Efficiency Valuation Organization

M&V ISSUES AND EXAMPLES

WORKING DOCUMENT

FIVE-YEAR STATUTORY PROTOCOL REVIEW

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2. Introduction – M&V Purpose and Process Overview

"*Measurement and Verification*" (*M&V*) is the process of using measurement to reliably determine *savings*[1] created within an individual facility by an energy management program. Savings cannot be directly measured since they represent the absence of energy consumption and demand. Instead, *savings* are determined by comparing measured consumption and demand before and after the implementation of a project, making appropriate adjustments for changes in conditions.

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

» meter installation calibration and maintenance,

» data gathering and screening,

» development of a computation method and acceptable estimates,

» computations with measured data, and

» reporting, quality assurance, and third-party verification of reports.

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

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

[1] Words in italics have the special meanings defined in Core Concepts April 2016; EVO 10000-1:2016.

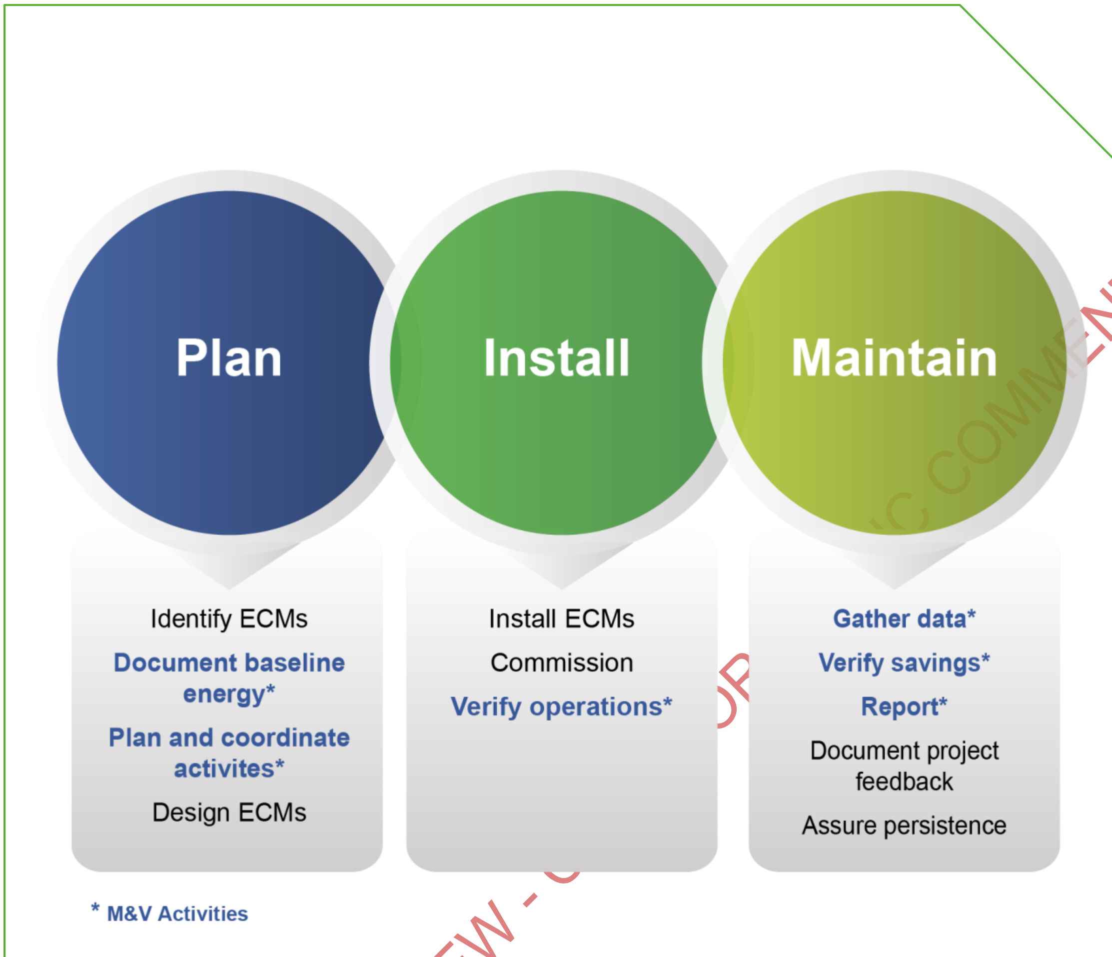

Figure 1. Process Timeline

2.1. Purposes of *M&V*

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

Increase energy savings

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

Document financial transactions

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

Enhance financing for efficiency projects

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

Improve engineering design and facility operations and maintenance

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

Manage *energy* budgets

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

Enhance the value of emission-reduction credits

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

Support evaluation of regional efficiency programs

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

Increase public understanding of energy management as a public policy tool

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

2.2. The *M&V* Design and Reporting Process

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

Step 1

Consider the needs of the user of the planned M&V report(s). If the user is focused on overall cost control, Whole-Facility methods may be best suited. If user focus is on particular ECMs, Retrofit Isolation techniques may be most suited (see Core Concepts, Sections 6.2 through 6.6).

Step 2

While developing the ECM(s), select the IPMVP Option (see Core Concepts, Section 6) that best suits the ECM(s), the needs for accuracy and the budget for M&V. Decide whether adjustment of all energy quantities will be made to the reporting period conditions or to some other set of conditions (see Core Concepts, Section 5.3). Decide the duration of the baseline period and the reporting period (see Core Concepts, Section 5.2). These fundamental decisions may be written into the terms of an energy-performance contract.

Step 3

Gather relevant energy and operating data from the baseline period and record them in a way that can be accessed in the future.

Baseline Data − Examples

- Whole-building energy consumption and demand can be significantly affected by weather conditions. Typically, a full year of monthly data is required to define a full operating cycle. If interval data (hourly or daily) are used, a full operating cycle may be captured in less than a year.
- The energy consumption and demand of a compressed air system may only be governed by plant production levels, which vary on a weekly cycle. So, one week's data may be all that is needed to define baseline performance.

Step 4

Prepare an M&V Plan (see Core Concepts, Section 7.1) containing the results of steps 1 through 3 above. It should define the subsequent steps 5 through 9.

Step 5

As part of the final ECM design and installation, also design, install, calibrate and commission any special measurement equipment that is needed under the M&V Plan.

Step 6

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

Step 7

Gather energy and operating data from the reporting period, as defined in the M&V Plan.

Step 8

Compute savings in energy and monetary units in accordance with the M&V Plan.

Step 9

Report savings in accordance with the M&V Plan.

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

A third party may verify that the M&V Plan adheres to the IPMVP, and possibly a performance contract. This third party may also verify that savings reports comply with the approved M&V Plan. The frequency and the format for these M&V reports will also be included in the M&V Plan. Verification of savings can be performed by an independent party or by the project developer as long as quality assurance oversight is performed by a qualified person.

