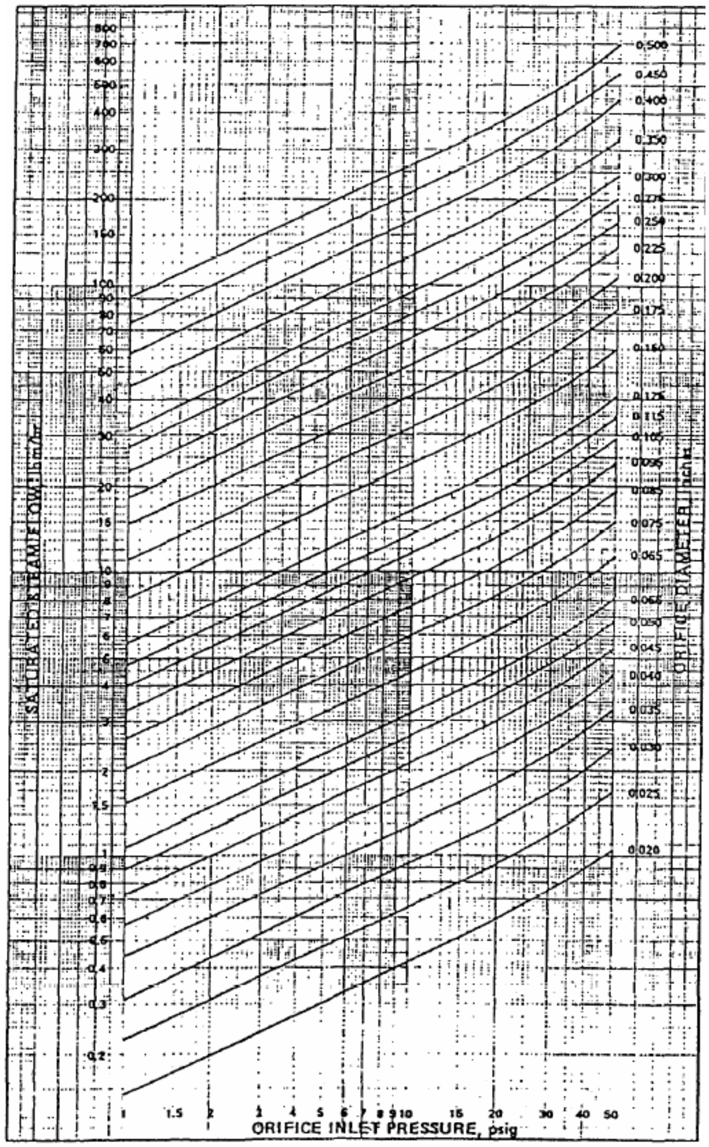

Figure 7.6.1.1

Steam Flow, 1 to 50 psig
Orifice Capacity for Saturated Steam

1 to 50 psig inlet pressure, zero back pressure with orifice size not exceeding:

Pipe Schedule	NPS		
40	1/2”	3/4”	Back pressure correction is
80	.145”D	.205”D	not required where r = .058
160	.135”D	.185”D	or less in the following
XX Strong	.114”D	.140”D	equation:
	.065”D	.110”D	r = Back Pressure (psia) / Inlet Pressure (psia)

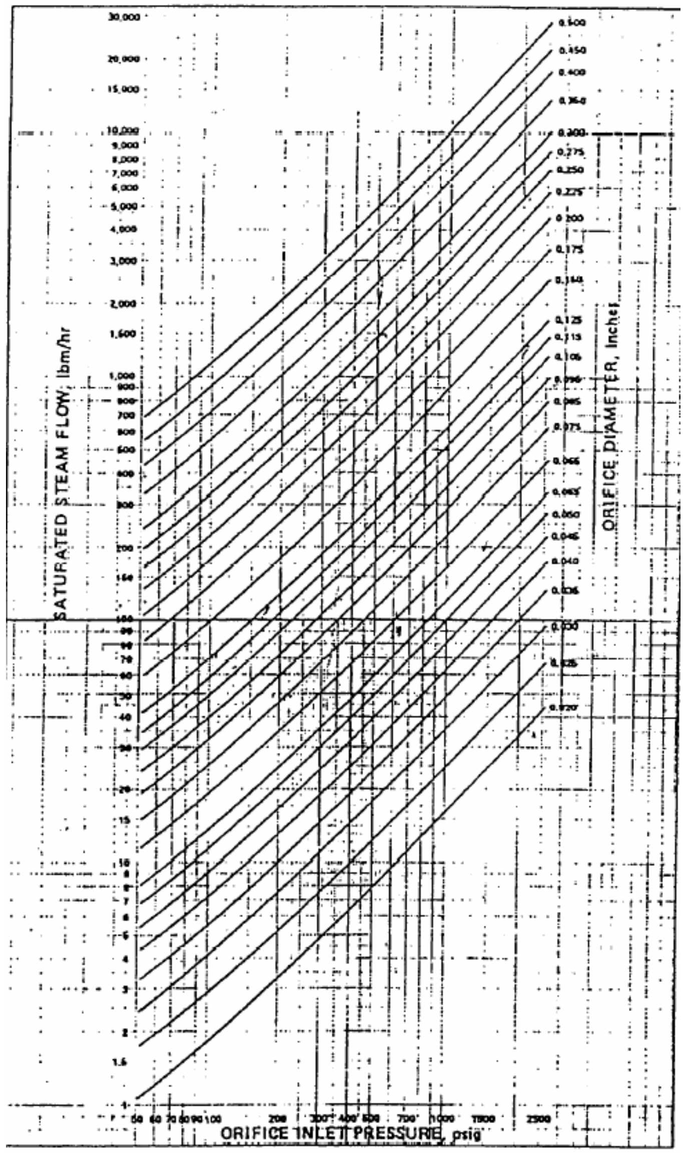

Figure 7.6. 1. 2

Steam Flow, 50 to 2500 psig
Orifice Capacity for Saturated Steam

50 to 2500 psig inlet pressure, zero back pressure with orifice size not exceeding:

Pipe Schedule	NPS	

40 80 160 XX Strong	1/2” 3/4” .145”D .205”D .135”D .185”D .114”D .140”D .065”D .110”D	Back pressure correction is not required where r = .058 or less in the following equation: r = Back Pressure (psia) / Inlet Pressure (psia)

7.7.6.6 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.7.6.7 Overall Advantages

For steam trap replacement projects, Option A is the only practical option for measurement and verification of energy performance. Option A is equally advantageous to the owner and the contractor in terms of low development cost and ease of implementation. However, the energy savings performance is not guaranteed.

7.8 CHILLER REPLACEMENTS

7.8.1 Description

The measurement and verification (M&V) process for chiller replacement projects involves calculating, or metering, the input electricity or fuel rate, the chiller output, and hours of operation at various load conditions. In some cases, this may involve switching input energy sources. For example, an electric chiller may be switched out for a steam-fired absorption chiller where the ultimate input fuel is fuel oil firing a steam boiler which feeds steam to the chiller. Another example is the installation of heat exchangers to utilize “free-cooling” from cooling tower water to displace chiller energy in winter months (see “Plate Heat Exchanger” section); additionally, the incorporation of a thermal storage system to shift the chiller’s electric demand from peak periods to non-peak periods is a consideration for the M&V process. In all of these cases, the parameters required for M & V are the same, but the methods of obtaining the parameters may be different.

Unless the system is large enough to warrant a full-time operator to monitor and log pertinent data, or the system has data acquisition capability, annual hours of operation would have to be estimated. The estimate would be based on interviews with maintenance personnel responsible for the equipment, a survey of the existing control systems, and recorded local weather bin data. Simple projects involving replacement of a chiller, or utilizing free-cooling to displace chiller energy, can utilize Option A or Option B, depending on the level of detail and available data

A more extensive project may include changeout of the secondary components of the cooling system in conjunction with the chiller, such as cooling coils, air handling units, secondary pumps, controls and distribution piping. If the effects of replacing these components must be considered in the project, Option C is the best method of sufficiently accounting for them, since more complex effects must be considered in the overall system. These include chiller energy input and end-use device cooling output. Assumptions must be made on a case-by-case basis taking into account system leaks, age, and overall condition. Some qualitative measurements can be made to bring these assumptions more in line with actual conditions, such as thermographic imaging of equipment and piping, conditioned space and secondary equipment temperature and flow measurements, and visual inspection of cooling system components. However, no economically effective way of absolutely quantifying overall system efficiency exists. All assumptions must be reviewed with respect to their impact and validity so that all parties to a performance contract can agree to them.

7.8.2 Energy Analysis Parameters

- chiller input power: $\mathbf{P_{ACT}}$ (kW, Btu/hr)
- condenser water pump input power: $\mathbf{P_{COND}}$ (kW)
- chilled water pump input power: $\mathbf{P_{CWP}}$ (kW)
- cooling tower input power: $\mathbf{P_{CT}}$ (kW)
- chilled water leaving (supply) temperature: $\mathbf{t_S}$ (F)
- chilled water entering (return) temperature: $\mathbf{t_R}$ (F)
- chilled water flow rate: $\mathbf{flow_{CHW}}$ (gpm)
- profile of operating hours vs. load
- chiller part-load performance (kW/ton)
- energy rates for all pertinent energy sources, including demand charges

7.8.3 Data Gathering

- nameplate data for system components, including pumps and fans
- perform electrical measurements on motors: voltage, current, PF, kW
- determine existing control method
- chiller part-load performance profile in kW/ton (through manufacturer's data or sample metering)
- document hours of operation for various load conditions (logs, operator interviews, observations, weather bin data and/or metering
- energy rate schedules

7.8.4 Measurement And Verification

The following tables define how the appropriate parameters are obtained for the baseline and post-installation for each of the three M&V options.

Table 7.8.4.1

PARAMETER VALUES FOR THE BASELINE

M&V OPTION PARAMETER	OPTION A	OPTION B	OPTION C
chiller power input, P_{ACT}	sample metering, manufacturer's data	meter readings, manufacturer's data	facility energy modeling calculations/utility bill analysis
condenser pumping kW, P_{COND}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
chilled water pumping kW, P_{CT}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
cooling tower fan kW, P_{CT}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
chilled water leaving temperature, t_S	measured values or historical log	measured values or historical log	measured values or historical log
chilled water entering temperature, t_R	measured values or historical log	measured values or historical log	measured values or historical log
chilled water flow rate, f_{CHW}	measured values or historical log	measured values or historical log	measured values or historical log
usage profile - operating hours vs. Load	stipulated (from logs or weather bin data)	actual (logs or sample measurements)	facility energy modeling calculations
chiller part load performance	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	calculated or metered	facility energy modeling calculations/utility bill analysis
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.8.4.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V OPTION PARAMETERS	OPTION A	OPTION B	OPTION C
chiller power input, P_{ACT}	meter readings, sampling measurements	sample or continuous metering	facility energy modeling calculations/utility bill analysis
condenser pumping kW, P_{COND}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
chilled water pumping kW, P_{CHWP}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
cooling tower fan kW, P_{CT}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
chilled water leaving temperature, t_S	stipulated	sample or continuous metering	facility energy modeling calculations
chilled water entering temperature, t_R	stipulated	sample or continuous metering	facility energy modeling calculations
chilled water flow rate, f_{CHW}	stipulated	sample or continuous metering	facility energy modeling calculations
usage profile - operating hours vs. load	stipulated	sample or continuous metering	facility energy modeling calculations/utility bill analysis
chiller part load performance	stipulated based on manufacturer's data or measured values	sample or continuous metering	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	calculated or metered	facility energy modeling calculations/utility bill analysis
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.8.5 Advantages And Disadvantages

The following tables list advantages and disadvantages for each of the M&V options from the owner's point of view as well as the contractor's point of view.

Table 7.8.5.1
OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
Option A	Option B	Option C	Option A	Option B	Option C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	longer development period
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
average probability of dispute	lower probability of dispute		Some owner risk associated with stipulation of savings		higher probability of dispute

Table 7.8.5.2
OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
Option A	Option B	Option C	Option A	Option B	Option C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	longer development period
simplified verification process	best monitoring of long term performance	some monitoring of performance	little or no monitoring of performance	continual validation requires more accounting	
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
	lower probability of dispute		higher probability of dispute		higher probability of dispute
outside variables stipulated so as not to affect savings		effect of outside variables more easily accounted for in modeling		outside variables such as weather and occupancy patterns can affect savings	

7.8.6 Option A: Energy Savings Analysis

This option is typically applicable in smaller systems where the chiller is being switched out and the effect of secondary cooling system elements, such as distribution piping and coils, is neglected, or is the same in the baseline as in the post-installation case (i.e. chiller plant conversion of a natural gas-fired absorption chiller to an electric chiller) and continuous metering is not a cost effective option. The baseline is fixed on stipulated parameters and short-term sample metering is recommended, although stipulations can be based on manufacturers data and survey observations. The post-installation performance is based on stipulated parameters. Again, short-term sample metering is recommended but not required.

7.8.6.1 Baseline

The baseline is established by determining the part-load performance of the existing chiller. The fuel or power input rate (Btu/hr for fuels, kW for electric chillers), chiller tonnage produced, and hours of operation at various load conditions are calculated using any, or all, of the methods listed in the M&V baseline options parameters table, Option A. The part-load performance curve for the baseline may be obtained directly, if the existing chiller is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make an accurate estimate of baseline operating parameters. The baseline performance efficiency is used to calculate the baseline energy consumption for various load conditions. If the chiller auxiliary equipment (pumps and fans) is also being replaced as part of the project, energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the sections dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application).

Assuming that no direct-metered data for chiller input and output is available (or is suspect as to its validity), the chiller input power must be estimated based on manufacturer’s part-load data or sample metering (preferably, not less than 10 percent load increments). Following are formulas used in calculating the baseline chiller tonnage output for the same load conditions as the chiller power input data:

$$\text{Chiller Output Rate(Btu/Hr)} = 500 \times [\text{Flow}_{CHW}\,(\text{gpm}) \times (T_R - T_S)(\text{F})] \text{ @ Corresponding Load Conditions}$$

The profile for hours of operation at various load conditions is stipulated based on sample metering, or temperature bin data (if applicable, generally not applicable for process cooling loads). For process loads, sample metering or historical data is recommended to establish a credible profile.

$$\text{Baseline Efficiency Curve} = \frac{\text{Chiller Output Rate @ Each Load Increment}}{\text{Chiller Power Input Rate @ Each Load Increment}}$$

Baseline Energy Consumption @ Corresponding Load Conditions = Summation of

$$\frac{(\text{Chiller Output Rates @ Each Load Increment}) \times (\text{Hours of Operation @ Each Load Increment})}{\text{Chiller Baseline Efficiency @ Each Load Increment}}$$

7.8.6.2 Post-Installation Verification

The post-installation performance efficiency is established by determining the part-load performance of the new chiller. The power input rate, chiller output, and hours of operation at various load conditions are calculated using the parameters listed on the post-installation M&V options parameters table, Option A. The retrofit part-load performance curve is stipulated based on the chiller manufacturer’s data, or by sample measurements of chiller performance at various load conditions. The performance data is used to determine energy consumption as compared to the baseline performance for the corresponding load conditions. If chiller auxiliary equipment (pumps and fans) is also being replaced, their energy consumption must also be calculated. The methodology for calculating the new system’s energy consumption is the same as described in the previous section for baseline performance calculations but using the stipulated efficiency of the newly installed system instead of the baseline system efficiency. Again, the system's performance curve is established by agreement on manufacturer's performance data, post-installation sample measurements, or simplified calculations using bin data.

7.8.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation energy consumption. Following is the formula used in performing the energy savings calculations:

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

Demand Savings = $kW_{POST} - kW_{BASE}$

7.8.6.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04, while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved in using a particular ECM. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Demand Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate Energy

Dollar Savings = $[kWh_{POST} - kWh_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.8.6.5 Performance Assurance

- verify new chiller meets specifications--check submittals and nameplates
- validate performance--perform routine inspections of metered and measured parameters

7.8.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on the estimate of the stipulated operating hours; however, run-hours at various load conditions are generally difficult to estimate because of the system's interdependent variables, such as effects of occupancy and usage patterns, building plug loads, lighting on cooling load, variable process cooling loads on the system, level of system maintenance, control schemes, and environmental (i.e. weather) operating conditions. Thus, accuracy for this M&V method can be off by a wide margin if the developed load profile is not representative of true operating conditions.

7.8.6.7 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of the total energy dollar savings over the term of the energy performance contract.

7.8.6.8 Overall Advantages

Option A can be equally advantageous to both the contractor and the owner because savings performance is guaranteed based on stipulations, and it does not require as much time, money, and personnel from either party in order to measure and verify the savings. However, if the stipulation is not made to monitor equipment operating efficiencies after installation and to correct the savings if equipment performance is lower than stipulated, this option is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that the stipulated equipment performance is being met.

Option A can be helpful in simple local chiller replacement projects, but it is not recommended for central plants where a chiller serves multiple buildings. Metering devices (Option B) are a more accurate and cost effective option for central plants. Option A is not recommended in the complete changeout of cooling systems where other system components, such as distribution systems or coils, are being replaced with the chiller.

