City of Edmonton
Facilities

Measurement & Verification General Guidelines

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INTENT OF USE

This guideline was developed for establishing standards for the City of Edmonton expectations in the design and construction of their infrastructure assets. Care has been taken to confirm the accuracy of the information contained herein. The views expressed herein do not necessarily represent those of any individual contributor. As the design of the assets and systems described herein continually evolves, and practices change and improve over time, so it is necessary to regularly consult relevant technical standards, codes, and other publications rather than relying on this publication exclusively. The City of Edmonton, authors, and members of the review committee, want to convey that this document does not constitute a project specific design. As such, no part of this document alleviates the responsibility of the professionals retained to design and/or construct specific projects from taking full responsibility and authenticating their designs in accordance with APEGA, AALA, AAA, Alberta Building Code, and any other statutory or safety requirements.

Authentication Table

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List of Abbreviations

ASHRAE	-	American Society of Heating Refrigeration and Air Conditioning Engineers
CHP	-	Combined Heat and Power
CMVP		Certified Measurement and Verification Professional
COE	-	City of Edmonton
EEM	-	Energy Efficiency Measure
EVO	-	Efficiency Valuation Organization
GJ	-	Gigajoule
HDD	-	Heating Degree Days
IIS	-	Integrated Infrastructure Services
IPMVP	-	International Performance Measurement and Verification Protocol
HVAC	-	Heating, Ventilation and Air Conditioning
kW	-	kilowatt(s)
LEED	-	Leadership in Energy and Environmental Design
RMS	-	Root Mean Square
kWh	-	kilowatt-hour(s)
M&V	-	Measurement & Verification
PV	-	Photovoltaic
TMY	-	Typical Meteorological Year

1. Purpose and Scope

The purpose of this document is to describe Measurement and Verification (M&V) practices and procedures for the City of Edmonton's (COE) energy projects, and to align and integrate M&V practices with existing COE policies and procedures.

The City has chosen to adopt more rigorous M&V practices to help measure and track energy savings from projects. M&V provides COE the ability to track the work outlined in the Greenhouse Gas Management Plan for Civic Operations, and also to support use of a reserve fund to harvest savings from energy saving projects to be used for future energy saving projects. The City's Climate Resilience Policy (previously Sustainable and Resilient Building Policy C532) supports the Existing City Buildings Administrative Procedure that requires Measurement and Verification of energy retrofit projects.

The practices outlined in this M&V guideline could be applied to the following types of energy projects: building retrofits, new buildings, solar photovoltaic (PV), and combined heat and power (CHP). Not all projects will necessarily justify the investment in conducting M&V. It is noted also that "energy projects" refer to projects affecting building energy systems and are expected to significantly change utility bill charges for a facility. Not all COE projects are undertaken only for the purpose of reducing energy consumption. Some projects are completed as part of facility rehabilitation and asset management. But these projects still can improve energy performance and may be chosen for investment in M&V.

COE utilizes the most widely-used industry M&V protocols, in particular the International Performance M&V Protocol (IPMVP) which is published by the Efficiency Valuation Organization (EVO, www.evo-world.org). EVO publishes a large number of M&V best practices and other reports. In this document, reference to the IPMVP refers to the latest version of the IPMVP Core Concepts, which is the primary M&V protocol published by EVO. The IPMVP defines M&V as follows:

> *M&V is the process of planning, measuring, and collecting and analyzing data for the purpose of verifying and reporting energy savings within an individual facility resulting from the implementation of ECMs*[1]

COE implements M&V on two broad categories of projects: energy efficiency such as lighting upgrades, and self-generation measures such as solar PV installations. In this document the term energy efficiency measure (EEM) is preferred over energy conservation measure. The reason for this is that energy efficiency is the accepted term for system improvements which deliver needed services while reducing energy consumption. Energy conservation often implies reduced level of service or sacrifice by building occupants, which is not the intent. Using EEM as the terminology also aligns with ASHRAE Standard 211-2018, which is the industry standard for energy audits for commercial and institutional facilities.

The overall goal of any M&V program is to balance the cost of M&V activity with the targeted level of uncertainty (or accuracy) of results. COE's objectives for completing M&V include the following:

- To improve the performance of energy savings investments: the process of conducting M&V is proven to contribute to increasing energy and utility bill cost savings, as compared to projects which do not undergo M&V
- To validate energy savings and associated avoided GHG emissions.
- To document credible and accurate utility bill cost savings so that COE can harvest cost savings and effectively manage budgets
- To create data and models which can be utilized by other building and energy management systems to track, maintain, and manage energy cost savings over the long term, after initial M&V activity is completed.

[1] The IPMVP currently uses the term energy conservation measure (ECM) but is scheduled to change at the next revision planned for 2021. Following ASHAE, the term energy efficiency measure (EEM) is preferred and used in this document.

M&V Integration in COE Project Processes

1.1 Common COE Projects

COE engages in a range of different projects. The scope and systems included in projects are major factors in determining which M&V methods to choose for a particular project.

1.1.1 Whole Facility Retrofits

Retrofit projects which involve multiple building systems may be categorized as whole facility retrofits. These projects typically would include lighting, heating, cooling, ventilation, and domestic hot water. As well, specialized, facility-specific systems may be included such as swimming pool heating. Whole facility retrofits often involve both passive systems (e.g. building envelope) and active systems (e.g. boilers). Typically, all purchased energy would be included, usually electricity and natural gas. As described in Section 3, whole facility retrofits are candidates for IPMVP Option C M&V methodology. COE's Life Cycle Management group oversees facility retrofits and rehabilitations.

1.1.2 System-Specific Retrofits

Retrofit projects which involve relatively few, discrete building systems may be categorized as system-specific facility retrofits. COE's Life Cycle Management group oversees facility retrofits and rehabilitations. These projects typically would include only a few lighting, heating, cooling, ventilation, or domestic hot water upgrades. Often only one form of purchased energy would be included, such as electricity for a lighting retrofit or natural gas for a boiler retrofit. As described in Section 3, system-specific facility retrofits are candidates for IPMVP Option A or B M&V methodologies.

1.1.3 New Buildings

COE's Integrated Infrastructure Services (IIS) department oversees construction of new buildings. New buildings may undergo M&V for two purposes. First, M&V is part of LEED certifications. Second, M&V can be implemented to verify energy savings for newly constructed buildings where code compliance is the baseline. As described in Section 3, new buildings (and also facility expansions) are candidates for IPMVP Option D M&V methodology.

The majority of new buildings M&V will be completed by consultants managed by the IIS team during completion of LEED requirements.

1.1.4 Solar Photovoltaics

Solar PV installations are a type of distributed generation which results in reductions of purchased electricity and utility cost savings. M&V may be implemented for purposes of validating the net delivered electricity by the solar PV system, and for claiming utility cost savings. As described in Section 3, solar PV performance can be verified using M&V retrofit isolation or whole facility methods.

The majority of City solar photovoltaic projects will be tracked through the solar program as outlined in the guideline documents.

1.1.5 Combined Heat and Power

Combined heat and power (CHP) installations are another type of distributed generation which results in reductions of purchased electricity, increased consumption of natural gas (or some other fuel), and associated utility cost savings. M&V may be implemented for purposes of validating the net delivered electrical and thermal energy by the CHP system, and for claiming utility cost savings. As described in Section 3, CHP performance can be verified using M&V retrofit isolation or whole facility methods.