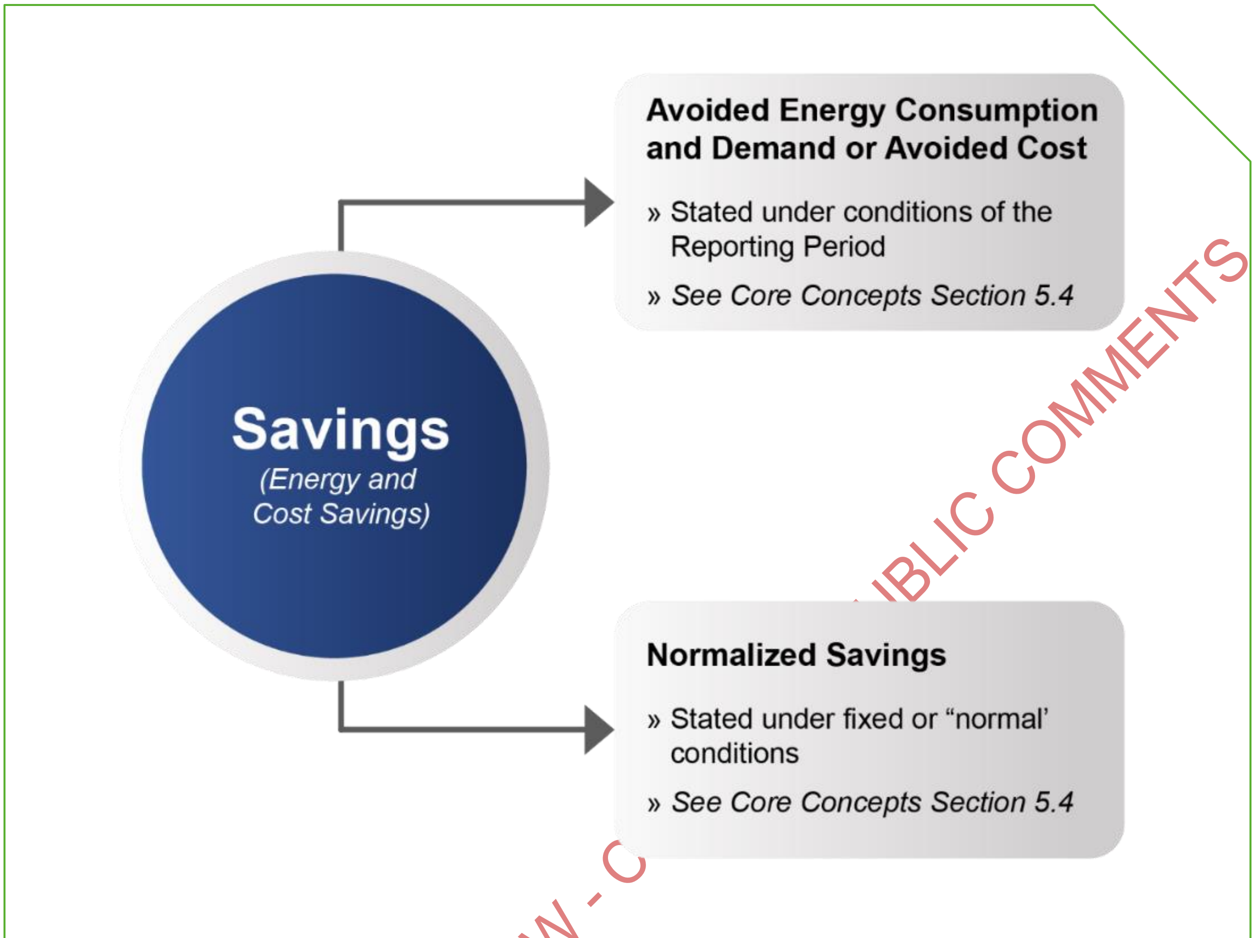

Figure 2. Two Types of Savings

3. M&V Option Selection Guide

The selection of an IPMVP Option is a decision that is made by the designer of the M&V program for each project, based on the full set of project conditions, analysis, budgets and professional judgment.

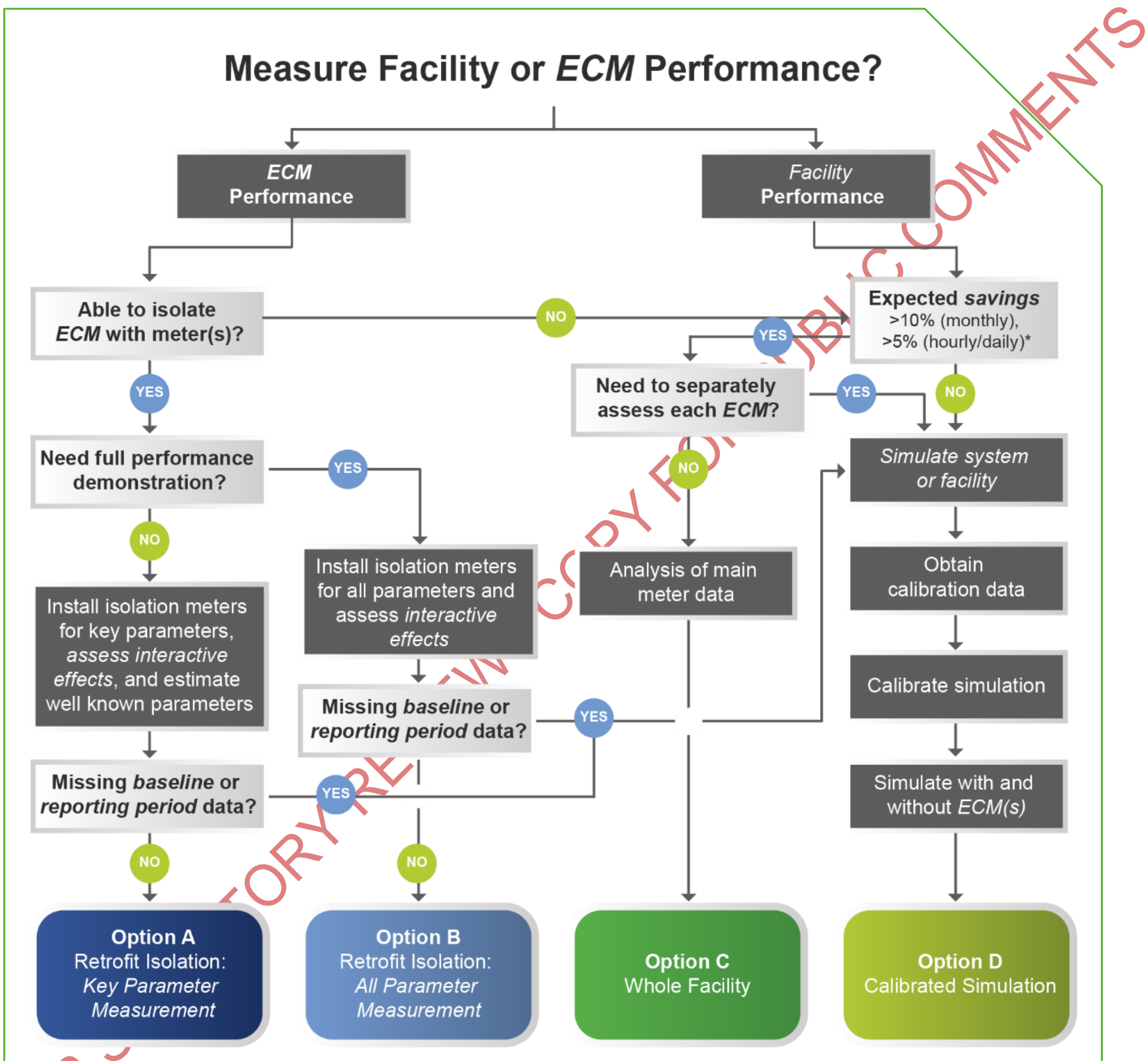

Figure 3. Decision Process of an IPMVP Option

*Note: Estimating savings uncertainty is complex and depends upon how "well-behaved" a building is and the resultant scatter in the data, the number of points being modeled, and the time interval between the points. The expected savings values presented here should be considered guidance – they are neither requirements nor proof of sufficiency of a model. They suggest that for *most* buildings, the signal-to-noise will be sufficiently high if the savings percentages are higher than these rules-of-thumb, and hence savings may be reliably estimated using meter-level data.

It is impossible to generalize on the best IPMVP Option for any type of situation. However, some key project characteristics suggest commonly favored Options as shown in Table 1 below.