7.8.7 Option B: Energy Savings Analysis

This option is typically only applicable in larger systems (100 tons or more) where the cooling source is being switched out and the effect of secondary heating system elements, such as distribution piping and coils, is neglected, or is the same in the baseline as in the post-installation case (i.e. central plant replacement of chillers). The baseline is based on stipulated parameters--short term sample metering is required, at a minimum. Post-installation verification is achieved by system-level (chiller input and output) continuous metering.

7.8.7.1 Baseline

The baseline is established by determining the part-load performance of the existing chiller. The power input rate, cooling output, and hours of operation at various load conditions are calculated using any, or all, of the methods listed in the M&V baseline options parameters table, Option B. The part-load performance curve for the baseline may be obtained directly if the existing chiller is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make an accurate estimate of baseline operating parameters. The baseline performance efficiency is used to calculate the baseline energy consumption for various load conditions. If the chiller auxiliary equipment (pumps and fans) is also being replaced as part of the project, their energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the sections dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application). The same methods described under Option A are used in calculating baseline energy for various load conditions.

7.8.7.2 Post-Installation Verification

The energy performance of the new system is determined by metering continuously or for a specified period of time. At a minimum, totaling meters are required for power input and cooling output; runtime meters are recommended. A separate meter which serves only chiller auxiliaries (pumps and fans) is recommended if the auxiliaries are also being replaced as part of the project. However, in most cases, auxiliary equipment will be spot-metered before and after installation to estimate energy consumption. If the chiller input and output is directly metered, no calculations are necessary; if indirect measurements (such as flow and temperature) are made, the same equations used for Option A are used to determine power input, cooling output, and energy consumption.

7.8.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation energy consumption. Following is the formula used in performing energy savings calculations:

Energy Savings = Baseline Energy Consumption - Post-Installation Energy Consumption

Keep in mind that in a situation involving an electric chiller and auxiliaries, electric demand costs/savings must also be taken into account.

7.8.7.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a “tiered” energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04, while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved using a particular ECM. With this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand Dollar

Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.8.7.5 Performance Assurance

- verify new chiller meets the specifications--check submittals and nameplates
- validate performance--periodically check and calibrate meters and instruments

7.8.7.6 Range Of Accuracy

The performance of the ECM will be based on metered data and the utility rate, which are generally well-defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline and should normally be within ten percent.

7.8.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The additional cost of Option B should not exceed the expected increase in savings resulting from using this M & V option.

7.8.7.8 Overall Advantages

Option B is most advantageous for the owner because savings performance is ensured through continual metering. However, Option B will require more time, money, and personnel to maintain an ECM's system performance and metering equipment as well as continually tracking and documenting energy savings. Option B has the potential to put the contractor at great risk if variables beyond his control result in little, or no, savings for the project. Some stipulation of variables, such as occupancy and usage patterns, may be required in order to utilize Option B. Conversely, the owner should broker the savings agreement under this option to capture part, or all, of any windfall savings resulting from the project.

7.8.8 Option C: Energy Savings Analysis

This option is recommended for projects which involve replacement of secondary cooling system components, such as air-handling coils, cooling towers, or distribution systems, in conjunction with a chiller replacement. Before using Option C, consideration should be given to Option A for small-scale projects involving small (100 tons, or less) systems and/or very few buildings. This option should be used only when simplified assumptions and calculations for Option A are considered inadequate, or the project scope is too extensive to effectively meter (Option B) all the components. The baseline is based on computer simulation modeling calibrated with utility billing data, nameplate data, and/or spot measurements. Post-installation is based on computer simulation modeling calibrated with utility billing data, nameplate data and/or spot measurements.

7.8.8.1 Baseline

The data collected during the initial site survey is used as input to the simulation program to build the baseline model. The process of calibrating the model then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the electric (i.e. kWh and kW) and fuel (MBtu) usage for a given time period (usually a year) are within approximately 10 percent of the totals for the measured data.

7.8.8.2 Post-Installation Verification

As with other M&V methods described in this document, the equipment installation of the ECMs should be verified and the system(s) commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.

Once the baseline model is considered calibrated, the baseline input file is saved. For ECM simulation, the new equipment performance data replaces the same parameters that were used in the baseline input file. The simulation is re-run with the new data and a post-installation model is generated. The post-installation model may, or may not, require calibration as described in the previous section, depending primarily on the number of changes required to model the new ECMs.

7.8.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.
Successive annually recalibrated models can be used to calculate savings using the following data:

- typical meteorological year (TMY) weather and/or average building occupancies (most common option); or
- actual post-installation values for the weather and/or building occupancies (more time-consuming and costly to verify), etc.

7.8.8.4 Energy Dollar Savings

To ensure the simulation model accurately calculates **the energy** (kW) savings, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04, while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved in utilizing a particular ECM. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to energy and demand savings of the ECM. Make sure utility rate structures are entered correctly in the simulation modeling program. Another consideration is how the demand is modeled compared to actual metering of demand charge. Generally, demand is metered at one location for the entire base; or at several locations which may be billed with a conjunctive demand charge. However, ECM modeling of demand is typically not performed at the basewide level; thus, it is sometimes difficult to determine the actual effect of a particular ECM on a basewide demand charge.

Following are formulas used in performing the dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.8.8.5 Performance Assurance

- ensure the simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes meet specifications
- perform annual or periodic audits consisting of a new calibrated simulation model based on the post-installation ECM data, the previous year’s weather, and utility bills and/or submetered data

7.8.8.6 Range Of Accuracy

To accurately model building energy performance, detailed data concerning the facility and its energy systems is required. The data includes the physical layout of a building, its properties, usage schedules, installed equipment, and the interaction between energy systems. In addition, computer simulations of building energy performance will largely depend on the experience of the modeling analyst. To obtain an accurate result using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is required. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc., enable the discovery and rectification of discrepancies much more rapidly. Therefore, accuracy of Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this method should normally be within ten percent of the actual utility bills.

7.8.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. The additional costs of Option C should not exceed the expected increase in savings resulting from using this option.

7.8.8.8 Overall Advantages

Option C is typically more advantageous to the contractor than to the owner because the contractor is largely responsible for developing the building energy simulation model and is considered the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models. The savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate since energy modeling is more an art than a science. The owner will need knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tools the owner has for validating the model. Option C is more costly for the contractor to develop than it is for the owner, but it can be equally costly to the owner to validate and ensure the performance of the energy project.

7.8.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The seven diagrams specific to chiller replacements are:

1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads;
2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
3) Figure 3, BTU Instrumentation;
4) Figure 6, Water Cooled Chillers;
5) Figure 7, Water Cooled Chillers/Plate Heat Exchanger;
6) Figure 8, Water Cooled Steam Absorption Chillers; and
7) Figure 9, Water Cooled Direct-Fired Or Gas Engine Driven Chillers.

7.9 COOLING TOWER REPLACEMENT

7.9.1 Description

The measurement and verification process for cooling tower replacement projects involves calculating, or metering, the input electricity, the tower output, and hours of operation at various load conditions. In many cases, tower modifications will be made in conjunction with a chiller replacement project. In this case, the methodology for M&V described in the chiller section of this document may be used by simply considering the tower fan and condenser pump as a part of the overall system changeout. Unless the system is large enough to warrant a full-time operator who monitors and logs the pertinent data, or has data acquisition capability, annual hours of operation must be estimated. Usually this can be easily done based on an interview with maintenance personnel responsible for the equipment along with a survey of the existing control system and local weather bin data. Simple projects which merely involve replacing the tower or adding a variable speed drive can utilize either Option A or Option B depending on the level of detail and available data.

A more extensive project may include changeout of all components in the cooling system in conjunction with the tower, such as chillers, cooling coils, air handling units, secondary pumps, controls and distribution piping. When the effects of replacing the components must be considered, Option C is the best method of sufficiently accounting for them because more complex interactive effects must be considered in the overall system.

Assumptions must be made on a case-by-case basis taking into account tower system leaks, age, and overall condition. Some measurements can be made to bring the assumptions more in line with actual conditions, such as tower water temperatures, air temperatures, and flow measurements; along with visual inspection of system components. However, no economically effective way of absolutely quantifying an overall system efficiency exists; therefore, all assumptions must be reviewed with respect to their impact and validity so that all parties to a performance contract can accept them.

Following are possible energy conservation measures (ECMs) for cooling tower systems:

- component changeout to use more efficient equipment (towers, tower fill, pumps, fans, and motors)
- addition of variable speed drives to tower fan or pump motors
- downsizing the cooling tower to match the load
- control scheme changes

7.9.2 Energy Analysis Parameters

- tower water pump input power requirement in kW: $\mathbf{P_{COND}}$
- cooling tower fan power requirement in kW: $\mathbf{P_{CT}}$
- tower water leaving (supply) temperature in degree F: $\mathbf{T_S}$
- tower water entering (return) temperature in degree F: $\mathbf{T_R}$
- tower water flow rate in gpm: $\mathbf{Flow_{COND}}$
- usage profile of operating hours: **Hr**
- cooling tower performance profile in kW/ton
- utility energy rate in $/kWh
- utility demand rate in $/kW

7.9.3 Data Gathering

- perform surveys of tower water pump motors, chilled water pump motors, and cooling tower fan motors
- obtain motor nameplate data
- perform electrical measurements on motor voltage, current, PF, and kW
- determine existing control method
- obtain cooling tower part-load performance profile in kW/ton (manufacturer data or sample metering of cooling tower part-load performance)
- document hours of operation for various load conditions
- obtain electric rate schedules

7.9.4 Measurement And Verification

The following tables define how energy savings parameter values for both the baseline and post-installation are obtained for each M&V option.

Table 7.9.4.1

PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
tower water pump motors kW, P_{COND}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
cooling tower fan motors kW, P_{CT}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
tower water leaving temp. degree F, T_S	measured values or historical log	measured values or historical log	measured values or historical log
tower water entering temp. degree F, T_R	measured values or historical log	measured values or historical log	measured values or historical log
tower water flow rate in gpm, F_{COND}	measured values or historical log	measured values or historical log	measured values or historical log
usage profile of operating hour, hr	stipulated	stipulated or measured values	facility energy modeling calculations
condenser part load performance	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	calculated	facility energy modeling calculations
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.9.4.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
tower water pump motors kW, P_{COND}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
cooling tower fan motors kW, P_{CT}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
tower water leaving temp. degree F, T_S	stipulated based on measured values	sample or continuous metering	facility energy modeling calculations
tower water entering temp. degree F, T_R	stipulated based on measured values	sample or continuous metering	facility energy modeling calculations
tower water flow rate in GPM, F_{COND}	stipulated based on measured values	sample or continuous metering	facility energy modeling calculations
usage profile of operating hour, hr	stipulated based on measured values	sample or continuous metering	facility energy modeling calculations
cooling tower part load performance	stipulated based on manufacturer data or on measured values	sample or continuous metering	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	sample or continuous metering	facility energy modeling calculations
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.9.5 Advantages and Disadvantages

The following tables provide advantages and disadvantages for each of the M&V options from the owner's point of view and from the contractor's point of view.

Table 7.9.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				metering is required	longer development period
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
average probability of dispute	lower probability of dispute		Some owner risk associated with stipulation of savings		higher probability of dispute

Table 7.9.5.2

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				metering is required	longer development period
simplified verification process	best monitoring of long term performance	some monitoring of performance	little or no monitoring of performance	continual validation requires more accounting	
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
	lower probability of dispute		higher probability of dispute		higher probability of dispute
outside variables stipulated so as not to affect savings		effect of outside variables more easily accounted for in modeling		outside variables such as weather and occupancy patterns can affect savings	

7.9.6 Option A: Energy Savings Analysis

This option is typically only applicable in systems where the tower is being switched out and the effect of other cooling system elements, such as the chiller, distribution piping, and coils are neglected (or is the same in the baseline as in the post-installation case), and continuous metering is not a cost effective option. The baseline is fixed on stipulated parameters, and short-term sample metering is recommended although stipulations can be based on manufacturer's data and survey observations. The postinstallation's performance is based on stipulated parameters; again, short-term sample metering is recommended, but not required.

7.9.6.1 Baseline

The baseline is established by determining the part-load performance of the existing cooling tower. The power input (kW), cooling tower's cooling tonnage produced, and hours of operation at various load conditions are calculated using the parameters listed in the baseline M&V options parameters table, Option A. The baseline's part-load performance and energy consumption data may be obtained directly if the existing cooling tower is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make accurate estimates of operating parameters. Energy consumption is calculated by multiplying the stipulated estimate of the usage/load profile by the appropriate operating point on the cooling tower's part-load performance curve (part-load kW/ton). If the tower's auxiliary equipment (pumps and fans) is also being replaced as part of the project, the energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the section dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application). Assuming that no direct-metered data for tower input and output is available or is suspect as to its validity, the input power must be estimated based on manufacturer's part-load data, or sample metering (preferably not less than 10 percent load increments). The following formulas are used in calculating the baseline power input and tonnage output of a cooling tower (input and output must be measured, or calculated, at the same load conditions):

Cooling Tower Input:

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

or

Estimated P_{ACT} = [0.746 x HP x LF (Estimated)] / [$\%E_{LO}$] (kW)

kWBASE = Measured P_{ACT} @ Various Baseline Load Conditions or = Estimated PACT @ Various Baseline Load Conditions Corresponding Cooling tower Output Is From Historical Log

o**r**

$$\text{Measured Cooling Tons} = \frac{\text{1 Btu/lb F x 8.34 lb/Gal x 60 Min/Hr x } Flow_{COND} \text{ x } (T_R - T_S)}{\text{12000 Btu/Ton}}$$

The profile of hours of operation at various load conditions is a stipulated estimate based on bin temperature data (bin data is not recommended for systems which contain process loads). The energy consumption of the baseline is then:

kWh_{BASE} = Sum [kW_{BASE} / Ton] x [Ton*$Hr_{STIPULATED}$] Produced @ Various Load Conditions

7.9.6.2 Post-Installation Verification

The post-installation energy performance is established by determining the part-load performance of the new tower. This information, along with the power input rate, tower output, and hours of operation at various load conditions are calculated using the parameters listed on the post-installation M&V options parameters table, Option A. The retrofit part-load performance curve is stipulated based on the tower manufacturer's data, or by sample measurements of tower performance at various load conditions. The performance data is used to determine energy consumption as compared to the baseline performance for the corresponding load conditions. If auxiliary equipment (pumps and fans) is also being replaced, their energy consumption must also be calculated. The methodology for calculating the new system's energy consumption is the same as described in the previous section for baseline performance calculations, but using the stipulated efficiency of the newly installed system instead of the baseline system efficiency. Again, the system performance curve is established by agreement on manufacturer's performance data, post-installation sample measurements, or simplified calculations using bin data.

7.9.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline's energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations:

Energy Savings = kWh_{POST} - kWh_{BASE}

Demand Savings = kW_{POST} - kW_{BASE}

7.9.6.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04 while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved using a particular ECM. With this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate

Demand Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.9.6.5 Performance Assurance

- verify new system meets specifications; check submittals and nameplates
- validate performance; perform routine inspections of metered and measured parameters

7.9.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on the estimate of the stipulated operating hours. However, for cooling tower replacement applications, the hours of operation at various load conditions are difficult to estimate because there are many interdependent variables, such as demand conditions on the systems, overall system equipment operating characteristics (condensers, pumps, fans, etc.), control schemes, and environmental operating conditions (i.e. weather). The accuracy for this M&V method could be off by a wide margin if the sample operating load profile is not representative of the actual operating conditions.

7.9.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the energy cost savings over the term of the energy performance contract.

7.9.6.8 Overall Advantages

Option A **can** be equally advantageous to the contractor and the owner because the savings performance is guaranteed based on stipulations and does not require as much time, money, and personnel from either party in order to measure and verify the savings. However, if stipulations are not made to monitor equipment operating efficiencies after installation and to correct the savings if equipment performance is lower than stipulated, this option is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that stipulated equipment performance is being met.

Option A can be helpful in simple tower replacement projects, but is not recommended for the changeout of complete cooling systems where other system components, such as chillers, distribution systems, or coils, are being replaced along with the tower.