1.2 COE Project Processes and Integration of M&V

Facility Lifecycle Management commissions a number of energy audits through consultants in advance of any whole facility rehabilitation. The energy audit report is one of the inputs, alongside Facility/Asset Condition Assessment reports (done in-house and/or via external consultants) and consultation with Business Partners where needed (e.g. Business Operator, Facility Maintenance Services, Facility Engineering Services and others) into forming COE's list of planned facility rehabilitations for the upcoming budget cycle.

Facility Lifecycle Management takes the recommendations from the energy audit and considers them for inclusion in the scope of works of the rehabilitation project, subject to available budget, overall asset condition and value for money. A preliminary calculation of energy savings is done based on the energy report information.

The total scope of work is taken by Facility Lifecycle Management for review and agreement with stakeholders, later validated or updated by Facility Planning and Design consultants. During concept and design, led by Facility Planning and Design, the consultant may verify the energy saving calculations[2].

At completion of checkpoint 3 (the completion of the design development report), the scope of work passes on to Facility Infrastructure Delivery. This is subject to budget availability.

Occasionally, energy retrofits are done as a dedicated project where the scope involves only assets that are retrofit for energy saving purposes. This is subject to budget availability.

Facility Engineering Services, via the Consultant Manual, asks for digital metering to be installed when new electrical distribution is installed as part of the City's retrofits and new builds.

Metering is supported by Facility Engineering Services to provide diagnostic capabilities for the City's maintenance group. Ideally this work will support M&V work by installing this equipment up front..

1.2.1 Selecting Projects to Undergo M&V

For COE, the decision for a project to undergo M&V is recommended to be linked to the plans to harvest utility bill cost savings. If COE intends to harvest these cost savings to be used as the basis for budget transfers and expenditures, these projects should undergo M&V.

Once a project is selected to undergo M&V, the M&V process is guided by the M&V plan. M&V plans should ideally be written during the design phase for a project. The M&V plan should include a concise description of how the M&V process and project process are related.

1.2.2 M&V Roles and Responsibilities

The M&V plan for each project identifies the specific roles for individuals who have responsibilities for the M&V activities, and what those responsibilities are.

A key requirement for each M&V project is the identification of the responsible M&V professional who serves as the single point of contact for all M&V activity. The responsible M&V professional for COE projects should be a Certified M&V Professional (CMVP). That person could be a COE employee or a consultant.

The responsible M&V professional should also be someone not directly involved in the energy study which derived the estimated savings or that completed the design of the project. For example, an employee of the consulting firm which performed the energy study or the firm which designed the system should not be the primary M&V professional to oversee the verification of energy and utility cost savings.

The M&V plan will include identification of additional roles such as equipment verification, metering, data collection, analysis, and reporting.

[2] As of the date of this document, there are two pilot projects in progress. The process will be confirmed once pilots are reviewed.

1.2.3 Resources and Cost Implications

The IPMVP guidelines suggest that the cost of M&V activity typically ranges up to 10% of the value of the expected utility bill savings. Factors which will affect M&V cost include the following:

- M&V method: Option A and C tend to be the least costly, while Option B and D tend to be the most costly.
- Targeted accuracy (or maximum uncertainty) of energy savings
- Availability of meters and submeters in a facility
- Personnel time to engage in M&V planning, analysis, tracking of data (e.g. static factors, occupancy), and reporting

The M&V plan for each facility should be written with consideration of the costs, and the IPMVP recommends that M&V budget be part of the M&V plan.

1.3 Project Verification

The "verification" function in M&V is the activity to confirm that equipment is installed as per the design and specifications. Verification generally involves visual inspection of equipment, collection of spot readings, testing of control logic, and review of as-built documents. The project-specific M&V plan (see Section 3) describes what specific activities and records are used for verification. The verification step confirms that EEMs are ready to move into the post-implementation phase of M&V, described as the reporting period. Verification is aligned with project commissioning, and in many cases commissioning reports form part of the verification step.

1.4 IPMVP Adherence

The IPMVP provides guidelines for claiming adherence to the protocol. In general, the criteria for adherence to the IPMVP include:

- Identify the responsible M&V professional
- States the publication date and version of the IPMVP protocol to be followed
- Use IPMVP terminology (Core Concepts Section 3) and principles (Core Concepts Section 4)
- Include an M&V plan with the elements identified in the IPMVP (Core Concepts Section 7)
- Define the minimum content of savings reports and frequency of reporting

In general, the requirement to adhere with the IPMVP is a decision that stakeholders in projects make. For COE, the default option is that all M&V activity adhere to the IPMVP. There may be projects where it is not possible to adhere to the IPMVP, such as when M&V is initiated after an installation is completed or when energy savings estimates were not made. This does not preclude M&V activity or determination of energy savings. In general, the person identified as the responsible M&V professional for each project would make the assessment as to whether the M&V adheres or not, using the criteria described in the IPMVP protocol.

2. M&V Options and Selection

2.1 Overview of M&V

The process of M&V, which was defined in Section 1, is illustrated in Figure 1.

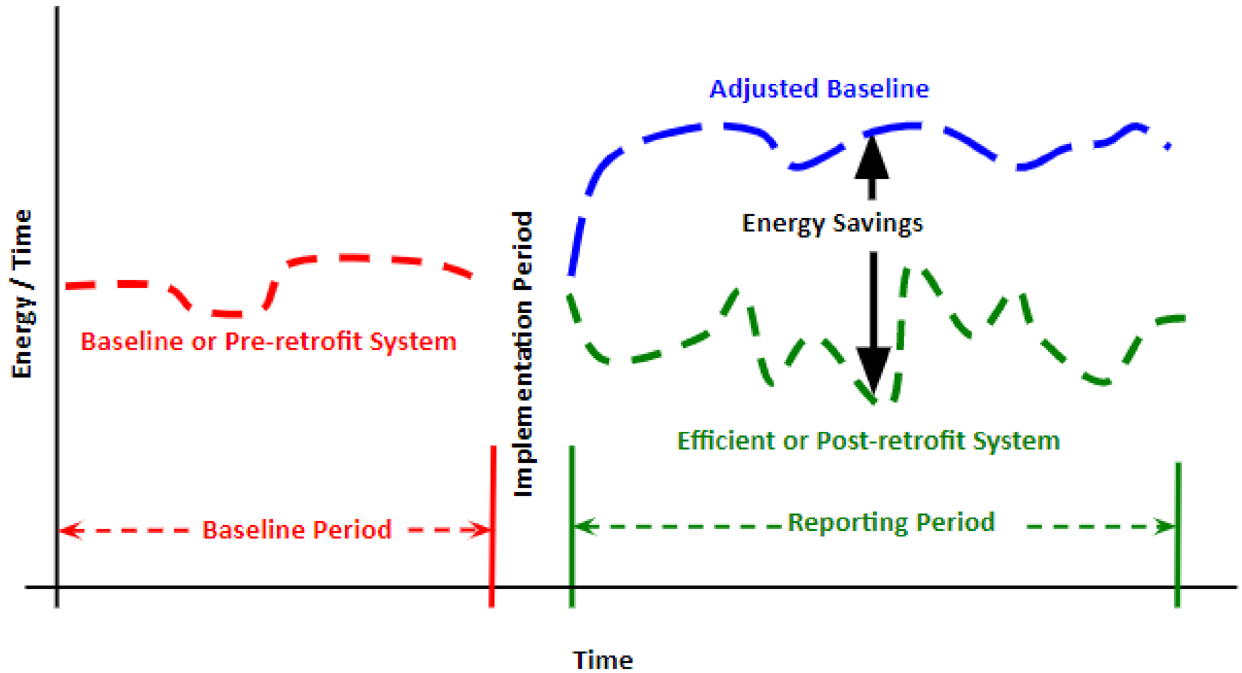


Figure 1: Overview of M&V Process

As implied in this figure, M&V spans the full cycle of a project from design and planning and beyond the time when systems are commissioned. Key terminology includes:

- Baseline: refers to the operating conditions, equipment, timeframe and energy use which form the reference case to quantifying energy savings.
    - *Baseline period* refers to the time period for collecting data for the baseline system. Typically, this data is actually collected by measurements prior to the implementation of an EEM. In some cases, data historians or utility data can be used to obtain baseline data after an EEM has been implemented. Because building energy use is affected significantly by weather and seasonal changes, 12 months is typically the preferred duration for the baseline period.
    - *Baseline system* refers to the equipment or facility that existed prior to implementing the EEM.
    - *Baseline conditions* refer to the types of activities, operating practices, and other conditions which drive the quantity of baseline energy.
    - *Baseline energy* refers to the energy consumption for the baseline system, typically measured or scaled to an annual basis (e.g. GJ/yr. of natural gas or kWh/yr. of electricity).
    - New construction: In the special case of new construction (e.g. a new building, or a building expansion), there is technically no baseline system that existed and no baseline period. For new construction, the baseline system is usually described as "hypothetical" such as the least cost, code-compliant building which could have been constructed instead of the high efficiency building (i.e. better than code) which actually was constructed.
- EEM implementation
    - This is the time period when an EEM is installed. The most common example is the removal of old equipment, and installation of new equipment for a retrofit.

- The implementation period includes construction, commissioning, and system verification.

- Post-implementation:
  - Post-implementation is the time period for which the EEM(s) which are within the scope of the M&V activity are functioning normally and presumed to be saving energy.
  - *Reporting period* is the time period for which post-implementation energy savings is to be determined. For buildings, the reporting period is typically 12 months duration in order to capture seasonal effects.
  - *Reporting period conditions* refer to the types of activities, operating practices, and other conditions which drive the quantity of reporting period energy.
  - *Reporting period energy* refers to the energy consumption for the EEMs typically measured or scaled to an annual basis (e.g. GJ/yr. of natural gas or kWh/yr. of electricity).

2.2 Avoided Energy and the Basic M&V Equation

A fundamental concept of M&V is that energy savings are determined as the difference between the baseline energy and the reporting period energy. It is critical that these two values are measured and, as necessary, adjusted to the same conditions. Common variables that change and can be used to adjust measured energy values are outdoor air temperature and occupancy.

There are three basic approaches to quantifying energy savings depending on the choice of reference conditions:

1. *Avoided energy* uses the reporting period conditions as the reference. This is the most common approach in M&V.
2. *Normalized energy* uses neither the baseline nor the reporting period conditions as the reference, but some normal set of conditions. The most often used application of this approach is to use long-term average outdoor air temperatures, or typical meteorological year values (TMY). TMY values are commonly available from public weather data sources.
3. *Backcast energy, considered to be a form of normalized energy,* uses the baseline period as the reference condition. This is an uncommon approach in M&V.

The approach used for specific M&V projects will be identified in the M&V plan. For the purposes of ongoing M&V and harvesting utility bill savings, the avoided energy approach would be used. For the purposes of one time M&V for projects which vary seasonally and where sufficient data are available for adjustments, the normalized approach would be used. The normalized approach might be used for a project where long-term performance is important, but M&V is performed only for 1 year post-install. Examples include: a) a project funded by a utility incentive where payment is based on long-term performance, but M&V is only done for 1 year post-install, and b) LEED or other green certification where performance is based on a typical meteorological year and not the climate conditions during the reporting period.

The default method for COE is assumed to be the avoided energy approach, which is the most common approach in M&V practice.

The basic M&V equation for determining energy savings using the avoided energy approach and using units for electricity follows (for natural gas, the units would be GJ):

$$kWh\ Savings = \left(kWh_{Baseline} - kWh_{Reporting\ period}\right) \pm kWh\ Adjustments$$

The energy adjustment term is a calculated energy value to adjust the baseline energy to be on the same basis as the reporting period. The energy adjustment value is usually referred to as baseline adjustment.

The IPMVP categorizes adjustments into two types:

- *Routine adjustments* are energy adjustments made for variables which drive energy use and typically are expected to change. Occupancy and outdoor air temperature are common routine adjustment variables.
- *Non-routine adjustments* are energy adjustments made for variables which drive energy use but typically do not change. The term for these variables is *static factors*. Examples of static factors include changes in square footage and substantial changes in operating hours. Common practice is for M&V planners to list potential static factors, and collect data to monitor these factors during the reporting period.

The basic equation for M&V energy savings considering both Routine and Non-routine adjustments and using units for electricity follows (for natural gas, the units would be GJ). The quantity in parentheses in this equation is referred to as the Adjusted Baseline Energy as illustrated in Figure 1.

$$kWh\ Savings = \left(kWh_{Baseline} \pm kWh\ Routine\ Adjustment \pm kWh\ NonRoutine\ Adjustment\right) - kWh_{Reporting\ period}$$

2.3 Four M&V Options

The IPMVP defines four general methodologies or "options," referred to as Option A, B, C and D. These four methodologies are divided into three general types: retrofit isolation, whole facility, and computer simulation. Retrofit-Isolation methods consider only the affected equipment or system independent of the rest of the facility. Whole-facility methods consider the total energy use and de-emphasize specific equipment performance. Computer simulation involves just as the name implies, which is that the use of computer simulation is integral to the M&V method.

Option B is retrofit isolation where all parameters or variables assessed to be critical for determining energy savings are measured. Option A is also a retrofit isolation method where, for the purpose of working within justifiable M&V cost constraints, only some critical parameters are measured. With Option A, some important parameters stipulated or estimated rather than directly measured. For any option, measurement may include spot measurements, short term measurements or continuous measurements. Option C is whole facility measurement where the measurement may be based on utility billing analysis or on supplementary whole building measurement. Option D utilizes computer simulation modeling to estimate baseline energy to determine the savings.

The four generic M&V options are summarized below.

2.3.1 Option A: Retrofit-Isolation: Key Parameter Measurement

Option A generally involves:

- Computations using a combination of sub-meter measurements of some parameters, and estimates of the other critical parameters (such as continuous hours of use measurements taken at end-end or system level where variations are expected). Using estimates for some parameters is done to reduce the cost of M&V activity. Measurements are short-term, periodic, or continuous.
- Engineering calculations or mathematical modelling to assess the significance of the errors in estimating any parameter in the reported energy savings.
- Reporting period energy is metered from system-specific sub-meters.
- Energy savings are calculated using the basic equation for M&V energy savings.

Appendix A provides a summary description and results of an Option A M&V project.

2.3.2 Option B: Retrofit-Isolation: All Parameter Measurement

Option B generally involves:

- Computations using a combination of sub-meter measurements of all relevant performance parameters (such as continuous hours of use and power measurements taken at end-use or system level where variations are expected).
- Reporting period energy is metered from system-specific sub-meters.
- Energy savings are calculated using the basic equation for M&V energy savings.
- Engineering analysis may involve adjustments to normalize the baseline and post-retrofit conditions so that change in energy consumption is isolated to the EEM.

Appendix B provides a summary description and results of an Option B M&V project.