Table 1. Suggested (not the only) Options

ECM Project Characteristic	Suggested Option			
	A	B	C	D
Need to assess ECMs individually	✗	✗		✗
Need to assess only total facility performance			✗	✗
Expected savings less than 10% (monthly) or 5% (daily/hourly) of annual baseline consumption	✗	✗		✗
The significance of some energy driving variables is unclear		✗	✗	✗
Interactive effects of ECM are significant or unmeasurable			✗	✗
Many future changes expected within the measurement boundary	✗			✗
Long-term performance assessment needed	✗		✗	
Baseline data not available				✗
Etc.				

Interactive Effects – Example

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

4. Common *M&V* Issues

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

4.1. Applying Energy Prices

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

Equation 1

$$\text{Cost Savings} = C_b - C_r$$

Where:

C_b = Cost of the baseline energy plus any adjustments

C_r = Cost of the reporting period energy plus any adjustments

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

> ***Note:*** *If cost savings are being calculated directly from energy unit savings, see section 4.3 below regarding utilization of proper marginal prices.*

When the conditions of the reporting period are used as the basis for reporting energy savings (i.e., avoided energy consumption and demand), the price schedule of the reporting period is normally used to compute "avoided cost". For a performance contract where there are guaranteed energy savings and the associated energy cost savings are used to determine payments to the contractor, particular care must be taken in applying energy prices. If the ECM performance is focused on the energy consumption and demand savings and the contractor is not taking any risk on the guarantee of energy prices throughout the contract reporting period, then the energy prices should be defined in the contract M&V plan and agreed to between the owner and contractor. These contractually defined energy prices would then be used rather than the actual reporting period energy prices to avoid the situation of energy cost savings meeting the guarantee due to higher than projected actual energy prices while the energy savings in consumption and demand do not meet the performance guarantee. This could increase the risk to the owner due to the contractor not meeting the energy performance guarantee in consumption and demand but still meeting the associated cost savings due to a factor out of the contractor's control while the owner is also subject to overall higher energy prices.

Examples of the application of energy prices are contained in the examples later in this Application Guide.

4.1.1. Price Schedules

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

Price schedules may change at points in time different from meter reading dates. Therefore, C_b and C_r in Equation 1 should be computed for periods exactly aligned with price change dates. This alignment may require an estimated allocation of quantities to periods before and after the price change date. The allocation methodology should be the same as that used by the energy supplier.

The selected price schedule may be fixed or changed as prices change. (Increasing prices will shorten the ECM payback period and decreasing prices will lengthen the payback period though total energy costs will drop when prices drop). Where a third party has invested in an owner's facility and/or payments are based on verified savings such as in a performance contract, the price schedule for savings reporting is normally fixed at a base price schedule at the time of commitment of the investment (or contract) and not normally allowed to drop below that for the purposes of determining verified energy cost savings to meet the guarantee and support payments.

In addition, the determination and stipulation of an annual escalation rate to be applied to the base price schedule (to reflect maximum projected reporting period prices) for each year of the reporting period is agreed to in order to determine contractual or investment cost savings. There are industry tools available to assist with the energy price escalation forecasts however this is a project and site-specific variable that must be carefully determined with and agreed to by the owner in the contract M&V Plan, before implementation of the project. For performance contracts, the defined energy prices then become the contract energy prices and the actual rates during the reporting period are for information only (they can be used to illustrate energy costs savings but the verified cost savings to prove the guarantee are calculated using the contract energy prices).

4.1.2. Marginal Price

An alternative procedure for valuing savings involves multiplying energy units saved by the marginal price of energy. Be careful to ensure that the marginal price is valid for the level of consumption and demand of both the baseline and reporting periods. The concept of establishing base prices and associated reporting period escalation factors, as discussed above, also apply to marginal price savings procedures, as well as the required use of the price schedule in determining the proper marginal price for the valuation of the project-specific savings projection.

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

4.1.3. Fuel Switching and Price Schedule Changes

The Section 4.1 general strategy of applying the same price schedule to baseline and reporting period energy introduces some special considerations when the ECM creates a change in fuel type or a change in price schedule between the baseline and reporting periods. Such situations arise, for example, when an ECM includes a change to a lower cost fuel or shifts the energy consumption and/or demand pattern such that the facility qualifies for a different price schedule.

In such situations, use the price schedule of the baseline commodity to determine C_b in Equation 1). The price schedule of the reporting-period commodity should be used in determining C_r. However, both commodity-price schedules would be for the same time period, usually the reporting period.

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

However, this treatment of an intentional change of price schedule does not apply if the change was not part of the ECM(s) being assessed. For example, if the utility changed its price structures for no reason related to the ECM(s) being assessed, the Section 4.1 general principle of using the same price schedule for C_b and C_r still applies.

4.2. Non-Routine Adjustments

Conditions, which vary in a predictable fashion and are significant to energy consumption and/or demand within the measurement boundary are normally included within the mathematical model used for routine adjustments, described in Core Concepts, Section 5.3. Where unexpected changes occur in conditions (including atypical operations) which are otherwise static (static factors) within the measurement boundary, non-routine adjustments must be made.

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

Values estimated for use in IPMVP Option A are usually chosen to eliminate the need for adjustments when changes happen within the measurement boundary (see Core Concepts Section 5.1). Therefore, non-routine adjustments can be avoided using Option A. For example, a chiller plant's cooling load was estimated rather than measured in order to determine Option A savings created by a chiller efficiency ECM. After the retrofit, a facility addition increased the actual cooling load within the measurement boundary. However, since Option A was chosen using a fixed cooling load, reported savings are unchanged. The use of Option A avoided the need for a non-routine adjustment.

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

Non-routine adjustments are determined from actual or assumed physical changes in the facility, equipment, or operations (static factors). Measurements used to quantify impacts of non-routine adjustments should be considered where possible. Sometimes it may be difficult to quantify the impact of changes, for example, if they are numerous or not well documented. The M&V Industry is rapidly advancing with the development of advanced data analytics-based tools (sometimes referred to as M&V 2.0 or advanced M&V) which could impact the tracking and quantification of non-routine adjustments in the future.

Static Factors

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

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

4.3. Advanced M&V Methods

It is common industry practice to verify savings from efficiency projects at the end of the M&V reporting period. Advanced M&V, sometimes referred to as M&V 2.0, improves upon past methods by enabling savings to be tracked on an on-going basis. These M&V methods couple shorter time interval energy use data (typically daily, hourly or sub-hourly data collected from whole-building utility meters) with advanced analytics. The approach increases savings resolution, expedites savings valuation, and enables the on-going assessment of energy performance. This supports early detection of performance changes and provides actionable insights for minimizing savings shortfalls. Perhaps most important, it allows Option C approaches to be credibly applied for much lower savings than is reasonable with monthly billing data.

The increased prevalence of advanced utility meters, ample data from energy management systems, inexpensive computing power, and the development of comprehensive data analytic methodologies are spurring the advancement of M&V methods. Market drivers include energy efficiency and climate change legislative activity and mandates, such as California's SB 350/AB 802, which requires utilities to use building metered energy data to determine or "measure" energy savings. Market needs are being met with newly emerging software tools that embed advanced analytics and M&V methods, which have the potential to automate M&V analysis, streamline processes, and reduce associated costs while retaining or improving accuracy.

These new developments directly impact the application of IPMVP Whole-Building Option C. Using interval meter data with Option C typically involves creating a series of multi-variant regression models to predict whole building energy consumption. IPMVP guidance for advanced M&V is under development to address application issues such as: selecting data intervals and groupings; considerations on independent variables; applying regression models; determining savings uncertainty; and testing the accuracy of energy information software (EIS) for M&V. Currently, some information on empirical models using whole building data is available through the California Commissioning Collaborative[2].