7.9.7 Option B: Energy Savings Analysis

- baseline fixed on stipulated parameters--short term sample metering recommended.
- post-installation energy savings analysis--periodic or continuous system-level metering required

7.9.7.1 Baseline

The baseline is established by determining the part-load performance of the existing cooling tower. The power input (kW), the cooling tower's cooling tonnage produced, and hours of operation at various load conditions are calculated using the parameters listed in the baseline M&V options parameters table, Option B. The baseline's part-load performance and energy consumption data may be obtained directly if the existing cooling tower is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made in order to make accurate estimates of operating parameters. Energy consumption is calculated by multiplying the stipulated estimate of the usage/load profile by the appropriate operating point on the cooling tower's part-load performance curve (part-load kW/ton). If the tower auxiliary equipment (pumps and fans) is also being replaced as part of the project, their energy performance and consumption must also be calculated and included as part of the overall system baseline. (See the sections dealing with M&V options for motors and/or variable speed drives for the appropriate M&V application). Assuming that no direct-metered data for tower input and output is available, or is suspect as to its validity, the input power must be estimated based on manufacturer's part-load data, or sample metering (preferably not less than 10 percent load increments). The following formulas are used in calculating the baseline power input and tonnage output for a cooling tower (input and output must be measured, or calculated, at the same load conditions):

Cooling Tower Input:

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

or

Estimated P_{ACT} = [0.746 x HP x LF (Estimated)] / [$\%E_{LO}$] (kW)

kWBASE = Measured PACT @ Various Baseline Load Conditions

or

= Estimated PACT @ Various Baseline Load Conditions Corresponding Cooling tower Output Is From Historical Log or

$$\text{Measured Cooling Tons} = \frac{1\text{ Btu/lb F x } 8.34\text{ lb/Gal x } 60\text{ Min/Hr x Flow}_{COND}\text{ x } (T_R - T_S)}{12000\text{ Btu/Ton}}$$

The profile of hours of operation at various load conditions is a stipulated estimate based on bin temperature data (bin data is not recommended for systems which contain process loads). Following is the energy consumption for the baseline:

$$\text{kWhBASE} = \text{Sum [kWBASE / Ton] x [Ton*Hr}_{STIPULATED}\text{] Produced @ Various Load Conditions}$$

7.9.7.2 Post-Installation Verification

The post-installation energy performance is established by determining the part-load performance of the new tower. This information, along with the power input rate, tower output, and hours of operation at various load conditions are calculated using the parameters listed on the post-installation M&V options parameters table, Option B. The retrofit part-load performance curve is stipulated based on the tower manufacturer's data, or by sample measurements of tower performance at various load conditions. The performance data is used to determine energy consumption as compared to the baseline performance for the corresponding load conditions. If auxiliary equipment (pumps and fans) is also being replaced, their energy consumption must also be calculated. The methodology for calculating the new system's energy consumption is the same as described in the previous section for baseline performance calculations but using the stipulated efficiency of the newly installed system instead of the baseline system efficiency. Again the system performance curve is established by agreement on manufacturer's performance data, post-installation sample measurements, or simplified calculations using bin data. Energy performance is based on continuous metering of the system's performance and energy usage. The following formulas are used in performing post-installation energy savings calculations:

$$kW_{POST} = [P_{ACT}]_{\text{METERING DATA}}$$

Cooling Ton*Hour Produced = Actual Metered Data

Actual Part Load Performance (kW/Ton) = Actual Metered Data

$$kWh_{POST} = \text{Sum } [kW_{POST}/\text{Ton}]_{\text{METERING DATA}} \times [\text{Ton*Hr}]_{\text{METERING DATA}}$$
Produced @ Various Load Conditions

7.9.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations:

$$\text{Demand Savings} = kW_{POST} - kW_{BASE}$$

$$\text{Energy Savings} = kWh_{POST} - kWh_{BASE}$$

In order to automatically compensate for the affect of changing variables (i.e. change in facility loads, operating schedules, weather, etc.) on the performance of the energy project, it is best to use the actual usage (in ton-hours) in each post-installation year to calculate what the energy consumption would have been for the baseline. In essence, the energy baseline is a sliding baseline which compensates for changes in the usage pattern, weather, and any increases in facility load. Project performance is based on the difference between the baseline cooling tower performance profile (kW/ton) and the postinstallation's cooling tower performance profile (kW/ton). The total annual usage (ton-hours) in the annual energy consumption calculation is the same for the baseline and post-installation. The following formulas are used in performing the sliding baseline energy savings calculations for various load conditions.

kWh_{BASE} = Sum[kW/Ton]$_{BASE}$ x [Ton*Hr] $_{POST\ METERING\ DATA}$
Produced @ Various Load Conditions

7.9.7.4 Energy Dollar Savings

When calculating **energy** (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket system where cost at the bottom tier is higher than the tiers above it. Energy savings are initially generated at the top tier where the rate is lowest. If the average rate is used to calculate savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on the time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to both the energy and demand savings of the ECM. The following formulas are used in performing dollar savings calculations:

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate Energy

Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating dollar savings for energy performance contracts, its is highly recommended that the energy rate at the time of the contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By applying this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.9.7.5 Performance Assurance

- validate installed cooling tower systems meet specifications
- validate installed cooling tower systems operate and perform as specified
- check metering performance periodically to ensure it functions properly

7.9.7.6 Range Of Accuracy

The performance of the ECM will be based on metered data and the utility rate which are generally well-defined variables. The accuracy of Option B is primarily dependent on the estimate of stipulated factors in the baseline and should normally be within ten percent.

7.9.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The additional cost of Option B should not exceed the expected increase in savings resulting from using this M&V option.

7.9.7.8 Overall Advantages

Option B is most advantageous for the owner since the savings performance is ensured through continuous metering. However, Option B will require more time, money, and personnel to maintain an ECM's system performance and metering equipment, as well as to continually track and document energy savings. Option B has the potential to put the contractor at great risk if variables beyond his control result in little or no savings for the project. Some stipulation of variables, such as occupancy and usage patterns, may be required in order to utilize Option B. Conversely, the owner should broker the savings agreement under this option to capture part, or all, of any windfall savings verified to occur as a result of the project.

7.9.8 Option C: Energy Savings Analysis

This option is recommended only for projects which involve replacement of other cooling system components, such as chillers, air-handling coils, or distribution systems in conjunction with a tower replacement. Before using Option C, consider Option A for small-scale projects of this type involving small (100 tons or less) systems and/or very few buildings. Option C should be used only where the simplified assumptions and calculations of Option A are considered inadequate; or the project scope is too extensive to effectively meter (Option B) all the components. The baseline is fixed on computer simulation modeling calibrated with utility billing data, nameplate data and/or spot measurements. The post-installation is based on computer simulation modeling calibrated with utility billing data, nameplate data and/or spot measurements.

7.9.8.1 Baseline

Data collected during the initial site survey is used as input to the simulation program to build the baseline model. The process of calibrating the model then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the electric (i.e., kWh and kW) and fuel (MBtu) usage for a given time period (usually a year) is within approximately 10 percent of the totals for the measured data.

7.9.8.2 Post-Installation Verification

As with other M&V methods described in this document, the equipment installation of the ECMs should be verified and the system(s) commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.

Once the baseline model is calibrated, the baseline input file is saved. For the ECM simulation, the new equipment performance data replaces the same parameters that were used in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration as described in the previous section; primarily depending on the number of changes required to model the new ECMs.

7.9.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.
Successive annually recalibrated models can be employed to calculate savings by using the following criteria:

- typical meteorological year (TMY) weather, and/or average building occupancies, etc. (most common option) or,
- actual post-installation values for the weather and/or building occupancies, etc. (more time-consuming and costly to verify)

7.9.8.4 Energy Dollar Savings

To ensure that the simulation model accurately calculates the **energy** (kW) savings, it is important to examine how utility rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04 while the next 50,000 kWh are priced at $0.03 5, and so on. Examine the overall base utility usage to determine the real cost of energy saved with a particular ECM. Typically with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to both the energy and demand savings of the ECM. Make sure the utility rate structures are entered correctly in the simulation modeling program. Another consideration is how the demand is modeled when compared to actual metering of the demand charge. Generally, demand is metered at one location for the entire base, or at several locations which may be billed with a conjunctive demand charge. However, ECM modeling of demand is typically not performed on a basewide level; therefore, it is sometimes difficult to determine the actual effect of a particular ECM on a basewide demand charge.
The following formulas are used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = $[kW_{POST} - kW_{BASE}]$ x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefit as well as the risk of future changes in the utility rate.

7.9.8.5 Performance Assurance

- ensure simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes match with agreed-to specifications
- perform annual, or periodic, audit consisting of new simulation model calibrated based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data

7.9.8.6 Range Of Accuracy

To accurately model building energy performance, detailed data concerning the facility and its energy systems is required. The data includes the physical layout of a building, its properties, usage schedules, installed equipment, and the interaction between energy systems. Additionally, computer simulations of building energy performance will largely depend on the experience of the modeling analyst. To obtain an accurate result using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is required. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc., enable the discovery and rectification of discrepancies much more rapidly. Therefore, accuracy of Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this method should normally be within ten percent of the actual utility bills.

7.9.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of energy cost savings over the term of the energy performance contract. The additional cost of Option C should not exceed the expected increase in savings resulting from using this option versus another option.

7.9.8.8 Overall Advantages

Option C is typically more advantageous to the contractor than the owner since the contractor is largely responsible for developing the building energy simulation model and is considered the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models. The savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate since energy modeling is more an art than a science. The owner will require knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tools the owner has for validating the model. Option C is more costly to develop for the contractor than the owner, but it can be equally costly to the owner to validate and ensure performance of the energy project.

7.9.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The seven diagrams specific to chiller replacements are:

1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads;
2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
3) Figure 3, BTU Instrumentation;
4) Figure 6, Water Cooled Chillers;
5) Figure 7, Water Cooled Chillers/Plate Heat Exchanger;
6) Figure 8, Water Cooled Steam Absorption Chillers; and
7) Figure 9, Water Cooled Direct-Fired Or Gas Engine Driven Chillers.

7.10 PLATE HEAT EXCHANGER INSTALLATION

7.10.1 Description

The measurement and verification (M&V) process for the installation of plate heat exchangers involves calculating and/or metering of a chiller's power input (kW for electric chillers, MBtu/hr for natural gas or absorption chillers), a chiller's cooling tonnage produced, and hours of operation at various load conditions. The installation of a plate exchanger will reduce run hours on existing cooling equipment by bypassing the chiller and using cooling tower water to remove heat from the building's chilled water loop. This is successfully accomplished when wet-bulb temperatures are below 48°F. When this condition is met, the chiller can be turned off or run at reduced load as cooling tower water circulated through the plate heat exchanger. The building's chilled water supply can also be circulated through the heat exchanger, thereby eliminating the need for the chiller to cool the water. To measure the performance of the heat exchanger, the supply and return chilled water temperatures along with the chilled water flow rate need to be recorded. The values can be used to calculate tons of cooling, which are compared to the chiller kW/ton load profile. Energy savings are calculated using the established chiller performance baseline. The installation of a plate heat exchanger project is generally done in conjunction with chiller replacement. If this is the case, performance of the new chiller with plate heat exchanger is evaluated against the existing chiller's performance baseline. Following are strategies for energy conservation measures (ECMs) for a plate exchanger application:

- use of more efficient equipment, including plate heat exchanger unit and high efficiency chiller
- use of electricity reducing technologies; reduction in chiller load and operating hours

7.10.2 Energy Analysis Parameters

- chiller active input power requirement in kW (for electric chiller): $\mathbf{P_{ACT}}$
- chiller active fuel input in MBtu/hr (for natural gas or absorption chiller): $\mathbf{P_{ACT}}$
- condenser water pump input power requirement in kW: $\mathbf{P_{COND}}$
- chilled water pump input power requirement in kW: $\mathbf{P_{CWP}}$
- cooling tower input power requirement in kW: $\mathbf{P_{CT}}$
- chilled water leaving (supply) temperature in degree F: $\mathbf{T_S}$
- chilled water entering (return) temperature in degree F: $\mathbf{T_R}$
- chilled water flow rate in GPM: $\mathbf{Flow_{CHW}}$
- usage profile of operating hours: **Hr**
- chiller part-load performance profile in kW/ton
- utility energy rate in $/kWh

- utility demand rate in $/kW

7.10.3 Data Gathering

- perform surveys of condenser water pump motors, chilled water pump motors, and cooling tower fan motors
- obtain motor name plate data
- perform electrical measurements on motor, including voltage, current, PF, kW
- verify motors have appropriate design characteristics for their application
- determine existing control method
- obtain chiller part-load performance profile in kW/ton (manufacturer data or sample metering of chiller part-load performance)
- document hours of operation for various load conditions
- obtain electric rate schedules

7.10.4 Measurement and Verification

The following tables define how energy savings parameter values for both the baseline and post-installation are obtained for each M&V option.

Table 7.10.4.1
PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
chiller power input kW or MBtu/hr, P_{ACT}	meter readings sampling measurements	meter readings sampling measurements	facility energy modeling calculations/utility bill analysis
Condenser water pump motors kW, p_{COND}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
chilled water pump motors kW, P_{CWP}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
cooling tower fan motors kW, P_{CT}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
chilled water leaving temp. degree F T_S	measured values or historical log	measured values or historical log	facility energy modeling calculations
chilled water entering temp. degree F, T_R	measured values or historical log	measured values or historical log	facility energy modeling calculations
chilled water flow rate in gpm, F_{CHW}	measured values or historical log	measured values or historical log	facility energy modeling calculations
usage profile of operating hour, Hr	stipulated	actual	facility energy modeling calculations/utility bill analysis
chiller part load performance	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	calculated	facility energy modeling calculations/utility bill analysis
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.10.4.2

PAREMETER VALUES FOR THE POST-INSTALLATION

M&V OPTION PARAMETERS	OPTION A	OPTION B	OPTION C
chiller power input kW or MBtu/hr, P_{ACT}	meter readings sampling measurements	continuous metering	facility energy modeling calculations/utility bill analysis
Condenser water pump motors kW, P_{COND}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
chilled water pump motors kW, P_{CWP}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
cooling tower fan motors kW, P_{CT}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
chilled water leaving temp. degree F, T_S	stipulated	continuous metering	facility energy modeling calculations
chilled water entering temp. degree F, T_R	stipulated	continuous metering	facility energy modeling calculations
chilled water flow rate in gpm, F_{CHW}	stipulated	continuous metering	facility energy modeling calculations
usage profile of operating hour, Hr	stipulated	continuous metering	facility energy modeling calculations/utility bill analysis
chiller part load performance	stipulated based on manufacturer data or on measured values	continuous metering	estimated from manufacturer data or stipulated based on measured values
energy consumption	calculated	continuous metering	facility energy modeling calculations/utility bill analysis
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.10.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view and the contractor's point of view.

Table 7.10.5.1

OPTION ADVANTAGES AND DISADVANTAGES TO THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute

Table 7.10.5.2

OPTION ADVANTAGES AND DISADVANTAGES TO THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensure long term system performance and savings			continual savings validation process	
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute
Guarantee of long term shared savings		guarantee of long term shared savings		no guarantee of long term shared savings	

7.10.6 Option A: Energy Savings Analysis

The baseline is fixed on stipulated parameters--short term sample metering required.
The energy savings analysis for the post-installation is based on stipulated parameters--short term, sample metering required.

7.10.6.1 Baseline

Determination of a baseline for the installation of a plate heat exchanger is the same as for a chiller replacement. The baseline is established by determining the part-load performance of the existing chiller. The power input (kW for electric chiller; Btu/hr for natural gas or absorption chiller) for the chiller's cooling tonnage produced and hours of operation at various load conditions are calculated using the parameters listed in the baseline M&V options parameter table, Option A. The baseline's part-load performance and energy consumption data may be obtained directly if the existing chiller is equipped with data acquisition capability and historical data is available; otherwise, sample measurements must be made to make an accurate estimate of operating parameters. The energy consumption is calculated by multiplying the stipulated estimate of usage/load profile to the appropriate point on the chiller's part-load performance (part-load kW/ton) curve. If the chiller's auxiliary equipment (pumps and fans) is being replaced as part of the project, the energy performance and consumption must be calculated and included as part of the overall system baseline. (See M&V option for constant load motor and variable speed drives for the appropriate M&V application.)

The following formulas are used in performing the baseline energy savings calculations for various load conditions.

Chiller Input: From Historical Log

or

Measured $P_{ACT} = 1.732 \times V \times I \times PF \times 1/1000$ (kW) or

Estimated $_{PACT}$ [0.746 x HP x LF (estimated)] / [%E_{LO}] (kW)

kWBASE = Measured PACT @ Various Baseline Load Conditions

or

= Estimated PACT @ Various Baseline Load Conditions Corresponding Chiller Output From Historical Log

or

$$\text{Measured Cooling Tons} = \frac{1\ \text{Btu/lb F} \times 8.34\ \text{lb/Gal} \times 60\ \text{Min/Hr} \times \text{Flow}_{CHW} \times (T_R - T_S)}{12000\ \text{Btu/Ton}}$$

The profile of hours of operation at various load conditions is a stipulated estimated based on bin temperature data, if applicable.

kWhBASE = Sum [kW_{BASE}/Ton] x [Ton*$Hr_{STIPULATED}$] Produced @ Various Load Conditions

7.10.6.2 Post-Installation Verification

The baseline for the post-installation is established by determining the part-load performance of the existing chiller with plate heat exchanger or new chiller with plate heat exchanger. The power input (kW for electric chiller; Btu/hr for natural gas or absorption chiller) for the chiller's cooling tonnage produced and hours of operation at various load conditions are calculated using the parameters listed in the post-installation M&V options parameters table, Option A. The post-installation's part-load performance is stipulated based on the chiller manufacturer's data ,or sample measurements of chiller performance, to establish the post-installation's performance curve for various load conditions. Energy consumption is calculated by multiplying the stipulated estimate hours of usage/load profile to the appropriate point on the new chiller's part-load performance curve (part-load kW/ton). If the chiller's auxiliary equipment (pumps and fans) is being replaced as part of the project, energy performance and consumption must be calculated and included as part of the overall system baseline. (See M&V option for constant load motors and variable speed drives for the appropriate M&V application.) The following formulas are used in performing the baseline energy savings calculations for various load conditions.