2.3.3 Option C: Whole Facility Data

Option C generally involves:

- The use of whole facility energy data. Usually this data source is the utility data. In some cases, the data may come from a non-utility sub-meter which measures energy use for the whole facility. Metered data can be in the form of hourly, daily or monthly interval whole-facility data.
- Energy savings are calculated using the basic equation for M&V energy savings. Adjusted baseline energy is typically derived from a model of energy use using baseline energy data. These models are calculated using various commercial software tools.
- The model for adjusted baseline energy is usually in the form of a single- or multi-variable regression model. A model is based on the interval data and correlating energy to one or more independent variables such as outdoor air temperature, degree days, metering period length, facility activity data, day of the week, occupancy or operating model.
- Reporting period energy is metered from whole facility meters.

Appendix C provides a summary description and results of an Option C M&V project.

2.3.4 Option D: Calibrated Computer Simulation

Option D generally involves:

- New construction projects such as whole new buildings or building expansions. In these cases, the baseline system is hypothetical, such as what would have been constructed according to minimum code requirements. As such, baseline energy cannot be measured.
- Computer similar software is used to model energy performance of a whole facility (or sub-facility). Models must be calibrated with actual hourly or monthly billing data from the facility.
- Energy savings are calculated using the basic equation for M&V energy savings. Adjusted baseline energy is typically derived from the computer simulation of the hypothetical baseline system using data on conditions from the reporting period.
- Reporting period energy is metered from whole facility meters or sub-meters.

Appendix D provides a summary description and results of an Option D M&V project.

2.4 M&V Planning

The M&V Plan is required when a project is chosen for M&V. The M&V plan includes background information about the project and facility, expected savings, EEM information, M&V specific activities to be performed, M&V roles and responsibilities, M&V option to be used to determine the energy savings, savings calculations, type of metering equipment to be used and M&V budget, if applicable. The value of a project-specific M&V plan is to provide the opportunity to optimize the M&V activity to achieve acceptable levels at the lowest cost.

The recommended list of IPMVP Adherence items for M&V Plan document:

- Facility and Project Overview
- EEM Intent
- Selected IPMVP Option and Measurement Boundary
  - IPMVP Option
  - Measurement Boundary
- Baseline: Period, Usage and Conditions
- Reporting Period
- Basis for Adjustment
- Calculation Methodology and Analysis Procedure
- Meter Specifications
- Monitoring Responsibilities, including these key activities
  - Metering and data collection from instruments
  - Utility data collection
  - Analysis of energy savings and utility cost savings
  - Report writing
  - Approvals of key M&V deliverables including the M&V plan and M&V report(s)
- Metering Equipment Details: specify which existing instruments and BAS data will be used; specific all temporary instruments or spot readings to be measured.
- M&V Budget (If identified and applicable for the specific project.)
- Uncertainty
- Report Format
- Quality Assurance

2.5 Balancing Cost of M&V vs. Accuracy

One of the most important M&V tasks is providing adequate accuracy while ensuring that M&V costs are reasonable. In general, the more rigorous the M&V, the more expensive it will be to determine energy savings. Factors that typically affect M&V accuracy and costs:

- Use of sampling and sample sizes used for metering representative equipment.
- Metering duration and accuracy of metering activities and equipment.
- Level of data required for energy savings analysis. Number and complexity of independent variables to be metered or to account for to determine energy savings.
- Pre- and post-installation survey information needed.
- Level of accuracy needed in energy savings analysis.
- Availability of pre- and/or post-installation data from the existing facility data control and information systems.
- Level of expertise required to perform energy savings analysis.

2.6 Valuing Energy and Peak Power Savings

The valuation of energy and peak power savings is an important aspect of M&V. The valuations and the process for updating valuations are to be included in the M&V plan. Valuations may be used to harvest utility bill cost savings attributable to specific projects. As such, monetizing the value of energy or peak power savings should be done carefully to produce credible results.

The basic equation for calculating utility bill savings follows: $C_{savings} = C_{baseline} - C_{reporting}$

$C_{savings}$ = Annual costs savings

$C_{baseline}$ = Annual cost of baseline energy (including applicable adjustments)

$C_{reporting}$ = Annual cost of reporting period energy (including applicable adjustments)

In valuing energy or peak power savings, it is critical to use the *marginal* pricing for energy or power. In general, variable charges are used to value energy or peak power savings, while fixed charges are not.

For energy, the valuation is based on all the variable components of the energy costs including commodity charges, distribution, transmission, transportation, and rate riders. Where there are block rates or time-of-use rates, the variable charges will change as a function of total consumption and timing of savings. For peak electric power savings, demand charges based on kW or kVA (where kVA equals kW divided by power factor) may apply. For natural gas, some large service accounts have peak charges based on the highest daily consumption for the billing period.

Fixed charges such as customer charges, fixed rate riders, administration fees, and management fees typically are not included in the valuation of savings.

The M&V plans specify the marginal rates to be used for valuing energy and (if applicable) peak power savings. For example, consider an M&V plan which specifies electric energy valued at $0.125 per kWh, peak charges at $12 per kVA-month, and natural gas energy savings at $6.357 per GJ. If an M&V project is determined to save 500,000 kWh/year of electric energy, reduce peak power by 57 kW, and save 4,000 GJ/year of natural gas, the monetized savings would be as follows:

500,000 kWh/year * $0.125/kWh = $62,500

12 months * 57 kVA * $12/kVA-month = $8,208

4,000 GJ/year * $6.357/GJ = $25,428

Total annual utility cost savings = $96,136

If the rate structure for a facility is complicated, then to minimize the chance of calculation errors the full utility rate structure can be applied to the baseline and reporting period energy or peak power values separately using basic utility cost savings equation:

$C_{savings} = C_{baseline} - C_{reporting}$

$C_{savings}$ = Annual costs savings

$C_{baseline}$ = Annual total fixed plus variable cost of baseline energy (including applicable adjustments)

$C_{reporting}$ = Annual fixed plus variable cost of reporting period energy (including applicable adjustments)

2.7 Guide to Selecting M&V Methodology

Figure 2 provides a flowchart to illustrate the process of selecting the most appropriate M&V methodology. The selection flow chart applies to COE retrofit projects only. Newly constructed buildings utilize M&V Option D. The LEED certification process incorporates M&V and defines M&V activity required for that certification.