The availability of interval meter data and related analytics may also influence the implementation of other M&V methods beyond Option C. The analytic methods may be applied to interval data collected from building subsystems under an Option B approach. Interval energy meter data can confirm schedules used in Option A or B applications, and provide a basis for calibration of simulation models used in Option D.

4.4. The Role of Uncertainty

The measurement of any physical quantity includes errors because no measurement instrument is 100% accurate. The estimation of savings is uncertain because savings represents the absence of energy use and cannot be measured, only estimated. Errors are the differences between observed and true energy consumption and demand. In a savings-determination process, errors prevent the exact determination of savings.

Core Concepts Equation 1) usually involves at least two such measurement errors (baseline and reporting period energy), and whatever error exists in the computed adjustments. To ensure that the resultant uncertainty in the savings estimate is acceptable to the users of a savings report, be certain to manage the errors inherent in measurement and analysis when developing and implementing the M&V Plan.

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

- ***Instrumentation*** – measurement equipment errors are due to calibration, inexact measurement, or improper meter selection installation or operation.
- ***Modeling*** – the inability to find mathematical forms that fully account for all variations in energy consumption and demand. Modeling errors can be due to inappropriate functional form, the inclusion of irrelevant variables, or the exclusion of relevant variables. Model uncertainty is due to scattering in the data beyond what is characterized by appropriate independent variables.

[2] See http://www.cacx.org/resources/vos-guidelines/ for *Guidelines for Verifying Savings from Commissioning Existing Buildings.*

- ***Sampling*** – use of a sample of the full population of items or events to represent the entire population introduces error as a result of the variation in values within the population, or biased sampling. Sampling[3] may be performed in either a physical sense (i.e., only x number of the lighting fixtures are measured) or a temporal sense (instantaneous measurement only once per hour).
- ***Interactive effects*** (beyond the measurement boundary) that are not fully included in the savings computation methodology.
- ***Estimation of parameters using Option A, rather than measurement*** – you can minimize the variation between the parameter's estimated value and its true value through careful review of the ECM design, careful estimating of the parameter, and careful ECM inspection after installation.

Methods of quantifying, evaluating and reducing some of these uncertainties are discussed in the *Uncertainty Assessment for IPMVP EVO 10100–1:2018*. These quantification tools should be used to develop the M&V Plan, in order to test the inherent uncertainty associated with optional M&V program characteristics.

Establish the users' acceptable *savings* uncertainty during the M&V Planning process. Section 4.6 discusses some issues in establishing the correct level of uncertainty for any *ECM* or project. The *Uncertainty Assessment for IPMVP EVO 10100–1:2018* defines how large savings must be, relative to statistical variations in baseline data, for *M&V* reports to be valid.

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

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

When you describe precision within any savings report, report the savings with no more significant digits than the least number of significant digits in metered quantities, estimates or constants used in the quantification process (see Section 4.15).

4.5. Cost

The cost of determining savings through M&V depends on many factors such as:

- IPMVP Option selected,
- the number of ECMs and the complexity and amount of interaction among them,

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[3] As used in this Protocol, sampling does not refer to rigorous statistical procedures, but to the best practices as addressed in the *Uncertainty Assessment for IPMVP EVO 10100–1:2018.*

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

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

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

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

Table 2. Unique Elements of M&V Costs

Option A	» Number of measurement points. » Complexity of estimation. » Frequency of reporting period inspections.
Option B	» Number of measurement points. » Length of the reporting period.
Option C	» Number of static factors to be tracked during the reporting period. » Number of independent variables to be used for routine adjustments.

Option D	» Number and complexity of systems simulated. » Number of field measurements needed to provide input data for the calibrated simulation. » Skill of professional simulator in achieving calibration.

Commonly, since Option A involves estimates, it will involve fewer measurement points, and lower cost, providing estimation and inspection costs are not unusually high. Option A methods usually have lower cost and higher uncertainty than Option B methods. Since new measurement equipment is often involved in Options A or B, the cost of maintaining this equipment may make Option C less costly for long reporting periods, but this must be compared to the costs for tracking static factors and making non-routine adjustments. However, the costs of extra meters for Options A or B may be shared with other objectives of monitoring or cost allocation. When multiple ECMs are installed at one site, it may be less costly to use Options C or D than to isolate and measure multiple ECMs with Options A or B. An Option D simulation model is often time-consuming and costly. However, the model may have other uses such as for designing the ECMs themselves or designing a new facility.

Expect M&V costs to be highest at the beginning of the reporting period. At this stage in a project, measurement processes are being refined, and accurate performance monitoring helps to optimize ECM operation. The cost for each savings determination should be in proportion to the expected savings and the variation in savings (see Section 4.6).

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

4.6. Balancing Uncertainty and Cost

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

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

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

Enhanced feedback created by M&V may also allow higher payments to be made under an energy performance contract based on measured data rather than deemed values of savings, which must be conservative. Of course, not all uncertainties can be quantified (see Section 4.4). Therefore, both quantitative and qualitative uncertainty statements should be considered when considering M&V cost options for each project.

For each project, site and facility owner, there is an optimal M&V Plan. That optimal M&V Plan should include iterative consideration of the sensitivity of the savings uncertainty and M&V cost to each M&V design parameter. The Uncertainty Assessment for IPMVP EVO 10100–1:2018 presents methods of quantifying uncertainty and present methods of combining several components of uncertainty and setting uncertainty criteria or objectives.

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

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

- ***Low Energy Variation & Low-Value ECM.*** Low-value *ECM*s cannot typically afford much M&V, based on the 10%-of-savings guideline, especially if there is little variation in the measured energy data. Such combined situations would tend to favor the use of Option A, and short reporting periods, for example, in the case of a constant-speed exhaust-fan motor that operates under a constant load according to a well-defined schedule.
- ***High Energy Variation & Low-Value ECM.*** Low-value ECMs cannot generally afford much M&V, as above. However, with a high amount of variation in the energy data, the all-parameter measurement techniques of Option B may be needed to achieve the required uncertainty. Sampling techniques may be able to reduce Option B costs. Option C may not be suitable based on the general guidance in Core Concepts Section 6.5, that savings should exceed 10% of a facility's metered use in order to be measurable.
- ***Low Energy Variation & High-Value ECM.*** With low variation in energy consumption and demand, the level of uncertainty is often low, so Option A techniques may be most suitable. However, since you expect high savings, small improvements in precision may have monetary rewards large enough to merit more precise metering and data analysis, if you can keep M&V costs appropriate relative to the savings. For example, if the savings from an ECM are $1,000,000 annually, you may decide to increase the $5,000 annual M&V cost to $20,000, if it increases precision and provides more operational data. Alternatively, a high-value ECM may be clearly measurable with Option C. Option C can keep M&V costs low, if simple means are used to monitor static factors to detect the need for non-routine adjustments.
- ***High Energy Variation & High-Value ECM.*** This situation allows appropriate uncertainty reduction through extensive data collection and analysis using Options A, B or D. However, savings are also

likely to show in the utility records, so that Option C techniques may be used with careful monitoring of static factors to detect the need for non-routine adjustments. The reporting period may have to span multiple normal cycles of facility operation.

4.7. Review by an Independent Verifier

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

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

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

Independent verifiers are typically engineering consultants with experience and knowledge in ECMs, M&V, and energy performance contracting. Many are members of industry professional societies or are *Certified Measurement and Verification Professionals* (CMVP®s).[4]

4.8. Data for Emission Trading

Adherence to IPMVP can provide increased confidence in energy-savings reports, which also increases confidence in associated reports of emission-reduction commodities. Combined with the specific M&V Plan of each project, the IPMVP enhances consistency of reporting and enables validation and verification of energy-saving projects.