Chiller Input:

Measured PACT = 1.732 x V x I x PF x 1/1000 (kW)

or

Estimated P_{ACT} = [0.746 x HP x LF (estimated)] / [%E_{LO}] (kW)

kW_{POST} = Measured P_{ACT} @ Various Baseline Load Conditions

or

= Estimated P_{ACT} @ Various Baseline Load Conditions

Corresponding Chiller Output:

$$\text{Measured Cooling Tons} = \frac{1\ \text{Btu/lb F} \times 8.34\ \text{lb/gal} \times 60\ \text{min/hr} \times \text{Flow}_{CHW} \times (T_R - T_S)}{12000\ \text{Btu/Ton}}$$

The profile of hours of operation at various load conditions is established on a stipulated estimate based on bin temperature data, if applicable.

$$kWh_{POST} = \text{Sum}\ [kW_{POST}/\text{Ton}] \times [\text{Ton*Hr}_{STIPULATED}]\ \text{Produced @ Various Load Conditions}$$

7.10.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE} Energy Savings = kWh_{POST} - kWh_{BASE}

7.10.6.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04 while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved using a particular ECM. With this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.10.6.5 Performance Assurance

- validate installed chiller and plate heat exchanger systems meet specifications
- validate installed chiller and plate heat exchanger systems operate and perform as specified

7.10.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on the estimate of stipulated operating hours. However, for plate heat exchanger applications, the number of hours the chiller operates at various load conditions is difficult to estimate because of the system's interdependent variables, such as demand conditions, equipment (i.e. compressor, pump, fan, etc.) operating characteristics, control schemes, and environmental operating conditions (i.e. weather). Accuracy for this measurement and verification method could be off by a wide margin if the sample operating load profile is not representative of the actual operating conditions.

7.10.6.7 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.10.6.8 Overall Advantages

Option A is most advantageous for the contractor because savings performance is guaranteed based on stipulation. Also, it does not require as much time, money, and personnel to measure and verify the savings. Option A offers the same time and cost savings advantages to the owner but does not guarantee short term or long term system performance of the ECMs.

7.10.7 Option B: Energy Savings Analysis

The baseline is based on stipulated parameters--short term sample metering required.
The energy savings analysis for the post-installation is based on stipulated parameters--system level continuous metering required.

7.10.7.1 Baseline

Determination of a baseline for the installation of a plate heat exchanger is the same as for a chiller replacement. The baseline is established by determining the part-load performance of the existing chiller. The power input (kW for electric chiller; Btu/hr for natural gas or absorption chiller) of the chiller's cooling tonnage produced and hours of operation at various load conditions are calculated using the parameters listed in the baseline M&V options parameter table, Option A. The baseline's part-load performance and energy consumption data may be obtained directly if the existing chiller is equipped with data acquisition capability and historical data is available. Otherwise, sample measurements must be made in order to make an accurate estimate of operating parameters. Energy consumption is calculated by multiplying the stipulated estimate of the usage/load profile to the appropriate point on the chiller's part-load performance curve (part-load kW/ton). If the chiller's auxiliary equipment (pumps and fans) is being replaced as part of the project,

energy performance and consumption must be calculated and included as part of the overall system's baseline. (See the M&V option for constant load motors and variable speed drives for the appropriate M&V application.)
The following formulas are used in performing the baseline energy savings calculations for various load conditions.

Chiller Input From Historical Log

or

Measured P_{ACT} = 1.732 x V x I x PF x 1/1000 (kW)

or

Estimated P_{ACT} = [0.746 x HP x LF (estimated)] / [$\%E_{LO}$] (kW)

kWBASE = Measured P_{ACT} @ Various Baseline Load Conditions

or

= Estimated P_{ACT} @ Various Baseline Load Conditions Corresponding Chiller Output From Historical Log

or

Measured Cooling Tons = $\dfrac{1 \text{ Btu/lb F} \times 8.34 \text{ lb/gal} \times 60 \text{ min/hr} \times Flow_{CHW} \times (T_R - T_S)}{12000 \text{ Btu/Ton}}$

The profile for hours of operation at various load conditions is fixed to a stipulated estimated based on bin temperature data, if applicable.

kWhBASE = Sum [kW_{BASE}/Ton] x [Ton*$Hr_{STIPULATED}$] Produced @ Various Load Conditions

7.10.7.2 Post-Installation Verification

Energy performance is based on continuous metering of system performance and energy usage. Following are formulas used in performing the post-installation's energy savings calculations:

kWPOST = $[P_{ACT}]_{METERING\ DATA}$

Cooling Ton*Hour Produced = Actual Metered Data

Actual Part Load Performance (kW/Ton) = Actual Metered Data

kWh_{POST} = Sum $[kW_{POST}/Ton]_{METERING\ DATA}$ x $[Ton*Hr]_{METERING\ DATA}$ Produced @ Various Load Conditions

7.10.7.3 Energy Savings

Energy savings are calculated by taking the difference between baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

To automatically compensate for the affect of changing variables (i.e. change in facility loads, operating schedules, weather, etc.) on the performance of energy projects, it is preferred to use the actual usage (ton*hours) in each post-installation year to calculate what energy consumption would have been for the baseline. In essence, energy baseline is a sliding baseline which compensates for changes in usage patterns, weather, and any increases in the facility's load. The project's performance is based on the difference between the baseline chiller's performance profile (kW/ton) and the post-installation's chiller performance profile (kW/ton). The total annual usage (ton*hour) in annual energy consumption calculations are the same for both baseline and the post-installation. Following are formulas used in performing the sliding baseline energy savings calculations for various load conditions:

kWhBASE = Sum[kW/Ton]B_{ASE} x [Ton*Hr] POST METERING DATA
Produced @ Various Load Conditions

7.10.7.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket system where cost at the bottom tier is higher than the tiers above it. Energy savings are initially generated at the top tier where the rate is lowest. If the average rate is used to calculate savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on the time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to both the energy and demand savings of the ECM. The following formulas are used in performing dollar savings calculations:

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate Energy

Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating dollar savings for energy performance contracts, its is highly recommended that the energy rate at the time of the contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By applying this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use the tier bracket arrangement where the cost at the bottom tier is higher than at the tiers above it. Energy savings are generated at the top tier which has the lowest rate. If the average rate is used to calculate the savings, the actual dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use where the energy rate is higher during the on-peak period and lower during the off-peak period. For this kind of rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

7.10.7.5 Performance Assurance

- validate installed chiller and plate heat exchanger systems meet specifications
- validate installed chiller and plate heat exchanger systems operate and perform as specified
- periodically check metering performance to ensure meter functions properly

7.10.7.6 Range Of Accuracy

Performance for ECMs will be based on metering data and utility rates, which are well defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline. Accuracy for this M&V method should be within ten percent depending on the accuracy of the estimate of the stipulated factors in the baseline.

7.10.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.10.7.8 Overall Advantages

Option B is most advantageous for the owner since the savings performance is ensured through continuous metering. Option B offers the same time and cost savings advantages to the contractor in baseline development but will require more time, money, and personnel to maintain the system’s performance and metering equipment as well as tracking and documenting the energy savings.

7.10.8 Option C: Energy Savings Analysis

The baseline is fixed on computer simulation modeling calibrated with utility billing data.
The energy savings analysis for the post-installation is based on computer simulation modeling calibrated with utility billing data.

7.10.8.1 Baseline

The data collected during the initial site survey is used as input data to the simulation program to build the baseline model. The process of simulation calibration then follows. This often takes a number of iterations and requires an experienced building modeling analyst to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the output electric (i.e. kWh and kW) and gas use (i.e. therms and therms/hr.) closely match that of the measured data.

For programs that output hourly kWh and therm consumption, and with availability of actual hourly kWh and therm consumption, the mean bias error (MBE) and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption, and by what percentage. A small value for the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because of the possibility of cancellation in under-prediction and over prediction errors from one hour to the next.

The CV(RMSE) is an indication of variability in the data. The degree of variability is higher with a large CV (RMSE). Comparing monthly measured and simulated data with a low MBE and CV(RMSE) means the simulated results are well matched with the measured results. In general, the absolute value of the MBE should be less than 7 percent, and the absolute value of the CV(MBSE) should be less than 25 percent. The specifications are guidelines only and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values for the measured and simulated values, the MBE, and CV(RMSE) for each month in the year will yield a more comprehensive basis for simulation calibration. For the months where the MBE, the CV(RMSE), or both, are large, an indicated model adjustment can be achieved. The agency and ESCO should agree to acceptable levels for the MBE and CV(RMSE).

7. 10.8.2 Post-Installation Verification

As with other M&V methods described in this document, the energy conservation measures should be verified and the equipment/systems commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.
Once the baseline model is considered calibrated, the baseline input file is saved and the new description for the ECM replaces data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration primarily depending on the number of changes required to model the new ECMs.

7.10.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.
Following is data used to calculate savings for successive annually recalibrated models:

- typical meteorological year (TMY) weather and/or average building occupancies, etc. (most common option) or,
- actual post-installation values for the weather and/or building occupancies, etc.

7.10.8.4 Energy Dollar Savings

To ensure the simulation model accurately calculates energy dollar savings, examine how utility rate structures are applied. Many rate structures use the tier bracket system where cost at the bottom tier is higher than the tiers above it. Energy savings are initially generated at the top tier where the rate is lowest. If the average rate is used to calculate savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use

when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.
For electric demand dollar savings, it is also important to examine how rate structures are applied Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utilities have many methods of charging for demand. Possible demand structures include contract demand, on-peak/off-peak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Be sure utility rate structures are entered correctly in the simulation modeling program

When calculating dollar savings for energy performance contracts, its is highly recommended that the energy rate at the time of the contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By applying this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.10.8.5 Performance Assurance

- ensure simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes meet specifications
- validate installed equipment and control schemes operate and perform as specified
- perform annual energy audit to consist of recalibration of the simulation model based on the post-installation ECM data and the previous year’s weather, utility bills and/or submetered data.

7.10.8.6 Range Of Accuracy

To accurately model building energy performance, detailed data concerning the facility and its energy systems is required. The data includes the physical layout of a building, its properties, usage schedules, installed equipment, and the interaction between energy systems. In addition, computer simulations of building energy performance will largely depend on the experience of the modeling analyst. To obtain
an accurate result using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is required. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc., enable the discovery and rectification of discrepancies much more rapidly. Therefore, accuracy of Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this method should normally be within ten percent of the actual utility bills.

7.10.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.10.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The three diagrams specific are:

1) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
2) Figure 3, BTU Instrumentation;
3) Figure 7, Water Cooled Chillers/Plate Heat Exchanger.

7.11 DX UNIT/HEAT PUMP REPLACEMENT PROJECTS

7.11.1 Description

DX units are generally referred to as packaged terminal air conditioning units (commonly used for hotel rooms) or split system air conditioning units (commonly used for small single zone spaces, houses, small office buildings, etc.) which utilize direct expansion (DX) of refrigerant to obtain the cooling effect. Heat pumps operate the same as DX units in the cooling mode; however, the units are also capable of reversing the cycle to produce heat. The common sizes for DX units and heat pumps range from 1 to 50 tons of cooling capacity. Example projects for this technology category may include replacing an existing DX unit and gas heating system with an electric heat pump (or vice versa), or replacing existing electric equipment with a natural gas-fired heat pump. For energy conservation measures (ECMs) for DX units and heat pump replacement, the strategy involves:

- use of more efficient equipment, including higher EERs and COPs,
- use of electricity reducing technologies, including downsizing equipment to match the load and alternative energy sources

7.11.2 Energy Analysis Parameters

- DX unit / heat pump input power requirement in kW, therms, Btu/hr
- DX unit / heat pump energy output in Btu/hr
- DX unit / heat pump energy efficiency ratio (EER) rating in Btu/W*hr or coefficient of performance (COP) for cooling, coefficient of performance (COP) for heating, heating system efficiency (%)
- load profile on unit (Btu/hr output vs hrs per year)
- operating hours (hr)
- energy consumption
- utility rate

7.11.3 Data Gathering

- obtain unit nameplate data
- perform energy measurements on a representative sample of units over a representative load

usage pattern (stipulated measurement period)
- obtain unit energy efficiency ratio (EER) rating in Btu/W*hr, COP, and/or heating efficiency (%)
- document hours of operation
- obtain utility rate schedules

7.11.4 Measurement and Verification

The following tables define how energy saving parameter values are obtained for the baseline and post-installation for each M&V option.

Table 7.11.4.1

PARAMETER VALUES FOR THE BASELINE

M&V Option Parameters	Option A	Option B	Option C
unit's input power requirement	name plate data sampling measurements	name plate data sampling measurements	manufacturer/name plate data or measured values
unit's cooling and /or heating energy output in Btu/hr	name plate data sampling measurements	name plate data sampling measurements	manufacturer/name plate data or measured values
unit's EER, COP, and/or efficiency rating	stipulated based on name plate data and/or sampling measurements	stipulated based on name plate data and/or sampling measurements	manufacturer/name plate data or measured values
load usage profile/ operating hours	stipulated based on field data, weather data, and calculations	stipulated based on field data, weather data, and calculations or measured	facility energy modeling calculations/utility bill analysis
energy consumption	calculated	calculated or measured	facility energy modeling calculations/utility bill analysis
utility rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.11.4.2

PARAMETER VALUES FOR THE POST-INSTALLATION

M&V Option Parameters	Option A	Option B	Option C
unit's input power requirement	name plate data, sample measurements	continuous metering of a representative sample	manufacturer/name plate data or measured values
unit's cooling and /or heating energy output in Btu/hr	name plate data, sample measurements	continuous metering of a representative sample	manufacturer/name plate data or measured values
unit's EER, COP, and/or efficiency rating	stipulated based on name plate data and/or sample measurements	continuous metering of a representative sample	manufacturer/name plate data or measured values
load usage profile/ operating hours	stipulated based on field data, weather data, and calculations	continuous metering of a representative sample	facility energy modeling calculations/utility bill analysis
energy consumption	calculated	continuous metering of a representative sample	facility energy modeling calculations/utility bill analysis
utility rate	actual rate schedule	actual rate schedule	actual rate schedule

7.11.5 Advantages And Disadvantages

The following tables list advantages and disadvantages for each of the M&V options from the owner's point of view as well as the contractor's point of view.

Table 7.11.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V Option Advantages			M&V Option Disadvantages		
Option A	Option B	Option C	Option A	Option B	Option C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensures long term system performance and savings		no guarantee of long term system performance and savings	continuous savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute

Table 7.11.5.2

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensures long term system performance and savings			continuous savings validation process	
	best accuracy	acceptable accuracy	wide variation in accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute
guarantee of long term shared savings		guarantee of long term shared savings		no guarantee of long term shared savings	

7.11.6 Option A: Energy Savings Analysis

The baseline is based on calculations and stipulated parameters, Post-installation is based on calculation and stipulated parameters

7.11.6.1 Baseline

The determination of the baseline for the installation of DX units and heat pumps involves establishing the energy performance of the existing equipment, to include the EER rating, COP, and potentially the heating efficiency (%). The simplest approach is to obtain the performance rating from the existing equipment nameplate data and/or from the equipment manufacturer publications. Based on the condition of the existing equipment, the published EER/COP rating may, or may not, be de-rated by an agreed-to stipulation. With the use of stipulated baseline EER/COPs, the annual energy consumption per unit can be calculated using weather bin data or degree day data for the cooling and heating seasons.

The following formulas are used in performing the baseline energy savings calculations for various load conditions for electric equipment.

Cooling Season

$$kW_{BASE} = \frac{\text{Sum [Calculated Loads (Btu/hr) x 1000]}}{EER_{BASE}\ \text{(Btu/W*hr)}}$$

$$kWh_{BASE} = \frac{\text{Sum [Calculated Loads (Btu/hr) x Hour of Operation (hr) x 1 000]}}{EER_{BASE}\ \text{(Btu/W*hr)}}$$

Heating Season

$$Btu = \frac{\text{Sum [Calculated Loads (Btu/hr) X Hours of Operation (hr)}}{COP_{Base}}$$

For natural gas or other alternative fuels, the above equations can be utilized by substituting the equipment COP for the EER to calculate annual energy consumption in Btus.