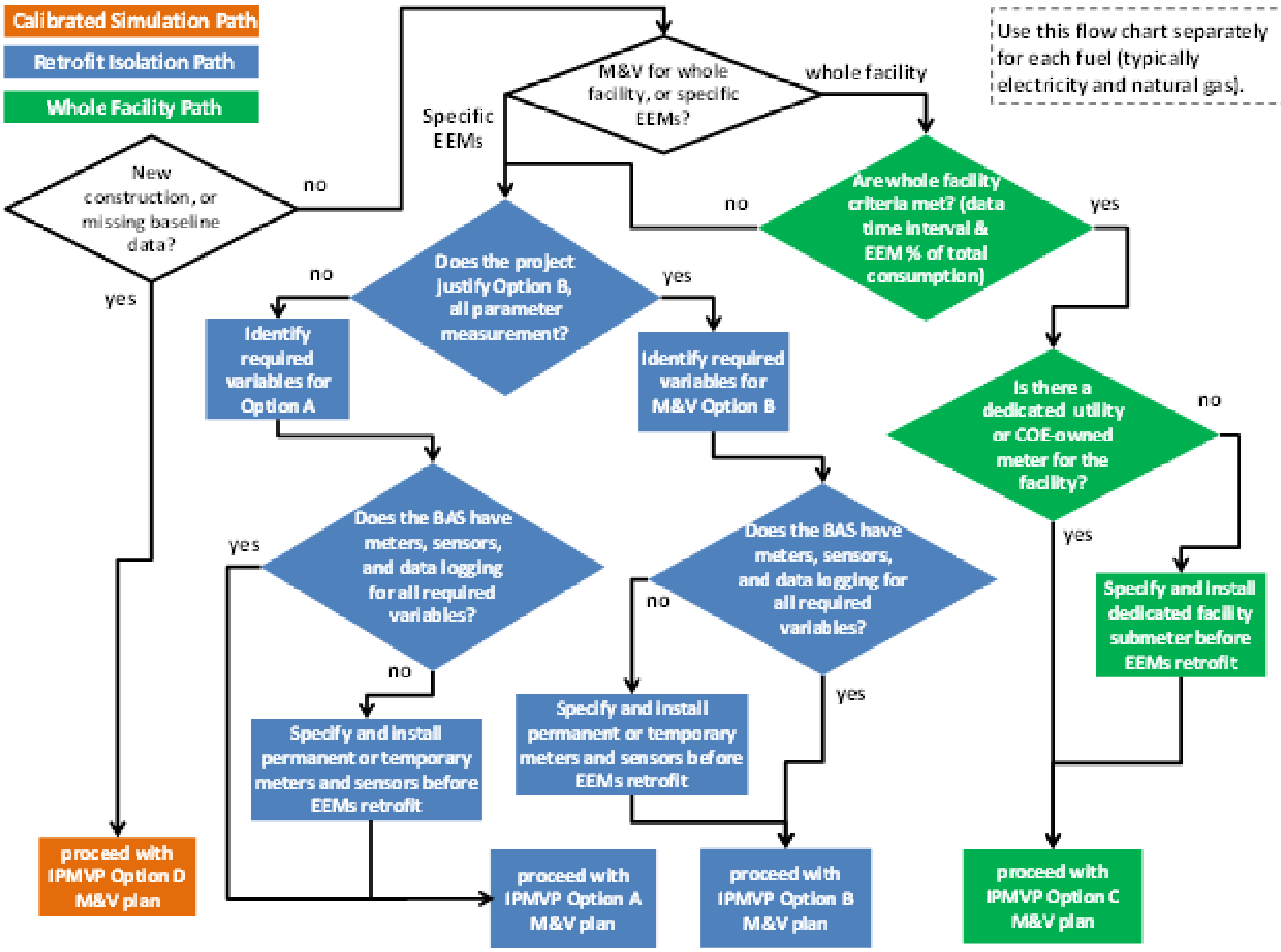


Figure 2: Flowchart for selecting M&V methodology for COE retrofit projects

2.7.1 When to use Option A

M&V Option A involves a retrofit - or system level M&V assessment. The approach is intended for retrofits where key performance factors (e.g. end-use capacity, demand, power) or operational factors (such as lighting operational hours) can be measured short-term, periodically or continuously during the baseline period and periodically after the project implementation (i.e. during the reporting period). Any factor not measured is estimated based on assumptions or information available in the manufacturer specifications.

The savings from a simple lighting retrofit will typically be measured with acceptable accuracy using Option A. If greater accuracy is required or for a complex equipment retrofit (such as chillers, cooling towers, motors, compressed air), Option B or D may be more appropriate.

When multiple pieces of identical equipment are involved, it is often more cost effective to perform the key parameter measurements on a random sample of the equipment involved.

Option A is appropriate for relatively simple EEMs whose baseline and post-installation conditions (such as equipment quantities or rating information such as luminaire or lamp watts for lighting or motor power) represent a significant portion of the uncertainty associated with the project.

2.7.2 When to use Option B

M&V Option B is a retrofit isolation or system level approach. This option is similar to option A but uses short-term, periodic or continuous metering of all energy quantities for all critical parameters needed to calculate energy. This approach provides higher accuracy in the calculation of savings but increases the M&V cost.

Option B is appropriate for measures in which the actual energy use needs to be measured for comparison with the baseline model for calculating savings. This option is typically used when any or all of the following conditions apply:

- Independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.
- Energy savings determination for individual EEMs are needed.
- Independent variables and operational data on the equipment are available through control systems; or sub-meters are already in place that record the energy use of sub systems under considerations.

2.7.3 When to use Option C

M&V Option C involves whole facility (either utility or sub-meter) data analysis to verify the performance of retrofit projects in which whole facility baseline and reporting period data are available. Option C method is typically used when determining savings from multiple interactive EEMs and for determining the benefits of projects that cannot be measured directly such as building envelope measures. This method should be used only for projects that meet the following requirements:

- Estimated savings are greater than 10% of the overall facility annual consumption (or consumption measured by the utility meter or sub-meter) measured on a monthly basis. Where daily or hourly interval data are available, then the guideline is that estimated energy savings are 3% or greater than the average whole facility metered value.
- Determination of energy savings for individual EEMs is not needed.
- At least 12 months (preferably 24 months) or more of pre-installation data are available to calculate the baseline model and at least of 12 months of reporting period data are available to calculate the actual consumption and to determine the savings.
- Adequate data on independent variables are available to generate an accurate baseline model. Independent variable data must correspond to the time periods of the utility or sub-meter readings dates and intervals.

- Additional loads on the utility or sub-meter that are not included in the project retrofit are small and expected to remain constant during the baseline and reporting period.

2.7.4 When to use Option D

Option D involves whole facility or system analysis procedures to verify the performance of retrofit or new construction projects using calibrated computer simulation models. This method may be useful for projects that meet the following requirements:

- When new construction projects are involved or where baseline is theoretical or when the baseline energy data are not available.
- When projects are complex with too many EEMs to cost-effectively use retrofit isolation Options A or B.
- When energy savings calculations per individual measure are desired.
- When complex baseline adjustments are expected during the reporting period.
- When expected savings amount is sufficient to permit the cost of simulation.

2.8 M&V Reporting

IPMVP Core Concepts defines the standard requirements for M&V reports:

Project background

- *EEM description*
- *M&V Option chosen for the EEM or project as part of the M&V Plan*
- *Reporting period start and end dates*
- *M&V activities conducted during the reporting period, including:*

Start and end time for the measurement period

Energy use data

Data for independent and static variables

Description of inspection activities conducted

Verified saving calculations and methodology

Provide detailed description of data analysis and methodology

Provide an updated list of assumptions and source of data used in the calculations

Provide details of any baseline or saving adjustments including both routine and non-routine adjustments to account for changes

Provide details of utility costs used to calculate the reported savings

Clear presentation of verified energy, cost savings and comparison to the proposed savings

2.9 Quality Control

Quality control provisions include the following:

- Measurement equipment re-calibration frequency
- Data review to identify anomalies
- Third party quality assurance review of the M&V report including the following key items where applicable:
    - Correct application of measurement boundaries

- Spot check data quality, handling of anomalies or missing data
- Review baseline energy models and model validity
- Review routine and non-routine adjustments
- Spot check calculations of energy savings, peak power reductions, and utility cost savings
- Check for rebound effects, system interactions, and analysis of stacking or sequence of analysis where multiple measures are involved
- Review the M&V report and recommend edits to enhance and simplify the report while including all essential elements of the report.

The suggested criteria for triggering a third party quality assurance review for M&V reports are: a) whenever a project's utility cost savings for either electricity or natural gas exceed 10% of typical annual cost, and b) overall at least one out of every five M&V reports should undergo third party review.