However, to verify an emission-reduction commodity, the IPMVP and the project's M&V Plan must be used in conjunction with the emission-trading program's specific guidance on converting energy savings into equivalent emissions reductions. Emission trading will be facilitated if the following energy-reporting methods are considered when designing the process for determining the units of energy saved.

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

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

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

Each emission-trading system usually has its own rules surrounding emission factors to be applied to energy savings. For fuel savings, default emission rates may be given when no emission-measuring equipment is in place. For electricity savings, default values may also be given for the power grid emission rate. Alternatively, users may establish their own emission rate for electricity savings, following recognized principles

4.9. Minimum Operating Conditions

An energy-efficiency program should not affect the use of the facility to which it is applied, without the agreement of building occupants or industrial process managers. Key user parameters may include light level, temperature, ventilation rates, compressed air pressure, steam pressure and temperature, water flow rate, production rate, etc. The M&V Plan should record the agreed minimum operating conditions that will be maintained (see Core Concepts Section 7).

4.10. Weather Data

Where monthly energy measurements are used, weather data should be recorded daily so it can be matched to the actual energy-metering reading dates. For monthly or daily analysis, weather data published by governments are usually the most accurate and verifiable. However, weather data from government sources may not be available as promptly as site-monitored weather data. If you use on-site weather-monitoring equipment, be sure it is regularly and properly calibrated, and situated properly at or near the facility. When analyzing the response of energy consumption and demand to weather in mathematical modeling, daily mean temperature data or degree days may be used.

4.11. Minimum Energy Standards

When a certain level of efficiency is required either by law or the facility owner's standard practice, savings may be based on the difference between reporting-period energy and that minimum standard.

In these situations, baseline-period energy may be set equal to or less than the applicable minimum energy standards.

4.12. Measurement Issues

The proper application of meters for specific applications is a science in itself. Numerous references are available for this purpose, such as ASHRAE Guideline 14-2014, Table 3, below, summarizes some key types of meters, and provides comment on M&V matters for some of them. This Table should neither be taken as complete nor definitive.

4.13. Data Collection Errors and Lost Data

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

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

Table 3. Key Meter Types

Application	Meter Category	Meter Types	Typical Accuracy	Relative Cost	Best Uses	Special M&V Issues
AC Current (amps)	Current transformer (CT)	Solid torroid or split core transformer	+/-1%			Not for use where power factor is less than 100%, or there is sinewave distortion
AC Voltage (volts)	Voltage leads or 'potential transformer' (PT)	Solid torroid or split core transformer				
AC Electric Power (watts) or AC Energy (watthours)	True RMS watt meter or watthour meter	Measure watts (or amps volts and power factor), and watthours. Use digital sampling (IEEE 519-2014) to properly measure distorted waveforms				Necessary for inductive loads (e.g., motors, ballasts) or circuits with harmonics from components such as a variable speed drive
Runtime (hours)	Measure and record equipment operating periods	Battery operated		Lower cost than watthour recording	Logging of lighting periods	For equipment having a constant power usage rate when on
Temperature (degrees)	Resistance Temperature Detector (RTD)		Reasonable	Low cost	Air and water	Widely used. Take care to compensate for different lead lengths
	Thermo-couple		High	High		Narrow range. Suited to thermal energy metering. Need signal amplifiers
Humidity (%)						Regular re-calibration required
Liquid Flow (units/sec)	Intrusive	Differential Pressure	+/- 1-5% of max			
		Positive Displacement	+/-1%			
		Turbine, or hot tap insertion turbine	+/-1%		Clean fluid, straight pipe	
		Vortex Shedding	High			
	Non-intrusive	Ultrasonic	+/-1%		Straight pipe	Spot flow measurement
		Magnetic		High		
		Bucket & Stopwatch		Low	Steam condensate, plumbing outlet fixture	Spot flow measurement
Pressure		Digital manometer	+/- 2%			
Thermal Energy	Packaged flow and temperature logging and computation	Uses accurate flow and temperature sensors. For steam may need pressure and temperature sensors	<1%	High		Use matched temperature sensors for measuring a temperature difference. Carefully manage all possible sources of error

4.14. Use of Control Systems for Data Collection

A computerized control system (commonly referred to as a building automation system or BAS, building management system or BMS, energy management control system or EMCS, etc.) can provide much of the monitoring necessary for data collection. However, the system's hardware and software must be capable of performing control and data gathering simultaneously, without slowing computer processing, consuming excess communication bandwidth, or overfilling storage. Some measured parameters – electric power metering for example – may not be useful for control. Trending of small power, lighting, and main-feed power consumption may be very useful for high-quality savings determination and operational feedback, but useless for real-time control.

Control system software can often perform other functions to assist the tracking of changes to static factors during the reporting period, such as automatically recording changes in setpoints. Facility staff should be properly trained in this use of the system so they can develop their own trending information for diagnosing system problems, providing the system has the capacity for extra trending. However, where a contractor is responsible for some operations controlled by the system, security arrangements should ensure that persons can only access functions for which they are competent and authorized.

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

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

Great care should be exercised to:

- Control access and/or changes to the system trend log from which the energy data are extracted.
- Develop post-processing routines for changing any control-system COV data into time-series data for performing the analysis.
- Get from the control system supplier:
  - standard traceable calibrations of all sensors it supplies,
  - evidence that proprietary algorithms for counting and/or totaling pulses and units are accurate, and
  - the commitment that there are adequate processing and storage capacity to handle trending data while supporting the system's control functions.

4.15. Significant Digits

When performing any arithmetic calculation, one must consider the inherent accuracy of the data, so the result does not presume greater accuracy than is defendable. For this reason, engineers have adopted a standard of rounding rules that limit the resolution of a result to that which is supported by the data. Therefore, the IPMVP has adopted the following rules to ensure all calculations performed under this standard adhere to strict accuracy standards. Rules for significant digits are derived from the "total derivative" concept from calculus. Expressed as a function of two variables, the total derivative is:

Equation 2

$$df(x,y) = \frac{\delta f}{\delta x} \cdot dx \; \frac{\delta f}{\delta y} \cdot dy$$

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

Equation 3

$$df(x,y) = \frac{\delta f}{\delta x} \cdot \Delta x \; \frac{\delta f}{\delta y} \cdot \Delta y$$

From Equation 3, we can calculate the limits of absolute error. The rules for significant digits agree with Equation 3 when the absolute error is greater than or equal to ±1 unit of the smallest significant digit.

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

Table 4. Arithmetic Operation and Rule

Arithmetic Operation[5]	Rule
Addition/Subtraction *$X + Y$*	Round (up or down as appropriate) the result at the right-most decimal place (lowest unit) where all numbers have a common digit. The number of significant digits will be the total of the digits of the result.
Multiplication/Division *$X \times Y$*	The number of significant digits in the result equals the smallest number of significant digits of any one of the input numbers.
Powers *X^a*	The number of significant digits equals the number of significant digits in the input.

[5] Additional rules exist for logarithmic and exponential functions that are not included here.

Examples

Numbers

00123 → 3 significant digits

12300 → 3 significant digits (because it is represented as 1.23×10^4)

12300. → 5 significant digits (because it can be represented as 1.2300×10^4)

12300.000 → 8 significant digits

12300.012 → 8 significant digits

Addition

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

The number of significant digits is 5.