To determine the actual EER/COP of the existing unit, the energy consumption and equipment output need to be recorded at near design conditions. The energy input is relatively simple to measure depending on the energy source used by the equipment, i.e. electric meter, natural gas meter, etc. To measure the output for this equipment, the simplest approach is to take measurements on the air side inside the conditioned space. The temperature difference across the cooling / heating coil and the air flow rate need to be recorded to calculate tons, or Btu/hr output. The calculated output along with the metered input can be used to determine the actual EER, COP, or heating efficiency.

7.11.6.2 Post-Installation Verification

The determination of the post-installation energy performance of DX units and heat pumps involves determining the performance rating of the installed equipment (EER, COP, etc.). The simplest approach is to obtain the rating from the installed equipment nameplate data and/or from the equipment manufacturer specifications. With the use of the post-installation equipment EER/COPs, the annual energy consumption per unit can be calculated using the weather bin data or degree day data for the cooling and heating seasons. The actual performance of the new equipment should be evaluated on an annual basis to ensure performance is in accordance with manufacturer's data. The difference in energy consumption is used to calculate energy savings along with the current year's utility rates.
The following formulas are used in performing post installation energy savings calculations for various load conditions for electric equipment:

Cooling Season

$$kW_{POST} = \frac{\text{Sum [Calculated Loads (Btu/hr) x 1 000]}}{EER_{POST}\text{(Btu/W*hr)}}$$

$$kWh_{POST} = \frac{\text{Sum [Calculated Loads (Btu/hr) x Hour of Operation (hr) x 1 000]}}{EER_{POST}\text{ (Btu/W*hr)}}$$

Heating Season

$$Btu = \frac{\text{Sum [Calculated Loads (Btu/hr) X Hours of Operation (hr)}}{COP_{Post}}$$

For natural gas, or other alternative fuels, the above equations can be utilized by substituting the equipment COP for the EER to calculate annual energy consumption in Btus.

To determine the actual EER/COP of the new unit, the energy consumption and equipment output need to be recorded at near design conditions (for an accurate comparison to rated performance). The energy input is relatively simple to measure depending on the energy source used by the equipment, i.e. electric meter, natural gas meter, etc. To measure the output for this equipment, the simplest approach is to take measurements on the air side inside the conditioned space. The temperature difference across the cooling / heating coil and the air flow rate need to be recorded to calculate tons, or Btu/hr output. The calculated output along with the metered input can be used to determine the actual EER, COP, or heating efficiency.

7.11.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation's energy consumption. The following formulas are used in performing energy savings calculations for electric systems.

Demand Savings = kW_{POST} - kW_{BASE}

Energy Savings = kWh_{POST} - kWh_{BASE}

7.11.6.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use a tier bracket structure where the cost of the bottom tier is higher than the tiers above it. The reduction in energy consumption must first be reduced from the top tier, which has the lowest energy rate. If the average rate is used to calculate the energy dollar savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use where the energy rate is higher during the on-peak period and lower during the off-peak period. Thus, energy dollar savings will depend on the usage pattern of the ECM.

When calculating demand dollar savings, it is also important to examine how rate structures are applied. Demand dollar savings are generally realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings, but reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying the appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing energy dollar savings calculations:

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

Energy Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance for the implemented ECMs. By following this process, the owner and the contractor share the benefits as well as the risk of increasing rates from the utility company.

7.11.6.5 Performance Assurance

- validate installed units meet specifications
- validate installed units operate and perform as specified

7.11.6.6 Range Of Accuracy

The accuracy of Option A is primarily dependent on calculation of the stipulated load profiles/operating hours. For DX unit and heat pump replacement applications, the hours of operation at various load conditions are difficult to estimate because of the system's interdependent variables, such as load demand conditions on the systems, equipment (compressor, pump, fan, etc.) operating characteristics, control schemes, and environmental operating conditions (i.e. weather). Thus, accuracy for this M&V method could be off by a wide margin if the load profile calculated (based on stipulated assumptions) is not representative of the actual operating conditions.

7.11.6.7 Range Of Cost As A Percent Of Savings

Cost for Option A should be limited to five percent of the total energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.11.6.8 Overall Advantages

Option A can be equally advantageous to the contractor and the owner because savings performance is guaranteed based on stipulations and does not require as much time, money, and

personnel from either party in order to measure and verify savings. However, if stipulations are not made to monitor equipment operating efficiencies after installation and to correct savings if equipment performance is lower than stipulated, Option A is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that stipulated equipment performance is being met.

Option A can be helpful in simple local chiller replacement projects, but is not recommended for central plants where a chiller serves multiple buildings. Metering devices (Option B) are a more accurate and cost effective option for central plants. Option A is not recommended in the complete changeout of cooling systems where other system components, such as distribution systems or coils, are being replaced along with the chiller.

7.11.7 Option B: Energy Savings Analysis

The baseline is based on a representative sample metering of the DX units / heat pumps.
The post-installation is based on continuous metering of a representative sample of DX units/heat pumps.

7.11.7.1 Baseline

The baseline is established by metering the energy consumption of a representative number of units over the entire cooling and heating season. For example, in applications where multiple units would be installed, such as in family housing, meters would be installed in a representative sample of houses of each type and size. The demand and energy consumption along with weather data would establish the baseline energy performance. The baseline energy performance of the existing units is established with the actual cooling and heating season energy consumption and load conditions.

For electric equipment:

$$kW_{BASE} = \text{Measured kW}_{\text{@ VARIOUS BASELINE LOAD CONDITIONS}}$$

$$kWh_{BASE} = \text{Measured kWh}_{\text{OVER THE BASELINE SEASON}}$$

*Baseline consumption can be an annual sum or a monthly breakdown.

To determine the actual EER/COP of the existing unit, energy consumption as well as equipment output needs to be recorded. The energy input is relatively simple to measure depending on the energy source used by the equipment, i.e. electric meter, natural gas meter, etc. To measure the output for this equipment, take measurements on the air side inside the conditioned space. The temperature difference across the cooling / heating coil as well as the air flow rate need to be recorded to calculate tons, or Btu/hr output. The calculated output along with the metered input can be used to determine the actual EER, COP, or heating efficiency.

7.11.7.2 Post-Installation Verification

The post-installation is established by continuously metering energy consumption of a representative number of new units during the entire cooling and heating season. For the family housing example, new units would be metered in the same housing units by the same meters as in the baseline. The demand and energy consumption along with weather data would be recorded as the post-installation energy performance. The post-installation energy performance for the new units is established with the current year's energy consumption and current year's load conditions. The energy consumption may need to be adjusted for changes in load conditions, such as weather, renovations, etc. This is done by multiplying the measured consumption by stipulated adjustment factors to account for changes in load conditions.
For electric equipment:

$$kW_{POST} = \text{Measured kW x } CF_{WEATHER} \times CF_{OTHER\ STIPULATED\ FACTOR}$$

$$kWh_{POST} = \text{Measured kWh x } CF_{WEATHER} \times CF_{OTHER\ STIPULATED\ FACTOR}$$

To determine the actual EER/COP of the new unit, the energy consumption as well as equipment output needs to be recorded. The energy input is relatively simple to measure depending on the energy source used by the equipment, i.e. electric meter, natural gas meter, etc. To measure the output of this equipment, take measurements on the air side inside the conditioned space. The temperature difference across the cooling / heating coil as well as the air flow rate need to be recorded to calculate tons, or Btu/hr output. The calculated output along with the metered input can be used to determine the actual EER, COP, or heating efficiency.

7.11.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline energy consumption and the post-installation energy consumption. The following formulas are used in performing energy savings calculations for electric equipment.

$$\text{Demand Savings} = kW_{POST} - kW_{BASE}$$

$$\text{Energy Savings} = kWh_{POST} - kWh_{BASE}$$

7.11.7.4 Energy Dollar Savings

When calculating energy dollar savings, it is important to examine how rate structures are applied. Many rate structures use tier brackets where the cost of the bottom tier is a higher rate than the tier above. The energy savings is generally the top tier rate where it is the lowest. If the average rate is used to calculate the energy dollar savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use where the energy rate is high during the on-peak period and low during the off-peak period. Thus, the energy dollar savings will depend upon the usage pattern of the ECM.

When calculating demand dollar savings, it is also important to examine how rate structures are applied. The demand dollar savings are generally realized when the ECM reduces its demand (kW) during the peak electric demand period when the demand charge is applied. For example, reducing the demand (kW) for light fixtures operating during the day will have an affect on the demand savings; however, reducing the demand (kW) for light fixtures operating only at night will not have an affect on the demand savings. Some of the demand structures include contract demand, on-peak/off-peak demand, ratchets demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying the appropriate rate structure to the energy and demand savings of the ECM. The following formulas are used in performing energy dollar savings calculations.

$$\text{Demand Dollar Savings} = [kW_{POST} - kW_{BASE}] \times \text{Affected Rate}$$

$$\text{Energy Dollar Savings} = [kWh_{POST} - kWh_{BASE}] \times \text{Affected Rate}$$

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By following this process, the owner and the contractor share the benefit as well as the risk of increases in utility rates.

7.11.7.5 Performance Assurance

- validate installed units meet specifications
- validate installed units operate and perform as specified
- ensure meter is functioning properly by periodically checking the metering performance

7.11.7.6 Range Of Accuracy

The performance of the ECM will be based on metered data and utility rates, which are generally well defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors. The accuracy for this M&V method should normally be within ten percent.

7.11.7.7 Range Of Cost As A Percent Of Savings

Cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from this measurement and verification method.

7.11.7.8 Overall Advantages

Option B is most advantageous for the owner because savings performance is ensured through continual metering. However, Option B will require more time, money, and personnel to maintain an ECM's system performance and metering equipment, as well as to continually track and document energy savings. Option B has the potential to put the contractor at great risk if variables beyond his control result in little to no savings for the project. Stipulation of variables, such as occupancy and usage patterns, may be required in order to utilize Option B. Conversely, the owner should broker the savings agreement under this option to capture part, or all, of any windfall savings verified to occur as a result of the project.

7.11.8 Option C: Energy Savings Analysis

The baseline is based on computer simulation modeling, or utility billing data.
The post-installation energy savings analysis is based on computer simulation modeling or utility billing data.

7.11.8.1 Baseline

The data collected during the initial site survey is used as input data to a simulation program to build the baseline model. The process of simulation calibration then follows. This often takes a number of iterations and requires an experienced building model expert to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the output electric (i.e. kWh and kW) and gas (i.e. therms and therms/hr.) use closely match that of the measured data.

For programs that output hourly kWh and therm consumption used in conjunction with available actual hourly kWh and therm consumption, the mean bias error (MBE) and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation generally under-predicts (negative) or over-predicts (positive) the measured consumption, and by what percentage. A small value for the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because of the possibility of cancellation in under-prediction and over prediction errors from one hour to the next.

The CV(RMSE) is an indication of variability in the data. The degree of variability is higher with a large CV (RMSE). Comparing monthly measured and simulated data with a low MBE and CV(RMSE) means the simulated results are well matched with the measured results. In general, the absolute value of the MBE should be less than 7 percent, and the absolute value of the CV(MBSE) should be less than 25 percent. The specifications are guidelines only and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values for the measured and simulated values, the MBE, and CV(RMSE) for each month in the year will yield a more comprehensive basis for simulation calibration. For the months where the MBE, the CV(RMSE), or both, are large, an indicated model adjustment can be achieved. The agency and ESCO should agree to acceptable levels for the MBE and CV(RMSE).

7.11.8.2 Post-Installation Verification

As with other M&V methods described in this document, installation of the ECMs should be verified and the equipment/systems commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of the new equipment may be necessary to verify the performance data.

Once the baseline model is calibrated, the baseline input file is saved and the new ECM's description replaces the data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration depending primarily on the number of changes required to model the new ECMs.

7.11.8.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, and utility bills and/or submetered data.
Following are ways to calculate savings for successive annually recalibrated models:

- typical meteorological year (TMY) weather and/or average building occupancies, etc. (most common option) or,
- actual post-installation values for the weather and/or building occupancies, etc.

7.11.8.4 Energy Dollar Savings

To ensure the simulation model accurately calculates **energy dollar savings,** examine how utility rate structures are applied. Many rate structures use the tier bracket arrangement where the cost of the bottom tier is higher than the upper tiers. Energy savings are usually generated at the top tier where the rate is lowest. If the average rate is used to calculate energy dollar savings, the actual energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, energy dollar savings will depend on the usage pattern of the ECM.

For electric demand dollar savings, it is also important to examine how rate structures are applied. Demand dollar savings are realized when the ECM reduces demand (kW) during the peak electric demand period at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings but reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Be sure utility rate structures are entered correctly in the simulation modeling program.

When calculating dollar savings for energy performance contracts, its is highly recommended that the energy rate at the time of the contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By applying this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.11.8.5 Performance Assurance

- ensure simulation model accounts for any field changes in implementation phase
- validate installed equipment and control schemes meet specifications
- validate installed equipment and control schemes operate and perform as specified
- perform annual energy audit to consist of recalibration of simulation model based on post-installation ECM data, the previous year's weather, or utility bills and/or submetered data

7.11.8.6 Range Of Accuracy

To accurately model building energy performance and cost, detailed data concerning the facility and its energy systems are required. The data includes the physical layout of a building, its physical properties, intended use, installed equipment, and the interaction between energy systems. Additionally, computer simulations of building energy performance and cost will largely depend on the experience of the modeling analyst. To obtain an accurate result using this method, it is necessary to calibrate the simulation model with actual utility metering data and/or short term metering of individual systems. If the simulation results do not agree with measured whole-building energy data, often only trained and experienced personnel are able to determine the cause of the discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, and occupancy schedules, etc. enable the discovery and rectification of discrepancies much more rapidly. The accuracy of Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. The accuracy for this measurement and verification method should be less than ten percent of the actual utility bills.

7.11.8.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of the energy cost savings over the term of energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.11.8.8 Overall Advantages

Option C is typically more advantageous to the contractor than to the owner because the contractor is the one largely responsible for developing the building energy simulation model and is considered to be the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models. The savings are often guaranteed based on results of the simulation model; however, long term energy performance is difficult to validate since energy modeling is more an art than a science. The owner will need knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tools the owner has for validating the model. Option C is more costly to develop for the contractor than for the owner, but it can be equally costly for the owner to validate and ensure performance of the energy project.

7.11.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The four diagrams specific to DX unit/heat pump replacement projects are:

1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads;
2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
3) Figure 10, Single Zone Direct Expansion Unit; and
4) Figure 11, Single Zone Heat Pump Unit.

7.12 ENERGY MANAGEMENT & CONTROL SYSTEMS

7.12.1 Description

The energy management and control systems (EMCS) consists of a head-end computer with EMCS software, microprocessor-based, field programmable controller; communication links; numerous field sensors, and actuator devices. EMCS systems are primarily designed to manage and control HVAC systems; however, many EMCS systems have the capability of controlling other loads, such as light circuit relays, power circuit breakers, etc. EMCS provides many sophisticated controlling functions, including on/off, lead/lag, incremental, proportional, proportional-integral, and proportional-integralderivative (PID). The strategy for energy conservation measures (ECMs) for energy management and control systems includes:

- programmed start/stop of HVAC and other electrical equipment
- economizer cycle
- unoccupied cycle
- temperature reset
- supply air reset
- chiller management
- intermediate season control
- variable air volume control
- load management

7.12.2 Energy Analysis Parameters

There are energy analysis parameters associated with the application of EMCS systems. Below is a general list of parameters necessary to perform an energy analysis.

- physical characteristics and orientation of building
- building heat losses
- weather data
- occupancy and equipment loads of building
- energy performance of HVAC equipment
- design and configuration of HVAC system
- control schemes for HVAC equipment
- usage profile
- utility energy rates
- utility demand rates

7.12.3 Data Gathering

A detailed site survey is required to perform an energy analysis. Following is a sample list of data required to perform an energy analysis:

- building orientation, floor plans, fenestration and construction--much of this information can be collected from a set of “as-built” architectural drawings;
- descriptions of “as-built” mechanical systems, including all HVAC equipment (primary and secondary); information on zoning of HVAC systems can be provided by drawings;
- descriptions of all electrical systems in the building; drawings can also provide lighting load information and control system specifications;
- directions that major facades of the building face; estimate of distance and height to surrounding buildings for shading calculations; photographs of building’s exterior and surroundings;
- record of HVAC system’s nameplate data, type, and locations of all primary and secondary

HVAC systems; obtain air balance report, including supply and return measurements of air temperature; from the manufacturer; obtain part-load performance characteristics of equipment;

- obtain hourly HVAC schedules and thermostat settings, including day/night setback, as well as a printout of EMCS program settings, where possible;
- verification of estimated lighting loads from electrical diagrams by counting fixtures and measuring lamp and ballast wattage; procure indoor and outdoor lighting schedules;
- measurement of wattage of internal plug loads (appliances, computers, etc.); obtain usage schedules;
- weather data, such as air temperature, humidity, wind speed and direction, as well as solar insolation (vertical and south-facing horizontal), either measured at the nearest airport or on-site (TRY or TMY weather files for a typical year of data may be substituted, where necessary);
- utility electric and gas rate schedules.