3. M&V Measurements

A basic principle of M&V is that measurements of the actual EEM equipment are critical. Experience in M&V reveals that often surrogates for direct measurements are proposed for reasons such as the absence of installed meters, failed metering systems, and the cost of measurements. Substitutes for direct measurements include the use of engineering estimates, assumptions or handbook values, anecdotal reports by staff and occupants, findings from published projects (often classified as "deemed" values), and manufacturer specifications. While these substitutes for direct measurements inevitably are used to some degree in M&V, direct measurements of the EEM equipment always improves the accuracy and credibility of the M&V findings. In this section we overview a number of measurements which are common for M&V for municipal facilities.

3.1 Operational Data

Operational data refers to M&V data used for a variety of purposes, usually for independent variables in energy models or static factors. These data are often used to identify routine and non-routine adjustments. Examples include:

- Temperatures and pressures of air and water flows
- Operating schedules (operating time)
- Occupancy or other measure of facility activity
- Equipment usage (e.g. in transit garages)
- Energy and power

For COE, the main source of these types of data is the building automation system, entiliWEB (https://deltacontrols.com/products/enteliweb). Other sources of operating data could include operation and maintenance logs, staff interviews, or portable instruments. Examples of potential data collection for operational or static factors are provided in the following table, based on the type of EEM.

EEM type	Types of Operational Data or Static Factors						
	Facility operating hours	Outdoor variables other than temperature (e.g. hours of cloud cover)	Facility activity (e.g. ticket sales or revenue)	Building occupancy (e.g. number employees signed in)	Facility modification (other than the EEM)	Changes in Setpoints (building automation data historian)	Change in facility use
Space heating and cooling	*		*	*	*	*	*
Indoor lighting	*		*	*	*		*
Outdoor lighting	*	*	*	*	*		*
Service or domestic hot water heating	*		*	*	*		*
Combined heat and power	*		*	*	*	*	*

3.2 Utility Meters and Data

Electricity and natural gas data are essential sources of energy and power data. Even projects which are sub-metered and use retrofit isolation M&V methods, collection of facility-level utility data should be included as an indicator of operation of the facility. Electricity data is often available as hourly interval data from ATCO Electric, or in some cases a 3rd party billing company.

Natural gas data is usually recorded on a monthly basis. According to ATCO[3], only large accounts with 8,000 GJ/year are meters read on a daily basis. Otherwise gas meters are ready on a monthly basis. It should be noted however that for some small or medium accounts, utility bills will include daily values. In these cases, the daily values are estimates made by the utility and must not be used the same as meter readings for M&V.

3.3 Weather Data

Weather data is critical to M&V for buildings. Specifically, outdoor air temperature is almost always used as either an independent variable in an energy model, operational data, or both. For COE, the EnergyCAP typically includes outdoor air temperature data. When using these data from EnergyCAP, the M&V analyst should confirm

[3] Email communication from ATCO Gas customer service (December 11, 2019) "ATCO Gas reads low and medium use sites monthly. High use sites that consume more than 8000 GJ/year are read daily or more often. High use sites are the only sites that are billed on 24 hr demand ($/GJ/day)."

the source of these data and perform cross checks to other public sources. Common public sources for COE include the following:

- https://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp
- https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

In particular, the Agriculture Alberta site has been found to be more user-friendly.

3.4 Measurements and Safety

A number of portable or field instruments can be used for M&V as described in the following sections. The first consideration for the use of field meters is personnel safety and protection of property. Installation of portable or permanent meters will require a shutdown of portions, if not the entire facility. The City of Edmonton has a shutdown permit, which needs to be completed prior to any shutdown. The permit identifies the proper stakeholders and safety processes that need to be involved with the shutdown (i.e. operations).

Following are some general considerations:

- Personal protection: equipment such as safety glasses, gloves, and hardhats
- Fall protection: when working on rooftops or planning to install loggers in high locations, ensure personnel are trained in fall protection procedures
- Confined space: follow existing protocol
- Working alone: follow existing protocol
- Electrical qualifications: connection of temporary power meters or current transformers should only be performed by qualified staff and follow City of Edmonton procedure (eg. partial shutdown procedure).[4]
- Natural gas safety: natural gas piping modifications, such as to install thermal mass meters, should be performed only by qualified gas fitters.
- Protection of property: when performing measurements, M&V staff can at times be exposed to a variety of hazards such as rotating equipment or combustion sources.

3.5 Measuring Hours of Use and Lighting Intensity

Metering hours of use is, in general, a cost-effective approach to improve the accuracy of energy consumption in cases where continuous monitoring of energy is prohibitively expensive. In many cases the operating electric power, gas flow, or thermal energy flow can be determined from spot readings, manufacturer specifications, or building automation sensors. To improve the accuracy of energy consumption, the use of non-intrusive loggers to meter operating hours (e.g. for one week or one month) can substantially reduce the uncertainty.

Time-of-use (TOU) data loggers are commonly used for time-of-use measurements for lighting outputting systems or for current drawing loads. Some commonly used TOU devices are listed below:

- Dent Instruments SMARTlogger: Measure the On/off status (event trigger), time-of-use operating schedule and total On-time for energy consuming devices and systems. The measurements are stored in on-board up to 32,000 readings in a time series format and the data can be extracted at an interval selected by the user (such as 1 or 5 or 15 minute or hourly intervals). Time-of-use logger with an internal photo sensor such as the example in Figure 3 can be used for lighting outputting systems.

[4] www.westernenergy.org/community-groups/northwest-electric-meter-school/ is a useful source for training for electric power metering

Figure 3: Dent Instruments™ Light Usage Data Logger (TOU-LL)

- HOBO Light On/Off Data logger: Monitors indoor light changes with an internal sensor and records light on and off conditions with time stamps, similar to Dent Instruments SMARTlogger.

Figure 4: HOBO™ Light Usage Data Logger - Onset UX90 Time of Use Data Logger

- Time-of-use logger with an internal magnetic field sensor (TOU-Mag Logger) is commonly used for motors. These can be useful for measuring hours of use for smaller motors for which the cost of temporary power meters cannot be justified. Another application for metering motor on/off hours of use is for small combustion air fans on unit heaters, as a means of measuring operating time. Variable frequency drives often have the capability to record the percent speed or HZ, this would need to be enabled and connected to the logger.
- Time-of-use logger with an external current transformer (TOU-CT) commonly used for lighting systems, motors, relays and switches, and virtually any electric load.
- Time-of-use contact logger with an external switch or relay.

Time-of-use (TOU) data loggers are not suitable for lighting fixtures that are controlled via dimmers and/or the networked lighting control system. For such applications, HOBO MX2202 Data Logger (as shown in Figure 5) can be used to measure the lighting intensity (i.e. Lux) and this is a cost-effective approach to improve the accuracy of energy consumption in cases where continuous monitoring of energy is prohibitively expensive. This type of logger can be used to measure the lux levels to estimate power usage using luminaire specifications and percentage on-time at different lighting levels.

Figure 5: HOBO MX2202 Data Logger

Some commonly used metering equipment based on different lighting types and/or controls are listed in Table 1.