Multiplication

$12.345 \times 0.0369 = 0.456$

$56.000 \times 0.00785212 = 0.43972$

Powers

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

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

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

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

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

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

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

Special Cases

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

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

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

5. Measurement and Verification Application Examples

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

Table 5. Examples of 12 Different Scenarios

Option A	» Pump/motor efficiency improvement » Boiler efficiency improvement » Lighting efficiency » Lighting operational control » Compressed air leakage management
Option B	» Street lighting efficiency and dimming » Turbine-generator set improvement » Pump/motor demand shifting
Option C	» Multiple ECM with metered baseline data » Whole facility energy accounting relative to budget
Option D	» Multiple ECMs in a building without energy meters in the baseline period » New building designed better than building code

These examples go into varying levels of depth, in order to highlight different features of common M&V approaches. None of them is comprehensive.

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

Table 6. Technical Quantities Expressed in Approximate Alternate Units

Multiply		By	to get
Natural gas	m^3	35	ft^3
	mcf	1,000	ft^3
Steam	pound	0.45	kg of steam
Oil	Liter	0.26	gallon (US)

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

5.1. Pump/Motor Efficiency Improvement: **Option A**

Situation

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

Factors Affecting the M&V Design

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

The owner sought the lowest possible cost for gathering and reporting information to the utility. The owner hired a contractor to select and install pumps that met his and the utility's specifications. Pump flow is constant when operating because there are no restricting valves and well depth is largely unaffected by the pumping.

M&V Plan

The M&V Plan was jointly developed by the owner and utility, following a model provided by the utility. IPMVP Core Concepts, Option A was selected to minimize M&V costs. The agreed Option A method involves negotiating an estimate of the annual pump operating hours for a normal year and multiplying that number by measured power reductions.

It was agreed that the installation contractor's measurement equipment would be adequately accurate to measure motor wattage requirements. Before removal, the contractor measured the power draw of each old motor after it had been running for at least three hours. The utility company maintained the right to witness these measurements. Since the pumps are constant-flow, average annual operating hours were derived from the billed electricity kWh consumption of the past year divided by the measured kW power draw of the old pump motors.

This computation showed that on average the pumps operated for 4,321 hours in the dry year before retrofit. The utility found data revealing that total rainfall during that dry season was 9.0% less than normal. The owner and utility, therefore, agreed that pump operation during that year was 9.0% longer than normal. They agreed that normal hours would be 91.0% of 4,321 or 3,932[6] hours per year.

[6] Note this 3,932 number should be expressed with only 3 significant digits, since 91.0% has only 3 significant digits. It should more correctly be expressed as 3.93 x 103. However common form is used.

Results

The energy savings were determined using IPMVP Option A as follows:

Total load of all pumps before retrofit	132 kW
Total load of all pumps after retrofit	98.2 kW
Net load reduction	**33.8 kW[7]**

Energy savings = 34 kW x 3,932 hours/year = 130,000 kWh/year[8]

The utility company's final payment of its subsidy was based on 130,000 kWh energy savings. Using the same estimated operating periods, the owner's estimated savings under normal rainfall conditions and at current utility prices were determined to be 34 kW × 3,932 hr[9] x R0.2566/kWh = R34,000/year.[10] Utility service and network charges were unchanged.

5.2. Boiler Efficiency Improvement: **Option A**

Situation

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

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

[8] The products of 34 and 3,932 have only 2 significant digits. Though the result is133,688, the proper expression of their product is 1.3 x 105, or 130,000.

[9] 133,688 is the actual calculated value before significant digit rounding.

[10] This amount can be expressed in no more than two significant digits, as from the above observations about the minimum number of significant digits. The actual calculated value is R34,103 and should better be expressed as R3.4 x 104, though 34,000 is customary currency format.

Factors Affecting the M&V Design

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

M&V Plan

IPMVP Core Concepts, Option A was chosen to isolate the boiler from the changes going on in the rest of the building. The measurement boundary was drawn to include only the boiler, measuring fuel use and net thermal energy delivered to the building. This boundary excludes the electricity use of the boiler's burner and blower. Changes to these electrical interactive effects were regarded as negligible, and not worth inclusion within the measurement boundary or even separate estimation.

The contractor's guarantee was stated relative to the usage of the year before the submission of its proposal. During that period, the facility purchased 241,300 liters of heating oil for the boiler. There was a 2,100-liter increase in oil inventory between the beginning and end of that year. Therefore, the actual consumption was 239,200 liters. The energy load on the boiler will be determined from this oil-use data, once the efficiency of the old boiler is established. An estimate of 239,200 liters will be used; this estimate has no error since most of it[11] comes from oil shipment data, which is the reference source with no error.

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

Baseline efficiency tests were conducted over three separate one-week periods when daily mean ambient temperatures ranged from -5°C to +5°C. Identical tests were planned for the first period after commissioning of the new boiler when ambient temperatures are once again in the -5°C to +5°C range, using the same oil and thermal energy meters left in place since the baseline efficiency tests. Since the three individual one-week tests are expected to include periods representing a range of boiler loads, from low to high, it was agreed that the test results would adequately represent the annual improvement that the owner could expect.

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

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

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

Results

Baseline oil and thermal energy data were collected continuously over a five-week period until three were found where daily mean ambient temperatures stayed within the specified range -5°C to +5°C. Dividing net thermal energy delivered by oil consumed, the average efficiency readings for the old boiler during the three one-week periods were found to be 65.2%. After installation and commissioning of the boiler, the three-week reporting period was again found with an average ambient temperature between -5°C to +5°C. Boiler efficiency test results averaged 80.6%. There were no other changes to the boiler plant between the time of the baseline-period tests and reporting-period tests. Therefore, non-routine adjustments were not needed.

Annual savings using 239,200 liters as the estimated annual oil use from the baseline period are:

$$\text{Oil savings} = 239{,}200 \text{ liters} \times (1.000 - 0.652 / 0.806) = 45{,}700 \text{ liters}$$

The value of the savings is €0.70 x 45,700 = €31,900.[12] These estimated annual savings from a short-term test validated that the contractor had met its guaranteed performance.

5.3. Lighting Efficiency: **Option A**

Situation

More efficient lighting fixtures are installed in place of existing fixtures in a Canadian school while maintaining light levels. This project was part of a broader program of the school board to hire a contractor who would design, install and finance many changes in a number of schools. Payments under the contract are based on verified savings at the utility prices prevailing at the time of signing the contract. Savings are to be demonstrated, according to an IPMVP adherent M&V Plan, immediately after commissioning of the retrofit. Since the owner controls operation of the lights, the contract specified that the M&V Plan follows IPMVP Core Concepts, Option A, using estimated operating hours. The M&V Plan was to be detailed before contract signing.

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

- All light fixtures are powered by a common 347-volt supply system dedicated to lighting. This situation makes power measurement simple.

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

- Operation of lights significantly affects heating loads and heating energy requirements, so the interactive effects needed to be accounted for and estimated.
- Operation of lights significantly affects mechanical-cooling requirements. However, since very little of the school is mechanically cooled and that space is usually vacant during the warmer weather, cooling interactive effects were ignored.
- School-board officials had difficulty accepting an arbitrary assumption of lighting operating periods. They agreed to pay for a carefully instrumented two-month period of logging lighting patterns in one school. This test would substantiate the estimated operating hours that would be agreed for all schools.

M&V Plan

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

- The heating interactive effect was determined by engineering calculations to be a 6.0% increase in boiler-output energy requirements, for the period from November through March. Boiler efficiency in winter was estimated to be 79% under typical winter conditions.
- The static factors recorded for the baseline included a lighting survey giving a description, location, light level, and count of the number of operating and burned out lamps, ballasts, and fixtures.
- Thirty lighting loggers were placed in randomly chosen classrooms, corridors, locker rooms, and offices and also in the gym and auditorium, for two months. This period included the one-week spring holiday and two legal holidays. Table 7 summarizes the data obtained.