7.12.4 Measurement And Verification

Because of the high degree of interaction between numerous energy systems and conservation measures as well as the enormous cost of having to measure individual components of the energy systems, Option C is the only viable option for performing M&V for an EMCS system. Option C employs statistical analysis of utility meter billing data or computer simulation modeling of facility energy systems calibrated with billing data to predict the total energy savings of the energy conservation measures. For an EMCS project, computer simulation modeling of facility energy systems calibrated with utility bills is an appropriate M&V method to use.

7.12.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view as well as the contractor's point of view.

Table 12.5.1

PARAMETER VALUES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
n/a	n/a		n/a	n/a	moderate development cost
n/a	n/a		n/a	n/a	no guarantee of long term system performance and savings
n/a	n/a	acceptable accuracy	n/a	n/a	n/a
n/a	n/a		n/a	n/a	probability of dispute

Table 12.5.2
PARAMETER VALUES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
n/a	n/a		n/a	n/a	moderate development cost
n/a	n/a	acceptable accuracy	n/a	n/a	
n/a	n/a		n/a	n/a	probability of dispute
n/a	n/a	guarantee of long term shared savings	n/a	n/a	

7.12.6 Option C: Energy Savings Analysis

The baseline is fixed on computer simulation modeling calibrated with utility billing data. Post-installation energy savings analysis is based on computer simulation modeling calibrated with utility billing data.

7.12.6.1 Baseline

The data collected during the initial site survey is used as input data to the simulation program to build the baseline model, and the simulation calibration process follows. This often takes a number of iterations and requires an experienced building modeller to determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the output electric (i.e. kWh and kW) and gas (i.e. therms and therms/hr.) use closely match that of the measured data.

When programs that output kilowatt hours and therm consumption on an hourly basis are used in conjunction with actual hourly kilowatt hour and therm consumption, the mean bias error (MBE) and coefficient of variation for the root-mean square error (CV(RMSE)) is used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation under-predicts (negative) or over-predicts (positive) the measured consumption and by what percentage. A small value for the MBE is desirable each month when determining model calibration. However, the MBE alone is not an accurate indication because the possibility of cancellations for under-prediction and over-prediction errors exists from hour to hour.

The CV(RMSE) is an indication of variability in the data. If the CV(RMSE) is larger, the degree of variability is higher. Comparing monthly measured and simulated data with a low MBE and a low CV(RMSE) means the simulated results match well with the measured results. In general, the absolute value of the MBE should be less than seven percent, and the absolute value of the CV(MBSE) should be less than 25 percent. The specifications are guidelines only, and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Tabulated values for the measured and simulated values (MBE and CV(RMSE) for each month during the year) will yield a more comprehensive basis for simulation calibration. For the months when the MBE or the CV(RMSE), or both, are large, an indication of model adjustment can be obtained. The agency and ESCO should both agree to acceptable levels for the MBE and CV(RMSE).

7.12.6.2 Post-Installation Verification

As with other M&V methods described in this document, installation of the ECMs should be verified and the equipment/systems commissioned. As part of this activity, performance data for the new equipment should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of new equipment may be necessary to verify the performance data.
Once the baseline model is calibrated, the baseline input file is saved and the new ECM description replaces data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration depending on the number of changes required to model the new ECMs.

7.12.6.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit shall consist of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather, utility bills and/or submetered data.

Successive annually recalibrated models can be used to calculate savings using either of two options:

- typical meteorological year (TMY) weather and/or average building occupancies, etc. (most common options); or
- actual post-installation values for the weather and/or building occupancies, etc.

7.12.6.4 Energy Dollar Savings

To ensure the simulation model accurately calculates energy dollar savings, examine how utility rate structures are applied. Many rate structures use a tier bracket structure where the cost at the bottom tier is higher than the upper tiers. Energy savings are generated at the top tier where the rate is lowest. If the average rate is used to calculate savings, the energy dollar savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this kind of rate structure, the savings will depend on the usage pattern of the ECM.

For electric demand dollar savings, it is also important to examine how rate structures are applied. Demand dollar savings are generally realized when the ECM reduces demand (kW) during the peak electric demand period when the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will have an affect on demand savings. However, reducing demand (kW) for light fixtures operating only at night will not generate demand savings. Some available demand structures include contract demand, on-peak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge.
Energy dollar savings are calculated by applying an appropriate rate structure to energy and demand savings

of the ECM. Make sure utility rate structures are entered correctly in the simulation modeling program.

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By applying this process, the owner and the contractor share the benefits as well as the risk of future increases in utility rates.

7.12.6.5 Performance Assurance

- ensure simulation model accounts for any field changes in the implementation phase
- validate installed equipment and control schemes meet specifications
- validate installed equipment and control schemes operate and perform as specified
- perform an annual energy audit consisting of recalibration of the simulation model based on the post-installation ECM data, the previous year's weather, utility bills, and/or submetered data

7.12.6.6 Range Of Accuracy

To accurately model building energy performance and cost, detailed data concerning the facility and its energy systems are required. Data includes the physical layout of a building, its physical properties, intended use, installed equipment, and the interaction between energy systems. Additionally, computer simulations of building energy performance and costs will largely depend on the experience of the modeling analyst. In order to obtain an accurate result using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is required. If simulation results do not agree with measured whole-building energy data, trained and experienced personnel usually are able to determine the cause of the discrepancy. Fortunately, software is evolving and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc. enable the discovery and rectification of discrepancies much more rapidly. The accuracy of Option C will depend on the complexity of the facility and its energy systems as well as the skill of the modeling analyst. Accuracy for this measurement and verification method should be within ten percent of the actual utility bills.

7.12.6.7 Range Of Cost As A Percent Of Savings

The cost for Option C should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.12.6.8 Overall Advantages

Option C is typically more advantageous to the contractor than the owner because the contractor is largely responsible for developing the building energy simulation model and is considered to be the expert. The contractor has the advantage of being intimately familiar with the baseline and ECM models. The savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate because energy modeling is more an art than a science. The owner will need knowledgeable energy engineers to review the simulation model and validate the input and assumptions. Utility bills are the best tools the owner has for validating the model. Option C is more costly to the contractor than the owner to develop, but it can be equally costly to the owner to validate and ensure performance of the energy project.

7.13 COGENERATION PLANTS

7.13.1 Description

Cogeneration plant projects generally involve using fuel sources (wood, coal, oil, gas, etc.) to produce electric energy, steam, hot water, and chilled water. The measurement and verification process for cogeneration plant projects involves calculating and/or metering of the plant's electric consumption and fuel energy input, thermal and electric energy output, and hours of operation at various load conditions. The baseline is established by determining the cost and amount of existing thermal and electric power/energy being displaced by the cogeneration plant. The strategies involved in ECMs for cogeneration plants involve:

- use of more efficient equipment
- load management strategies
- improved combustion efficiency
- heat recovery and economizer installation
- alternative fuel sources

7.13.2 Energy Analysis Parameters

- fuel input rate (Btu/hr) and total fuel consumption (Btu)
- electric power input requirement (kW) and energy consumption (kWh)
- steam output rate (Btu/hr) and total consumption (Btu)
- hot water output rate (Btu/hr) and total consumption (Btu)
- chilled water output rate (Btu/hr) and consumption (Btu)
- electric power output (kW) and consumption (kWh)
- energy performance displaced equipment
- utility rates

7.13.3 Data Gathering

- obtain nameplate data and energy performance data for displaced equipment
- obtain utility rate schedules for each energy source used

7.13.4 Measurement And Verification

The following tables define how energy savings parameter values for both the baseline and post-installation are obtained for each maintenance and verification option.

Table 7.13.4.1

PARAMETER VALUES FOR THE BASELINE

M&V OPTION PARAMETERS	OPTION A	OPTION B	OPTION C
equipment operating input power requirement kW, P_{OPER}	estimated from name plate data or measured values	estimated from name plate data or measured values	estimated from name plate data or measured values
usage profile of operating hour, Hr	stipulated	actual	facility energy modeling calculations
energy/demand consumption	calculated	calculated	facility energy modeling calculations
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

Table 7.13.4.2
PARAMETER VALUES FOR THE POST INSTALLATION

M&V OPTION PARAMETERS	OPTION A	OPTION B	OPTION C
equipment operating input power requirement kW, P_{OPER}	stipulated based on name plate data or measured values	sample or continuous metering	estimated from name plate data or measured values
usage profile of operating hour, hr	stipulated	sample or continuous metering	facility energy modeling calculations
energy/demand consumption	calculated	sample or continuous metering	facility energy modeling calculations
energy rate	actual rate schedule	actual rate schedule	actual rate schedule

7.13.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view and from the contractor's point of view.

Table 7.13.5.1
OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensure long term system performance and savings		no guarantee of long term system performance and savings	continual savings validation process	no guarantee of long term system performance and savings
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute

Table 7.13.5.2

OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
lowest development cost				highest development cost	moderate development cost
short development period				continuous metering is required	
simplified verification process	ensure long term system performance and savings			continual savings validation process	
	best accuracy	acceptable accuracy	wide variable of accuracy		accuracy dependent on stipulated values
low probability of dispute	low probability of dispute				higher probability of dispute
guarantee of long term shared savings		guarantee of long term shared savings		no guarantee of long term shared savings	

7.13.6 Option A: Energy Savings Analysis

The baseline is fixed on stipulated parameters--short-term sample metering required.
The energy savings analysis for the post-installation is based on stipulated parameters--short-term sample metering required.

7.13.6.1 Baseline

The baseline is established by calculating the thermal and electric energy produced (steam, hot water, chilled water, and electricity) by the cogeneration plant, and the energy performance efficiency of energy displaced equipment at various load conditions.

Following are baseline energy calculations based on stipulated energy parameters:

$$\text{Steam Energy (Btu)} = \text{Sum } \frac{[\text{Steam Energy Used By Energy Displaced Equipment}]}{\text{Efficiency Of Energy Displaced Equipment}}$$

$$\text{Hot Water Energy (Btu)} = \text{Sum } \frac{[\text{Steam Energy Used By Energy Displaced Equipment}]}{\text{Efficiency Of Energy Displaced Equipment}}$$

$$\text{Chilled Water Energy (Btu)} = \text{Sum } \frac{[\text{Steam Energy Used By Energy Displaced Equipment}]}{\text{Efficiency Of Energy Displaced Equipment}}$$

Baseline Thermal Energy = Sum [Total Displaced Thermal Energy By Fuel Source Type (wood, coal, oil, natural gas, etc.)]

Baseline Electric Energy (kWh) = Electric Energy Produced by the Cogeneration Plant + Sum (Displaced Electric Energy)

Baseline Electric Demand (kW) = Electric Power Produced By The Cogeneration Plant + Sum (Displaced Equipment Electric Demand)

TOTAL BASELINE ENERGY CONSUMPTION (in equivalent unit, Btu or kWh) = STEAM ENERGY + HOT WATER ENERGY + CHILLED WATER ENERGY + ELECTRIC ENERGY

7.13.6.2 Post-Installation Verification

The post-installation's measurement and verification process for cogeneration plant projects involves calculating and/or metering of the cogeneration plant's electric consumption and fuel energy input.

Following are general formulas used in performing the post-installation energy calculations:

Post-Installation Energy Calculations Based On Stipulated Energy Parameters or Metering:

Post-Installation Fuel Consumption (Btu) = Sum [Total Fuel Consumption by Fuel Source (wood, coal, oil, natural gas, etc.)]

Post-Installation Electric Consumption (kWh) = Electric Energy Consumed by the Plant

Post-Installation Electric Demand (kW) = Electric Power Demand Consumed by the Plant

TOTAL POST-INSTALLATION ENERGY CONSUMPTION (in equivalent unit, Btu or kWh) = POST-INSTALLATION FUEL CONSUMPTION + POST-INSTALLATION ELECTRIC CONSUMPTION

7.13.6.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline, displaced energy consumption, and the total plant energy consumption of the post installation. The following formulas are used in performing the energy savings calculations.

Energy Savings (in equivalent Btu or kWh) = Total Baseline Energy Consumption -Total Post-Installation Energy Consumption

Electric Demand Savings (in kW) = Baseline Electric Demand - Post-Installation Electric Demand

7.13.6.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04, while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved in using a particular ECM. Typically, with this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Demand Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

Energy Dollar Savings = [kWh_{POST} - kWh_{BASE}] x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.13.6.5 Performance Assurance

- validate installed cogeneration plants meet specifications
- validate installed cogeneration plants operate and perform as specified

7.13.6.6 Range Of Accuracy

The accuracy of Option A primarily depends on the accuracy of the stipulated parameters. For cogeneration plant projects involving several energy systems using various fuel sources, it is difficult to achieve good M&V accuracy by applying Option A. There are too many energy parameters that need to be estimated and stipulated. The accuracy for this M&V method could be off by a wide margin; consequently, Option A is not recommended for M&V of cogeneration plants.

7.13.6.7 Range Of Cost As A Percent Of Savings

The cost for Option A should be limited to five percent of the total energy cost savings over the term of the energy performance contract. The cost for M&V should not exceed the expected increase in savings resulting from this measurement and verification method.

7.13.6.8 Overall Advantages

Option A can be equally advantageous to both the contractor and the owner because savings performance is guaranteed based on stipulations, and it does not require as much time, money, and personnel from either party in order to measure and verify the savings. However, if the stipulation is not made to monitor equipment operating efficiencies after installation and to correct the savings if equipment performance is lower than stipulated, this option is more advantageous to the contractor. Since actual savings are never verified with this option, the only protection the owner has is to verify that the stipulated equipment performance is being met.

Option A can be helpful in simple local chiller replacement projects, but it is not recommended for central plants where a chiller serves multiple buildings. Metering devices (Option B) are a more accurate and cost effective option for central plants. Option A is not recommended in the complete changeout of cooling systems where other system components, such as distribution systems or coils, are being replaced with the chiller.

7.13.7 Option B: Energy Savings Analysis

The baseline is based on stipulated parameters--continuous metering required.
Post-installation energy savings analysis is based on stipulated parameters--continuous metering required.

7.13.7.1 Baseline

The baseline is established by continuous metering of thermal and electric energy produced (steam, hot water, chilled water, and electricity) by the cogeneration plant and by stipulation of energy performance efficiency of displaced equipment based on available data and/or sample metering of displaced equipment.

Baseline Energy Based On Metering Data:

$$\text{Steam Energy (Btu)} = \text{Sum}\ \frac{\text{[Steam Energy Used By Energy Displaced quipment]}}{\text{Efficiency Of Energy Displaced Equipment}}$$

$$\text{Hot Water Energy (Btu} = \text{Sum}\ \frac{\text{[Steam Energy Used By Energy Displaced Equipment]}}{\text{Efficiency Of Energy Displaced Equipment}}$$

$$\text{Chilled Water Energy (Btu)} = \text{Sum}\ \frac{\text{[Steam Energy Used by Energy Displaced Equipment]}}{\text{Efficiency Of Energy Displaced equipment}}$$

Baseline Thermal Energy = Sum [Total Displaced Thermal Energy By Fuel Source Type (wood, coal, oil, natural gas, etc.)]

Baseline Electric Energy (kWh) = Electric Energy Produced By The Cogeneration Plant + Sum (Displaced Equipment Electric Energy)

Baseline Electric Demand (kW) = Electric Power Produced by the Cogeneration plant + Sum (Displaced Equipment Electric Demand)

TOTAL BASELINE ENERGY CONSUMPTION (in equivalent unit, Btu or kWh)
= STEAM ENERGY + HOT WATER ENERGY + CHILLED WATER ENERGY + ELECTRIC ENERGY

7.13.7.2 Post-Installation Verification

The post-installation's M&V process for cogeneration plant projects involves continuous metering of electric consumption and fuel energy input. Following are general formulas used in performing the post-installation energy calculations:

Post-Installation Energy Based On Continuous Metering:

Post-Installation Fuel Consumption (Btu) = Sum [Total Fuel Consumption By Fuel Source (wood, coal, oil, natural gas, etc.)]

Post-Installation Electric Consumption (kWh) = Electric Energy Consumed By The Plant

Post-Installation Electric Demand (kW) = Electric Power Demand Consumed By The Plant

TOTAL POST-INSTALLATION ENERGY CONSUMPTION (in equivalent unit, Btu or kWh) = POST-INSTALLATION FUEL CONSUMPTION + POST-INSTALLATION ELECTRIC CONSUMPTION

7.13.7.3 Energy Savings

Energy savings are calculated by taking the difference between the baseline, the displaced energy consumption, and the total plant energy consumption of the post-installation. Following are formulas used in performing energy savings calculations:

Energy Savings (in equivalent Btu or kWh) = Total Baseline Energy Consumption - Total Post-Installation Energy Consumption

Electric Demand Savings (in kW) = Baseline Electric Demand - Post-Installation Electric Demand

7.13.7.4 Energy Dollar Savings

When calculating energy (kW) dollar savings, it is important to examine how rate structures are applied. Many rate structures use a "tiered" energy charge system. For example, the first 50,000 kWh used in a month may cost $0.04, while the next 50,000 kWh are priced at $0.035, and so on. Examine the overall base utility usage to determine the real cost of energy saved using a particular ECM. With this type of rate structure, energy savings are initially generated at the top tier where the rate is lowest. If the average energy rate is used to calculate savings, the actual dollar savings achieved will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, savings will depend on the usage pattern of the ECM.