Table 1: Commonly Used Metering Equipment for Lighting M&V

Lighting Type / Controls	Logger Model / Description
Interior high-bay luminaires and if all luminaires on a circuit are controlled by a single control unit, either all On or Off (example: controlled via switch or local occupancy sensor or timer)	▪ Dent Instruments, Time-of-Use Datalogger with an external current transformer (TOU-CT) - On/off event trigger logger measures % on-time (clamp on a lighting circuit)
Interior high-bay luminaires and if each luminaire is individually controlled – On/off and/or dimmed using an integrated occupancy sensor and/or programmed by the networked lighting control system	▪ Dent 3-phase electric power meter (ELITEpro XC Portable Power Data Logger, as shown in Section 4.6) – measures real power consumption (1 or 5 or 15 or hourly interval readings) ▪ If possible to place logger near the lighting fixture: HOBO MX2202 Data Logger – measures light intensity (lux) to estimate power consumption using luminaire specifications (lux vs. power curve)
Interior low-bay luminaires (On/off, no dimming)	▪ HOBO Light Usage Data Logger - Onset UX90 Time of Use Data Logger ▪ Dent Instruments LIGHTINGlogger, Time-of-Use Datalogger (TOU-LL) with an internal photocell sensor
Interior low-bay luminaires (On/off, with dimming) – if each luminaire is individually controlled using an integrated OS and/or programmed by the networked lighting control system	▪ HOBO MX2202 Data Logger – measures light intensity (lux) to estimate power consumption using luminaire specifications (lux vs. power curve) ▪ Dent 3-phase electric power meter (ELITEpro XC Portable Power Data Logger) – measures real power consumption (1 or 5 or 15 or hourly interval readings)

Exterior parkade or street lighting (On/off, no dimming) – if all luminaires on a circuit are controlled by a single control unit (example: photocell)	▪ Dent Instruments, Time-of-Use Datalogger with an external current transformer (TOU-CT)
Exterior parkade or street lighting (On/off, with dimming) – if each luminaire is controlled by an integrated occupancy sensor, photocell and/or programmed by the networked lighting control system	▪ Dent 3-phase electric power meter (ELITEpro XC Portable Power Data Logger)

3.6 Sub-Metering Electricity

It is the City of Edmonton preference to use permanent meters over temporary meters as noted below. Ideally the City will configure permanent meters with the BMS and utilize it for the baseline measurement period. For the retrofit project, the same metering equipment can be reused and the previous configurations can be used for the reporting period.

Special temporary meters may be used to perform electric power parameters (kW, amps, volts and power factor) and/or energy. The Dent Instruments ELITEpro XC power meter, shown in Figure 6, is the recommended meter for temporary electric power measurements for M&V.

Figure 6: Dent 3-phase electric power meter (ELITEpro XC™ Portable Power Data Logger)

- This meter is capable of measuring, storing and analyzing consumption data including volts, amps, watts, volt-amps (VA), volt-amps reactive (VAR), true RMS power (kW), KVAH, KVARh and power factor (PF) of an electrical load (single or 3 phase) or an entire building. The logger has the ability to show the measured data and power waveforms in real-time for power quality purposes and for troubleshooting. The logger also has a capability to measure and store peak demands and energy data (kWh).

- Meter is line-powered from the service being measured using current transformers (CT's) for single or 3-phase systems (using 80-600V phase-to-phase (AC or DC) services when line powered or 0-600V (AC or DC) when externally powered).
- The measurements are stored on-board in a time series format at an interval selected by the user (such as 1 or 5 or 15 minute or hourly intervals). The logger can monitor up to four single phase loads at a same time or up to two 3-phase loads depending on the metering configuration.
- The meter requires a software called 'ELOG' installed on a computer for setup, data retrieval, and data analysis.
- Meter accuracy is better than 1% (<0.5% typical) for Volts, Amps, kW, KVAR, KVA and PF, and logger resolution is 1 watt. Split-core current transformer accuracy is +/- 1% at 10% to 130% of rated current. Flexible CT's (Rogowski Coil) are <0.6% accuracy.
- This logger is suitable for bi-directional metering i.e. capable of monitoring power generated by a renewable energy source versus power imported from the grid.

3.7 Sub-Metering Natural Gas

Sub-metering of natural gas is useful for retrofit-isolation M&V of large natural gas-fired equipment, such as boilers. As an example, if a boiler is retrofit in a building with other end-uses of natural gas, typically data from the utility gas meter is not suitable due to the presence of other gas loads such as domestic hot water, heated make-up air units, and unit heaters. However, installing permanent sub-meters for natural gas equipment is usually not cost-effective. Non-intrusive (e.g. strap-on) fluid flow meters typically only work if gas pressures are at least 25 atmospheres (over 2,500 kPa), and do not work at building gas pressures.

For buildings, the best available approach for sub-metering natural gas equipment has been found to be the use of insertion design, thermal mass meters. Figure 7 provides an example of such a meter. The main advantage of this meter to sub-meter natural gas for M&V includes the following:

- Suitable and acceptable accuracy for typical building gas pressures which are well under 1 atmosphere
- Fittings and small piping can be installed during a shutdown to enable use of temporary gas meters.
- Once the fittings are installed, then these insertion meters can be installed and removed for M&V without the need for any further shutdowns. The thermal mass meters can be reused for multiple projects.
- These meters could be used for other purposes such as boiler tune-ups and troubleshooting.

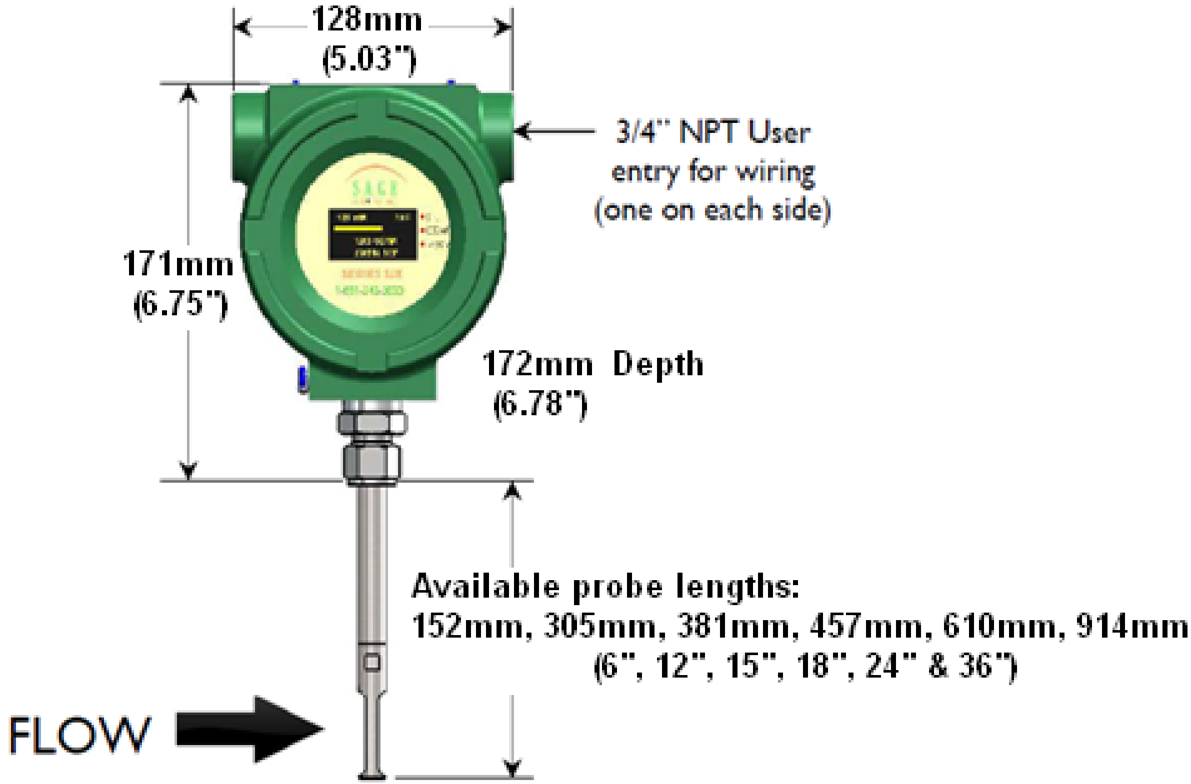


Figure 7: Sage "RIO" Integral Industrial Mass Flow Meter

4. M&V Strategies and Calculations

4.1 Sampling Methods

Where there are multiple loads involved, it may not be cost effective to meter all EEM equipment. In these cases, sampling methods can be employed. For COE, lighting retrofits are a common project where sampling can be effectively used. Appendix E provides a detailed procedure for sampling

4.2 Regression Modelling

4.2.1 Introduction and Example

Regression modelling is a statistical method to relate changes in a dependent variable of interest (e.g. monthly natural gas consumption) to changes in independent variables (e.g. monthly HDD). This section presents a basic introduction to regression modelling, provides guidelines for acceptability, and illustrates regression modelling with an example.