Table 7. Operating Period Survey

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

Since classrooms represent the largest load, the relative precision of the classroom operating period measurements was evaluated before school board officials could agree to estimated values.

For the 19 classroom loggers, the standard deviation among the readings for six recorded school weeks was found to be 15 hours per week. With 19 x 6 = 114 readings, the standard error in the mean values was computed to be 1.4 hours per week. At 95% confidence, the value of t for a large number of observations is 1.96. Therefore, it was established with 95% confidence that the relative precision in the measured classroom operating hours is:

$$= \frac{1.96x1.4}{48} = 5.7\%$$

School board officials deemed this measurement precision adequate.

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

Table 8. Estimated Operating Hours

Location	Fraction of Lighting Load	Estimated Weekly Hours		Estimated Annual Hours
		39.0 School Weeks	13.2 Holiday Weeks	
Locker rooms	5%	106	22	4,420
Offices	5%	83	21	3,480
Classrooms	61%	54	5	2,170
Auditorium	10%	31	11	1,350
Gymnasium	10%	82	25	3,530
Corridors	9%	168	168	8,770

Since the lighting retrofit was applied uniformly to all fixtures, the load-weighted average estimated annual operating hours for this school were determined to be 2,996, or 3,000 rounded to three significant digits (a better representation of the result would be 3.00 × 103).

- Baseline power measurements were made with a recently calibrated true RMS wattmeter of the three-phase power draw on the 347-volt lighting circuits. From a thirty-second measurement on the input side of two lighting transformers, it was found that with all fixtures switched on, the total power draw was 288 kW. Seventy lamps (= 3 kW or 1%) were burned out at the time of the test. It was determined that the fraction burned out at the time of this measurement was normal.
- Since lighting loads establish the building electrical peak at a time when all lights are on, electrical demand savings will be estimated to be the same as the measured load reduction on the lighting circuits. The utility bills showed a lower demand during the summer holidays, and there was minimal use of the facility during these months. Also, considering which other equipment was

used during the summer, it was assumed that the July and August lighting-circuit demand is only 50% of the peak measured circuit load.

» The marginal utility prices at the time of contract signing were CDN$0.063/kWh, CDN$10.85/kW-month, and CDN$0.255/$m^3$ of gas.

Results

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

Energy savings are 128 kW x 3.00 × 10^3 hrs/year = 384,000 kWh/year

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

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

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

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

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

Extra boiler input energy is:

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

The gas used in the boiler has an energy content of 10.499 kWh/m^3, so the amount of extra gas is:

= 15,000 / 10.499 = 1,400 m^3 gas

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

$39,500 – $360 = CDN$39,100

5.4. Lighting Operational Control: **Option A**

Situation

A knitting mill in southern India typically operates two shifts per day. There was a standing order for the supervisors to turn off all lights in each zone at the end of the second shift. There are 70 light switches. Supervisors regularly changed between working on the first and second shifts. They habitually forgot their duty to turn off lights. The plant manager undertook a project to modify the lighting so that occupancy sensors turned lights on and off. He wanted to document the results to show the supervisors how poorly they had been using the light switches.

Factors Affecting the M&V Design

None of the production areas had windows or skylights. It is neither heated nor cooled. Lighting circuits are integrated with other electrical loads so that lighting use could not be easily isolated from other usages of electricity. The plant manager did not wish to spend a lot to determine savings but needed a credible statement of the savings. The electricity price for medium sized commercial users is 450 p/kWh.

M&V Plan

To minimize M&V costs it was decided to perform savings measurements for only a short representative period and use IPMVP Core Concepts, Option A. Since the primary purpose of the retrofit was to control production area lighting hours, a sampling-based method was developed to measure the change in operating hours. The lighting power was estimated from manufacturers' ratings to be 223 kW.

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

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

Results

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

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

The reduction in operating hours was 118 – 82 = 36 hours per week. Savings were computed as:

223 kW x 36 hours/week = 8,000 or 8.0 × 103 kWh/week

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

= (8.0 × 103) x 48 x 450 / 100 = Rs 1.7 million

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

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

5.5. Street Light Efficiency and Dimming: **Option B**

Situation

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

Factors Affecting the *M&V* Design

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

Since dimming is critical to the savings, continuous recording of energy consumption is required. The 23 utility meters' measure energy consumption continually. However, these meters cannot provide the rapid operational feedback necessary to avoid significant energy wastage if a dimmer fails or is accidentally changed.

Consequently, an energy recording capability was added to the central dimming control system, to remotely record energy consumption in the city's central control station. Beyond simple energy reporting, the system compares actual hourly energy consumption on each circuit to an expected hourly profile. Variances from this target are used to spot burnouts and failures of the dimming system.

M&V Plan

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

Annual energy, recorded on the bills for same accounts will be totaled for determining savings using IPMVP Core Concepts, Option B. The only adjustments that will be made to baseline or reporting period energy consumption will be for additions or deletions to the system and for burnouts found to be more than 3% at any time.

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

The city staff will monitor burnout rates monthly. If the burnout rate is greater than 3.0%, a non- routine adjustment will be made to bring reporting-period metered data up to the contracted 3.0% burnout rate. Savings will be reported for the length of the 10-year guarantee period using a single price of 0.600 kuna/kWh.

Results

Savings were reported without adjustment for the first three years after retrofit because burnout rates remained below 3.0%. For the fourth year, the burnout rate was 5.0% for 7 months. Fourth-year savings were computed as follows:

Baseline Energy

- Fourth-year measured energy = 2,130,000 kWh
- The burnout adjustment is = 1,243,000 kWh

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

5.6. Compressed-Air Leakage Management: **Option B**

Situation

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

Factors Affecting the M&V Design

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

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

The local electric consumption rate (known as the "green rate") for low-load-factor commercial accounts over 0.5 MW is shown in Table 9.

Table 9. Electric Consumption Prices

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

Taxes totaling 42.9% are added to these rates.

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

M&V Plan

The M&V Plan uses IPMVP Core Concepts, Option B, for ongoing measurement of savings to indicate changes in compressed-air leakage rates. IPMVP Equation 4 was used to adjust baseline energy to reporting period conditions. The M&V Plan aimed to minimize extra measurement costs, so a simple three-phase true-RMS wattmeter was added to the electrical supply of the motor-control center feeding all equipment in the compressor room. This measurement boundary encompassed six compressors, three compressed-air dryers, and all other minor auxiliary systems in the compressor room. Heat generated within the compressor room is not an interactive effect since it does not affect any other energy uses. Plant staff was instructed to read the meter at the end of each shift (i.e., three times a day) whether the plant was operating or not. The meter was installed three months before leak-management activities began.

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

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

Results

It was found that to meet the 95/5 uncertainty criterion, the variation in shift energy during the baseline required readings for a seven-week period before retrofit. The baseline values were therefore established as the seven-week average electricity consumption of operating and non-operating shifts.

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

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

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

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

5.7. Turbine/Generator Set Improvement: **Option B**

Situation

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

Factors Affecting the M&V Design

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

M&V Plan

The mill and the utility agreed to use IPMVP Core Concepts, Option B to determine the increase in electricity output for a one-year period. Existing plant instrumentation was used to determine the efficiency of the old rotor as shown in Figure 4.