Demand dollar savings are realized when the ECMs reduce demand (kW) during peak electric demand periods at which time the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings. However, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Utility companies have many methods of charging for demand. Possible demand structures include contract demand, on-peak/offpeak demand, or ratcheted demand charges. Dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Following are formulas used in performing dollar savings calculations:

Energy Dollar Savings = Energy Savings x Affected Rate Demand

Dollar Savings = [kW_{POST} - kW_{BASE}] x Affected Rate

When calculating energy dollar savings for energy performance contracts, it is highly recommended that the existing energy rate at the time of the initial contract not be fixed to the baseline. Instead, the energy rate in the current contract year should be applied to the energy savings performance of the implemented ECMs. By using this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.13.7.5 Performance Assurance

- validate installed cogeneration plants meet specifications
- validate installed cogeneration plants operate and perform as specified
- check metering performance periodically to ensure proper functioning

7.13.7.6 Range Of Accuracy

The performance of the ECM will be based on metering data and the utility rate, which are generally well defined variables. The accuracy of Option B is primarily dependent on the estimate of the stipulated factors in the baseline and should normally be within ten percent for this M&V method.

7.13.7.7 Range Of Cost As A Percent Of Savings

The cost for Option B should be limited to ten percent of the energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.13.7.8 Overall Advantages

For a cogeneration plant project where metering of energy input and output is already an integral and essential part of the project, Option B offers an accurate and cost effective method for performing measurement and verification. Option B is the better choice over Option A or Option C. Option B is most advantageous for the owner since savings performance is ensured through continuous metering. Option B offers the same time and cost savings advantages to the contractor in baseline development and to the post-installation measurement and verification.

7.13.8 Option C: Energy Savings Analysis

Option C is applicable for projects where there is a high degree of interaction between multiple energy conservation measures, or where the measurement of individual component savings would be difficult, or lack cost effectiveness. Option C employs statistical analysis of utility meter billing data or computer simulation modeling of the facility’s energy systems calibrated with billing data to predict the total energy savings of the ECMs.

However, for a cogeneration plant project where metering of energy input and output is already an integral and essential part of the project, Option B will offer an accurate, cost effective, easy to develop, and easy to implement method for performing measurement and verification. Option C would require extensive effort in performing computer modeling and/or utility bill statistical analysis involving numerous assumptions and stipulations similar to Option A. Option C does not offer a significant advantage over Option A. Therefore, Option C is not recommended for measurement and verification of a cogeneration plant project.

7.13.9 Energy Systems Metering And Measurement Points

Refer to Section 8.0 for diagrams showing the type and location of metering and measurement points for measurement and verification of the energy system's performance. The nine diagrams specific to DX unit/heat pump replacement projects are:

1) Figure 1, Electrical Power Metering/Monitoring - Single Phase Loads;
2) Figure 2, Electrical Power Metering/Monitoring - Three Phase Loads;
3) Figure 3, BTU Instrumentation;
4) Figure 4, Hot Water Boiler;
5) Figure 5, Steam Boiler;
6) Figure 6, Water Cooled Chillers;
7) Figure 7, Water Cooled Chillers/Plate Heat Exchanger;
8) Figure 8, Water Cooled Steam Absorption Chillers; and
9) Figure 9, Water Cooled Direct-Fired Or Gas Engine Driven Chillers.

7.14 BUILDING ENVELOPE

7.14.1 Description

The building envelop modification project involves changing physical characteristics of the building. The strategies for energy conservation measures (ECMs) for building envelop projects include insulation, window films/glazing systems, roofing material and structure, building orientation, and passive solar.

7.14.2 Energy Analysis Parameters

There are many energy parameters associated with modification to the building envelop. Following is a general list of energy parameters necessary to perform energy analysis.

- building physical characteristics and orientation
- building heat losses
- weather data
- building occupancy and equipment loads
- energy performance of HVAC equipment
- HVAC system design and configuration
- control schemes of HVAC equipment
- usage profile of operating hour
- utility energy rates
- utility demand rates

7.14.3 Data Gathering

A detailed site survey is required to perform energy analysis. Following is a sample list of data required to perform energy analysis:

- building orientation, floor plans, fenestration and construction--much of this information can be collected from a set of as-built architectural drawings;
- descriptions of as-built building mechanical systems, including all HVAC equipment (primary and

secondary)--as-built mechanical drawings could be of use since information for the zoning of HVAC systems is on the drawings;

- descriptions of all electric systems--as-built electrical drawings can provide this information as well as lighting load information and control system specifications;
- verify lighting loads estimated from electric diagrams by counting fixtures and measuring lamp and ballast wattage; obtain indoor and outdoor lighting schedules;
- determine directions which major facades of building face; estimate distance from surrounding buildings and height of surrounding buildings for shading calculations; photograph the building exterior and surroundings;
- record nameplate data, type and locations of all primary and secondary HVAC systems; obtain air balance report, including supply and return measurements of air temperature; obtain part-load performance characteristics of equipment from manufacturer;
- obtain hourly HVAC schedules, thermostat settings, including day/night setback; obtain printout of EMCS program settings, where possible;
- measure wattage of internal plug loads (appliances, computers, etc.); obtain usage schedules;
- examine available local weather data, such as air temperature, humidity, wind speed and wind direction, and solar insolation (vertical and south-facing horizontal) measured at the nearest airport, or on -site (TRY or TMY weather files for a typical year of data may also be substituted, where necessary);
- utility electric and gas rate schedules.

7.14.4 Measurement And Verification

Due to the high degree of interaction between numerous energy systems and conservation measures as well as the enormous cost of having to measure individual components of energy systems, Option C is the only viable option for performing M&V for building envelop modification projects. Option C employs statistical analysis of utility meter billing data or computer simulation modeling of facility energy systems calibrated with billing data to predict total energy savings of the ECMs. For building envelop modification projects, computer simulation modeling calibrated with utility bills is a recommended M&V method.

7.14.5 Advantages And Disadvantages

The following tables provide advantages and disadvantages for each M&V option from the owner's point of view and the contractor's point of view.

Table 7.14.5.1

OPTION ADVANTAGES AND DISADVANTAGES FOR THE OWNER

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
n/a	n/a		n/a	n/a	moderate development cost
n/a	n/a		n/a	n/a	no guarantee of long term system performance and savings
n/a	n/a	acceptable accuracy	n/a	n/a	acceptable accuracy
n/a	n/a		n/a	n/a	probability of dispute

Table 7.14.5.2
OPTION ADVANTAGES AND DISADVANTAGES FOR THE CONTRACTOR

M&V OPTION ADVANTAGES			M&V OPTION DISADVANTAGES		
OPTION A	OPTION B	OPTION C	OPTION A	OPTION B	OPTION C
n/a	n/a		n/a	n/a	moderate development cost
n/a	n/a	acceptable accuracy	n/a	n/a	acceptable accuracy
n/a	n/a		n/a	n/a	probability of dispute
n/a	n/a	guarantee of long term shared savings	n/a	n/a	

7.14.6 Option C: Energy Savings Analysis

The baseline is fixed on computer simulation modeling calibrated with utility billing data.
The energy savings analysis for the post-installation is based on computer simulation modeling calibrated with utility billing data.

7.14.6.1 Baseline

The data collected during the initial site survey is used as input data to the simulation program for building the baseline model, and the simulation calibration process follows. A number of iterations are often required, as well as an experienced building modeling analyst who can determine the necessary improvements to the model.

Building simulation models can be calibrated using utility bill data and/or short term metering data. Only calibrations with utility data are described in this section. The simulation model is calibrated when the output electric (i.e. kWh and kW) and gas (i.e. therms and therms/hr.) use closely match that of the measured data.

When using programs that output hourly kilowatt hour and therm consumption combined with the available actual hourly kilowatt hour and therm consumption, the mean bias error (MBE) and coefficient of variation of the root-mean square error (CV(RMSE)) are used to specify calibration of the model.

Calculation of the mean bias error shows whether the simulation under-predicts (negative) or over-predicts (positive) the measured consumption and by what percentage. A small value for the MBE is desired for each month when determining model calibration. However, the MBE alone is not an accurate indication because of the possibility of cancellation in under-prediction and over-prediction errors from hour to hour.

The CV(RMSE) is an indication of variability in the data. The degree of variability is higher when the CV(RMSE) is larger. Comparing monthly measured and simulated data with a low MBE and a low CV(RMSE) means the simulated results match measured results. In general, the absolute value of the MBE should be less than seven percent, and the absolute value of the CV(MBSE) should be less than 25 percent. These specifications are guidelines only and the agency and ESCO may agree to tighter, or looser, calibration criteria.

Using tabulated values for measured and simulated values, the MBE and CV(RMSE) for each month during the year will yield a more comprehensive basis for simulating calibration. For the months when the MBE, or the CV(RMSE), or both, are large, an indication of model adjustment can be obtained. The agency and ESCO should both agree to acceptable levels for the MBE and CV(RMSE).

7.14.6.2 Post-Installation Verification

As with other M&V methods described in this document, installation of the ECMs should be verified and the equipment/systems commissioned. As part of the activity performance, data for new equipment

should be obtained from nameplate information and/or the manufacturer(s). Sometimes spot-metering of new equipment may be necessary to verify performance data.

Once the baseline model is calibrated, the baseline input file is saved and the new description for the ECM replaces data in the baseline input file. The simulation is re-run with the new data, and a post-installation model is generated. The post-installation model may, or may not, require calibration depending primarily on the number of changes required to model the new ECMs.

7.14.6.3 Savings Determination

Savings estimates for the first year are based on the difference between the pre-installation (calibrated) simulation results and the post-installation results (obtained by substituting the new performance data in the calibrated simulation). The annual energy audit consists of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather data, utility bills and/or submetered data.

Successive annually recalibrated models can be used to calculate savings using either of the following sets of data:

- typical meteorological year (TMY) weather and/or average building occupancies, etc. (most common options); or
- actual post-installation values for the weather and/or building occupancies, etc.

7.14.6.4 Energy Dollar Savings

To ensure that the simulation model accurately calculates the energy dollar savings, examine how utility rate structures are applied. Many rate structures use the tier bracket arrangement where cost at the bottom tier is higher than the tiers above it. Energy savings are generated at the top tier where the rate is lowest. If the average rate is use to calculate savings, the savings achieved in the billing will be significantly less than the calculated value. Other rate structures are based on time of use when the energy rate is higher during the on-peak period and lower during the off-peak period. For this rate structure, the energy dollar savings will depend on the usage pattern of the ECM.

For electric demand dollar savings, it is also important to examine how rate structures are applied. Savings are realized when the ECM reduces demand (kW) during the peak electric demand period when the demand charge is applied. For example, reducing demand (kW) for light fixtures operating during the day will generate demand savings; however, reducing demand (kW) for light fixtures operating only at night will not produce demand savings. Some demand structures include contract demand, onpeak/off-peak demand, ratchet demand, non-ratchet demand, or no demand charge. Energy dollar savings are calculated by applying an appropriate rate structure to the energy and demand savings of the ECM. Make sure utility rate structures are entered correctly in the simulation modeling program.

When calculating energy dollars savings for energy performance contracts, it is highly recommended that the current energy rate at the time of the initial contract not be fixed to the baseline. Instead, the rate in the current contract year should be applied to the baseline. By applying this process, the owner and the contractor share the benefits as well as the risk of future changes in utility rates.

7.14.6.5 Performance Assurance

- ensure simulation model accounts for field changes in the implementation phase
- validate installed equipment and control schemes meet specifications
- validate installed equipment and control schemes operate and perform as specified
- perform annual energy audits which consist of recalibrating the simulation model based on the post-installation ECM data, the previous year's weather data, the utility bills, and/or submetered data

7.14.6.6 Range Of Accuracy

To accurately model building energy performance and costs, considerable detail is required in data concerning the facility and its energy systems. The data includes the physical layout of a building, its physical properties, intended use, installed equipment, and interaction between energy systems. In addition, computer simulations of building energy performance and costs will largely depend on the experience of the modeling analyst. In order to obtain accurate results using this method, calibrating the simulation model with actual utility metering data and/or short term metering of individual systems is necessary. If the simulation results do not agree with measured whole-building energy data, trained and experienced personnel are often required to determine the cause of discrepancy. Fortunately, software is evolving, and powerful new user-friendly programs with libraries of building construction shapes, materials, equipment performance characteristics, occupancy schedules, etc. will make possible the discovery and rectification of discrepancies more rapidly. The accuracy of Option C will depend on the complexity of the facility and its energy systems and the skill of the modeling analyst. Accuracy for this M&V method should normally be less than ten percent of the actual utility bills.

7.14.6.7 Range Of Cost As A Percent Of Savings

Cost for Option C should be limited to ten percent of energy cost savings over the term of the energy performance contract. The cost of M&V should not exceed the expected increase in savings resulting from the measurement and verification.

7.14.6.8 Overall Advantages

Option C is more advantages to the contractor than the owner because the contractor develops the building energy simulation model and is considered to be the expert. The contractor has the advantage of manipulating the baseline and post-installation results since modeling is more of an art form than exact science. Savings are often guaranteed based on the results of the simulation model; however, long term energy performance is difficult to validate. The owner would need knowledgeable engineers to review the simulation model and validate the model input and assumptions. Actual utility bills are the most valuable tool the owner has for validating the energy performance results of the model. Option C is more costly to develop for the contractor than the owner, but it can be equally costly for the owner to validate and ensure the performance of the energy project.

8.0 ENERGY SYSTEMS METERING AND MEASURE POINTS

The following eleven diagrams show the types and locations of metering and measurement points for the measurement and verification of energy system performance. The M&V process may be performed by sample measurement or continuous metering.

Key Legend

kW/kWh	Electric Meter or Power Monitor
T	Temperature Measurement
P	Pressure Measurement
F	Flow Measurement
FUEL SOURCE METER	Gas Meter, Fuel Oil Meter, Steam Meter, Scale or Feed Rate Meter
STR	Motor Starter/Control
kW	kilowatt
kWh	kilowatt hour
STR	starter
OA	outside air
MA	mixed air
SA	supply air
RA	return air
HWR	hot water return
HWS	hot water supply
CHW	chilled water
T	temperature
P	pressure
F	flow