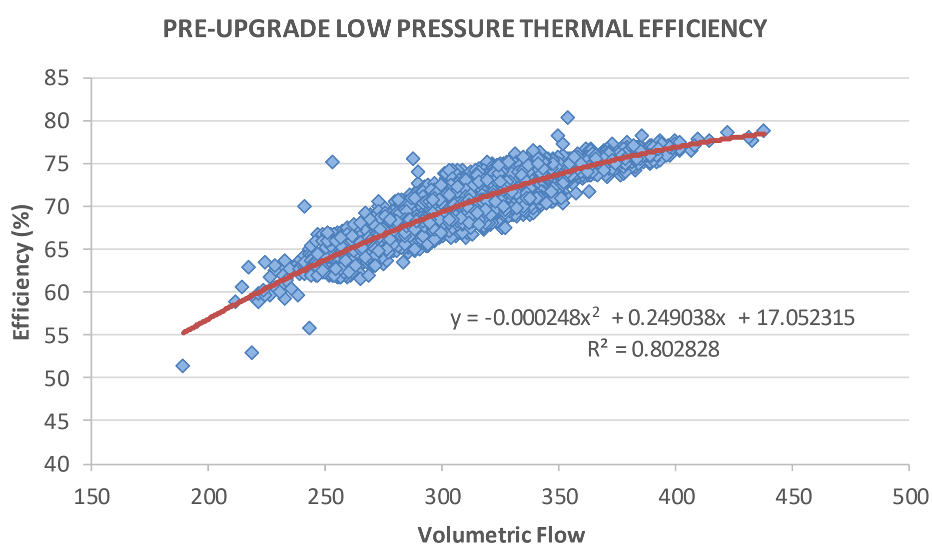

Figure 4. Old Rotor Performance

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

$$\textbf{Efficiency (\%)} = (-0.000248 \times \text{flow}^2) + (0.249 \times \text{flow}) + 17.1$$

This efficiency model will be used with the steam conditions of the one-year reporting period to determine what the electricity production would have been with the old rotor. Increased electricity production will be reported under reporting-period conditions.

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

Results

For a year after retrofit, the steam conditions every minute were applied to the mathematical model of old rotor efficiency to compute the adjusted-baseline energy. This value was compared to measured generation for the same period to determine the increase in electrical output. No changes happened to the TG unit during this year, so non-routine adjustments were unnecessary.

5.8. Pump/Motor Demand Shifting: **Option B**

Situation

The irrigation system described in Section 5.1 above was also eligible for a substantial utility incentive if the pumps are kept off during the peak periods of 0700-1000 and 1800-2000 on all weekdays that are not public holidays. The owner installed a radio-signal- based control system to remotely and automatically control the pumps to implement this load shifting strategy. The pump control will be reset by the owner annually according to the upcoming year's schedule of public holidays.

Factors Affecting the M&V Design

The owner believed that curtailing pumping for a maximum of 25 hours per week (15%) would not be critical to his operation in dry seasons. (He expected fewer breakdowns of the new pumps, so there would be no net impact on his dry- season growth). The utility recognizes that the owner decides whether to shut down the pumps based on his own needs. Therefore, the utility required adherence to IPMVP Core Concepts, Option B to substantiate each year's performance, before making the incentive payment. The owner felt that his financial payback period for the control and monitoring equipment was already long. Therefore, he does not want to spend a significant part of the incentive toward providing the evidence required by the utility.

M&V Plan

The utility and owner agreed that continuous recording of a proxy variable would give the ongoing evidence that the pumps were off during every peak period all year long. The proxy variable is the presence of electricity flow (in excess of the 500 mA, needed by the control equipment) through any of the five electrical feeds to the ten pumps. Small un-calibrated current sensors and data loggers were clamped on each power line near the five meters. The sensors and loggers have a re-chargeable battery-backup power system. The owner has hired the supplier of the control and monitoring devices to annually read the data, check the clock settings, and give a report to the utility of the dates and times of any operation within any weekday peak periods.

Results

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

5.9. Whole-Facility Energy Accounting Relative to Budget: **Option C**

Situation

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

Factors Affecting the M&V Design

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

M&V Plan

The energy manager followed IPMVP Core Concepts, Option C since she needed to explain budget variances in management accounting reports. She always stated her energy budgets under long-term average weather conditions and the previous year's occupancy.

Results

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

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

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

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

5.10. Multiple ECMs in a Building without Energy Meters in the Baseline Period*:* **Option D**

Situation

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

Factors Affecting the M&V Design

Since the project at the library was very small relative to the entire campus, its effect could not be measured using the main campus utility meters. The university wished to achieve savings as quickly as possible, despite the lack of a baseline energy record. Savings are to be reported continuously, as soon as possible after retrofit, using the then current energy contract prices.

M&V Plan

It was decided not to wait to obtain a year's worth of energy data from new meters before implementing the measures. Instead, IPMVP Core Concepts, Option D, Equation 15 would be used, simulating pre-retrofit performance. Therefore, as part of the energy-management program, steam, electricity and electric demand meters were installed on the main supply lines to the library.

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

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

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

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

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

Results

The following steps were used to compute savings.

Step 1

The new meters were calibrated and installed. Operating staff recorded monthly energy consumption and demand for 12 months throughout the first year after ECM commissioning.

Step 2

Then, the original planning simulation model was refined to match: the ECMs as installed, the weather, the occupancy, and the operating profiles of the reporting period. The resultant simulation of space temperatures and humidity were examined to ensure they reasonably matched the typical range of indoor conditions during occupied and unoccupied days. Initially, the simulation result did not match actual energy consumption and demand very well, so the M&V team investigated the site further.

During these additional investigations, the team found that unoccupied night periods experienced very little indoor temperature change. Therefore, they changed the thermal-mass characteristics of the computer model. After this correction, the modeled monthly results were compared to the monthly calibration data. The highest CV(RMSE) of the differences was 12%, on the electric demand meter. The university felt that because these CV(RMSE) values met ASHRAE Guideline 14 specifications, it could have reasonable confidence in the relative results of two runs of the model. Therefore this "calibrated as-built model" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

Step 3

The calibrated as-built model was then rerun with a weather-data file corresponding to the normal year. Occupancy statistics and static factors were also reset to what had been observed during the baseline period. The resultant "**post-retrofit normal-conditions model**" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

Step 4

The post-retrofit normal-conditions model was then adjusted to remove the ECMs. This "**baseline normal-conditions model**" was archived, with both printed and electronic copy of input data, diagnostic reports and output data.

Step 5

The energy consumption of the two normal models was then compared to yield energy *savings* as shown in Table 10.

Table 10. Simulated Library Savings under Normal Conditions

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

Step 6

The value of the savings at the campus meter was computed as shown in Table 11, allowing for transformation and line losses, and contract minimum gas quantities.

Table 11. Campus Savings

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

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

5.11. New Building Designed Better Than Code: **Option D**

Situation

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

Factors Affecting the M&V Design

Computer simulation was used extensively throughout the building design process to help meet a target energy use equal to 50% of the building code.

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

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

M&V Plan

IMPVP Core Concepts, Option D, will be used to demonstrate the new building's savings compared to an identical building built to building-code standards. It is possible to use either Equation 15 comparing two simulations, or Equation 16 comparing the simulated baseline energy and measured actual energy after correcting for calibration error. The incentive program did not specify which method should be used. The person performing the modeling felt that Equation 15 would be more accurate. However, the owner wished to use actual utility data in his final savings statement, so he required the use of Equation 16.

Following the first year of full operation ("year one"), year one's energy and operational data will become the baseline for an IPMVP Core Concepts, Option C approach to reporting ongoing performance.

Results

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

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

The calibration error in the as-built model relative to actual utility data is shown in Table 12.

Table 12. Monthly Calibration Errors

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

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

The standard model's monthly predicted energy use was adjusted by the monthly calibration errors in Table 12 to yield the "**corrected-standard model**." Actual metered data for year one was then subtracted from the corrected-standard model to yield the monthly savings. Percentage savings were computed to prove eligibility for the government incentive.

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

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