(E) electrical

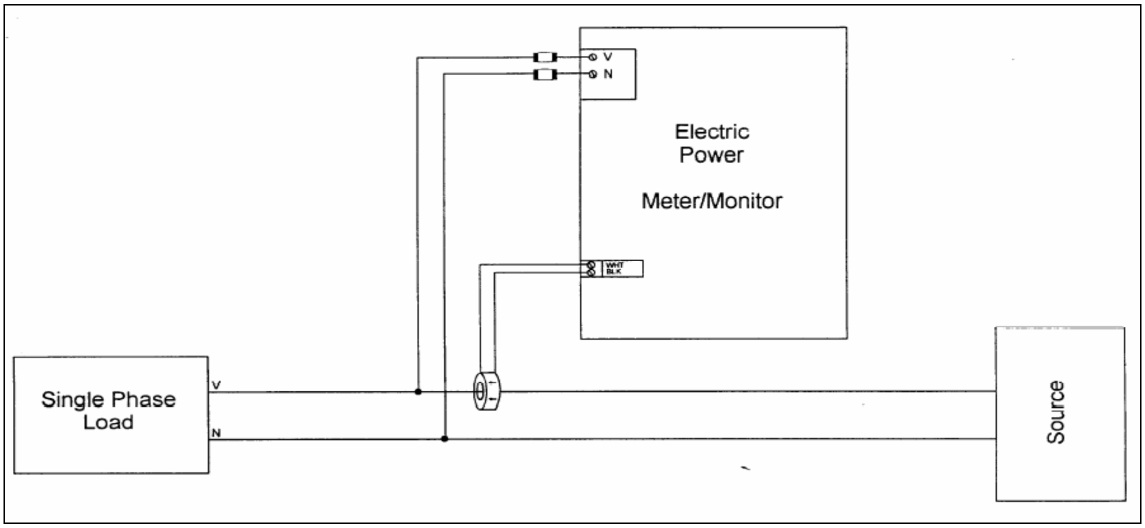

Figure 1
Electrical Power Metering/Monitoring – Single Phase Loads

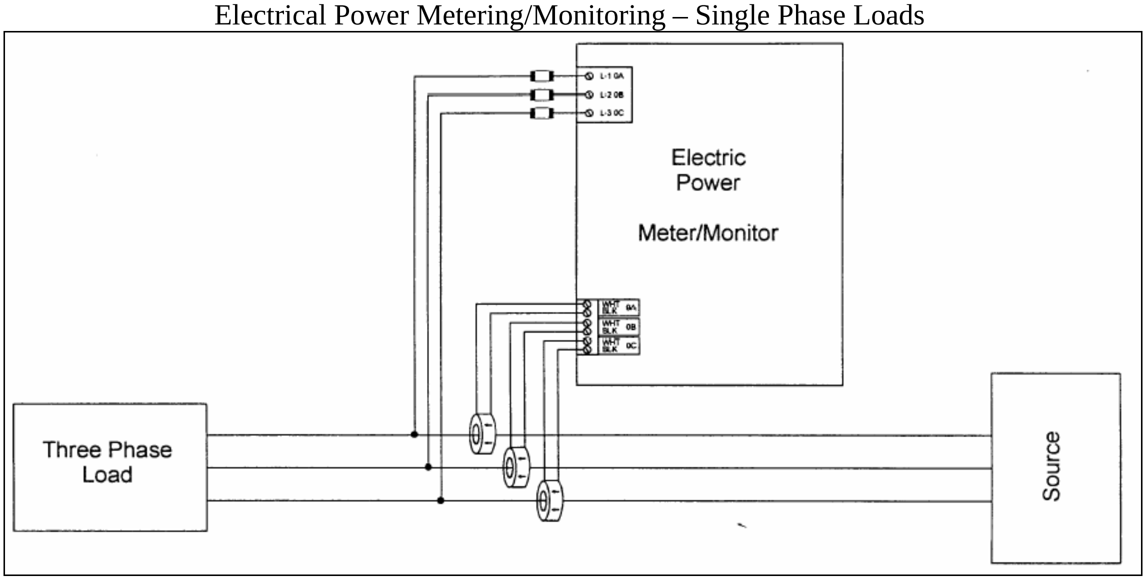

Figure 2
Electrical Power Metering/Monitoring – Three Phase Loads

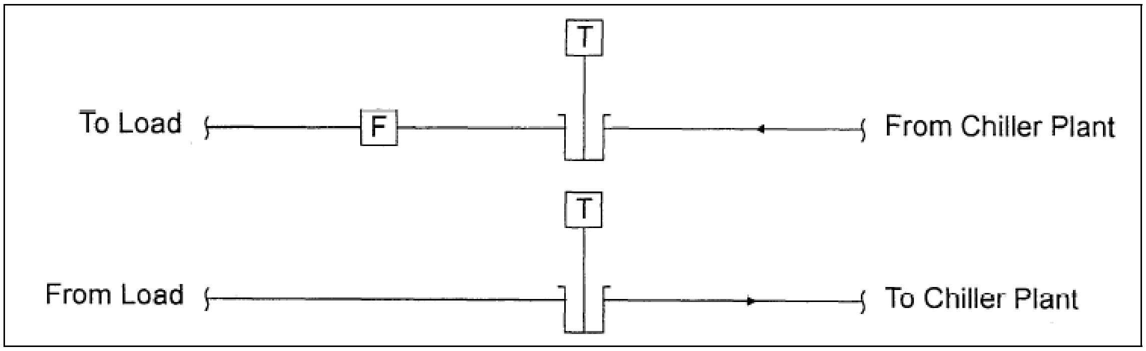

Figure 3
BTU Instrumentation

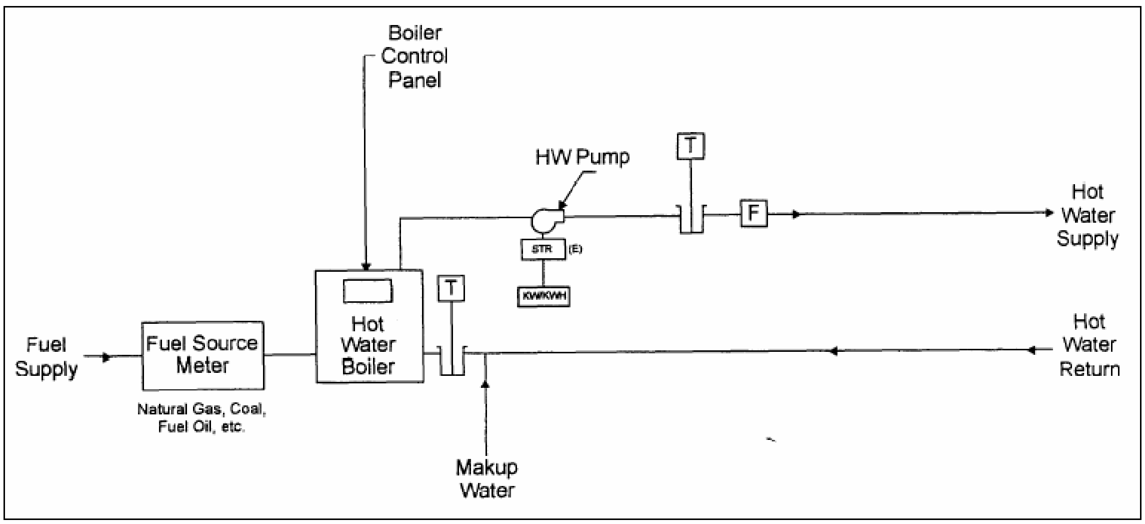

Figure 4
Hot Water Boiler

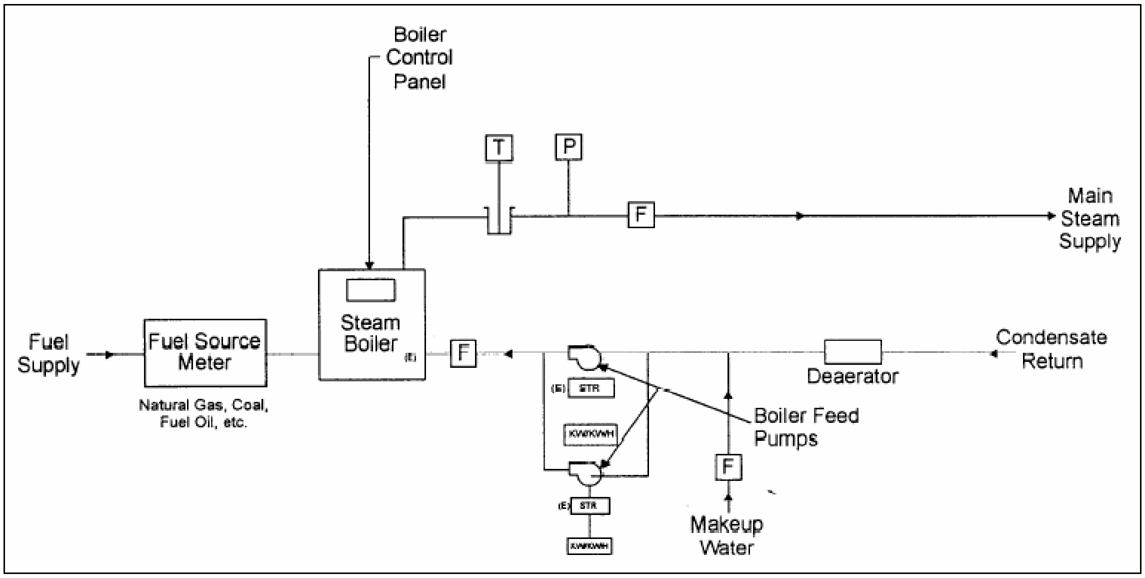

Figure 5
Steam Boiler

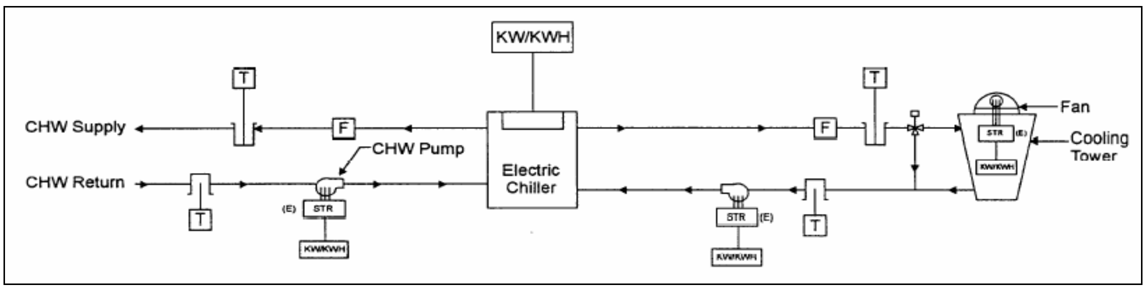

Figure 6
Water Cooled Chillers

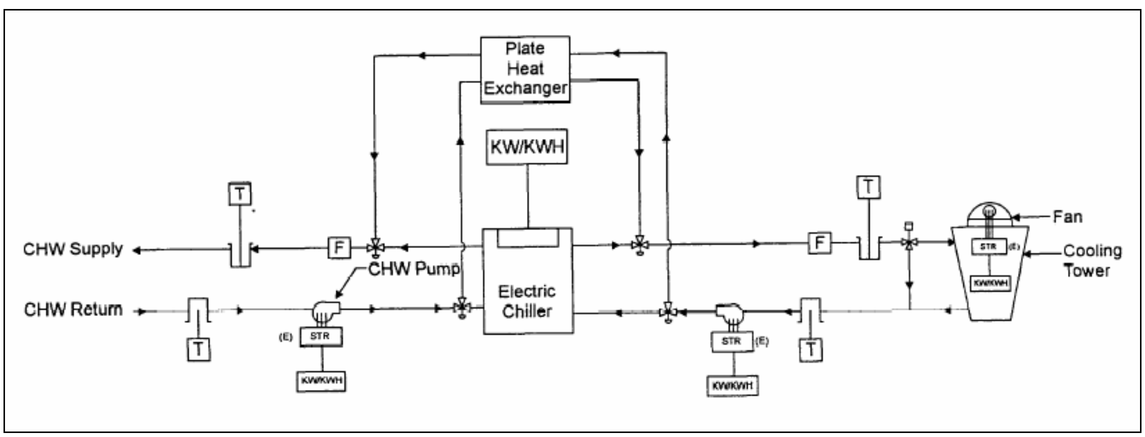

Figure 7
Water Cooled Chiller/Plate Heat Exchanger

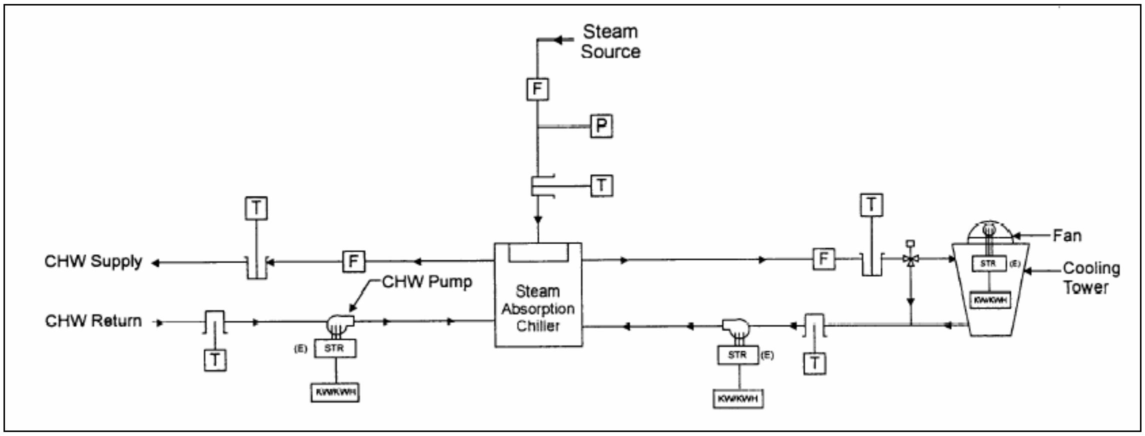

Figure 8
Water Cooler Steam Absorption Chiller

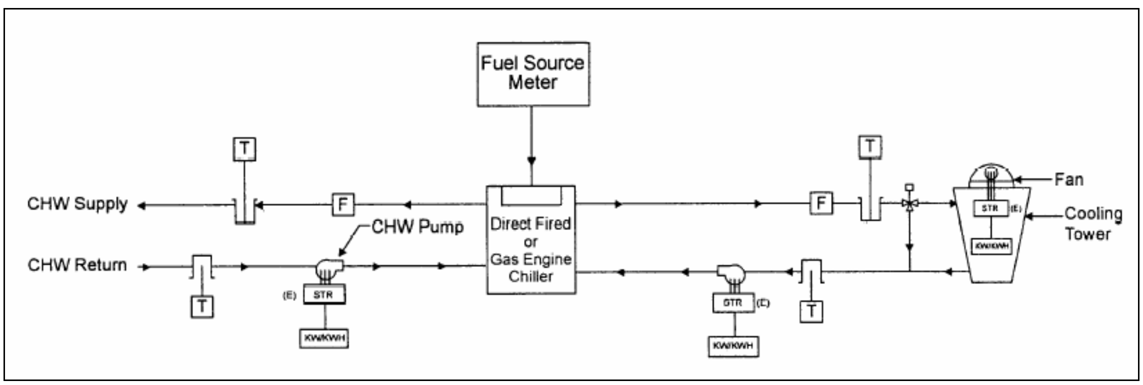

Figure 9
Water Cooled Direct Fired or Gas Engine Driven Chiller

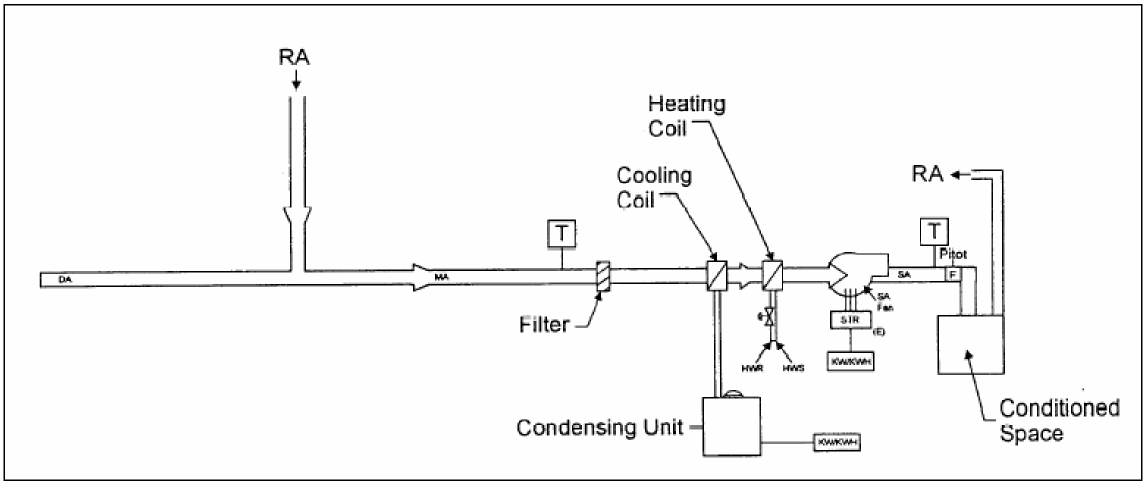

Figure 10
Single Zone Direct Expansion A/C Unit

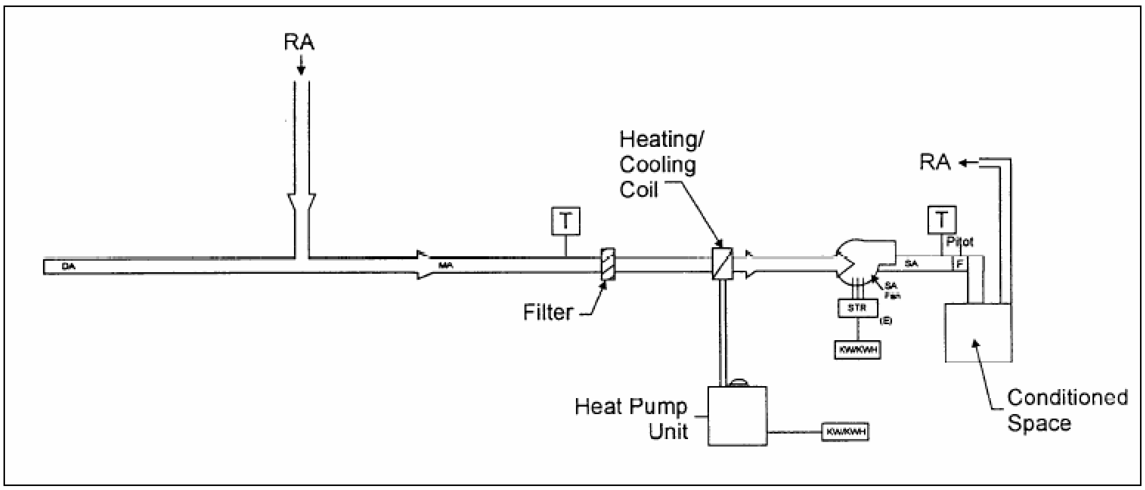

Figure 11
Single Zone Heat Pump Unit