Regression models are often used in M&V to make routine adjustments so that baseline energy and reporting period energy values are (as best as possible) quantified at the same conditions. As a common example, natural gas consumed by a heating system will be higher than expected during a colder winter (quantified by HDD), and so the M&V analyst needs to adjust the baseline energy to account for this effect to accurately determine energy savings.

A typical regression model is of the following form (illustrated for the case with two independent variables):

$Y = A + B_1 * X_1 + B_2 * X_2$

Y = dependent variable of interest, usually energy consumption (e.g. natural gas GJ/month)

X_1 = first independent variable (e.g. HDD)

X_2 = second independent variable (e.g. measure of facility activity such as occupancy)

A = fixed coefficient or intercept

B_1 = model coefficient for X_1

B_2 = model coefficient for X_2

Regression models are assessed for acceptability based on statistical criteria. For COE, the criteria presented in the CMVP training is commonly used, which will be stated below and then illustrated with an example.

Criteria for a valid regression model:

- $R^2 > 0.7$ which is coefficient of determination
- p-values for B_1 and B_2 model coefficients < 0.1
- Cv(RMSE) < 0.20 or 20%
- Bias Error < 0.005%

All four of the parameters above are calculated using software tools (see description of common tools below).

As an example, the result of a regression model for COE's Donnan Arena was developed to quantify monthly natural gas consumption as a function of HDD and the number of ice rink operating hours each month. The results using Microsoft Excel's Regression function are shown below (with highlights added, and manual equations inserted for Cv(RMSE) and Bias Error).

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.993790428					
R Square	0.987619416					
Adjusted R Square	0.984868175					
Standard Error	14.74529404	11.2%	=Cv(RMSE) = Standard Error / Average GJ per month			
Observations	12					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	156098.1867	78049.09337	358.9723413	2.61418E-09	
Residual	9	1956.813268	217.4236965			
Total	11	158055				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-23.73675628	7.754673322	-3.060961474	0.013550539	-41.27904608	-6.194466483
X Variable 1	0.308632103	0.024113264	12.79926675	4.43762E-07	0.254084109	0.363180097
X Variable 2	0.125694326	0.022962896	5.473800989	0.000393314	0.073748645	0.177640007
RESIDUAL OUTPUT				A = sum of actual GJ values (i.e. metered Y values)		
				B = sum of predicted GJ values (i.e. predicted Y values)		
Observation	*Predicted Y*	*Residuals*	Actual GJ / month	1,578.00000000	= A	
1	235.5849187	18.41508128	254.0	1,578.00000000	= B	
2	302.3191102	-2.319110221	300.0	0.0000000%	= Bias Error	
3	307.4961988	-9.496198762	298.0		**% bias error should be < 0.005%**	
4	220.6012601	16.39873991	237.0		Bias Error = (A - B) / A	
5	153.7074016	-2.707401623	151.0			
6	49.50871264	-19.50871264	30.0			
7	22.96635176	-7.966351761	15.0			
8	-9.748851177	14.74885118	5.0			
9	-14.37813273	17.37813273	3.0			
10	18.0185874	-6.018587396	12.0			
11	103.2514037	-15.25140366	88.0			
12	188.672839	-3.672839033	185.0			
			131.50	Average GJ per month		

The resulting energy equation from this model follows:

Natural gas GJ/month = -23.74 + (0.3086 * HDD/month) + (0.1257 * Ice Hours/month)

R^2 = 0.98 is > 0.7 meeting criteria

p-values for the Intercept, X_1 (HDD variable) and X_2 (Ice Hours variable) are all < 0.1 meeting criteria

Cv(RMSE) = 11.6% is <20% meeting criteria

Bias Error = 0.00000% is < 0.005% meeting criteria

This model could be used by the M&V analyst to account for differences in natural gas consumption from the baseline period (pre-retrofit) to the reporting period (post-retrofit), when HDD and Ice Hours are different for the two time periods.

This overview and example model provides a practical introduction to the use of regression for M&V. For further details on the definitions and methodology, see the ASHRAE M&V Guideline (2014) and Uncertainty Assessment for IPVMP (2019) listed in the references.

4.2.2 Software Tools

For Option C regression analysis, software is an essential resource needed for M&V. Microsoft Excel or Google Sheets can be used to perform regression analysis for most applications. However, there are some limitations as compared to dedicated statistical software designed to perform Option C analysis. For basic calculations and charting, spreadsheets work well.

Time series analysis, although not often needed for M&V, is challenging in MS Excel as it involves much manual manipulation of data by the user. Statistical analysis software is designed to handle complex data sets and there are less chances of errors. Excel uses only ordinary least squares regression, and in some cases energy models can be improved using other statistical regression approaches.

Table 2 provides a summary of software packages.

Table 2: Summary of Regression Modelling Software

Software	Description
Metrix 4	• Whole building utility accounting software • Tune usage with up to five variables • Data input: Monthly billing (kWh, kW, cost) data, correcting for weather and other parameters (such as production, occupancy or other facility level data) and weather data
Utility Manager Pro (Utility Accounting)	• Utility accounting software • Data input: Does not support the use of interval meter data
Energy Center (Utility Accounting)	• Utility accounting software • Data input: Does have ability to use 15-minute interval data
EnergyCAP	• web-based and window-based program • Utility savings analysis and reporting software • Data input: Monthly sub-meter readings or Interval data; correcting for weather (degree days) and other changes such as occupancy, schedule and equipment retrofits
JMP	• Statistical analysis and reporting software. JMP Pro is used for advanced predicative analytics and model building(s). • Data input (JMP & JMP Pro): Monthly Interval data; correcting for weather, production etc.
IBM SPSS	• Single user, window-based program • Statistical analysis and reporting software • Data input: Interval data set
RETScreen Expert	• Single user, window-based program • Can be used to model IPMVP Options A, B, C and D • Data input: Daily or monthly interval data

*Cost is in US dollars and may vary by edition of software and number of accounts/meter data to be analyzed.

4.3 Computer Simulations

Computer simulation software is used for Option D M&V. The types of calculations required cannot be done with spreadsheets and require simulation software packages. Following are some available options:

- eQUEST (www.doe2.com/equest)
- EnergyPlus (https://energyplus.net)
- CAN-QUEST (nrcan.gc.ca/energy-efficiency/energy-efficiency-buildings/energy-management-resources-buil/energy-management-software-new-buildings/22468)
- Passive House Planning Package - PHPP 9 (https://passivehouse.com/04_phpp/04_phpp.htm)
- IES Virtual Environment (https://www.iesve.com/software/building-energy-modeling)

5. Training Recommendations

The guidelines for training for COE staff involved in M&V projects are as follows:

- COE members of the M&V working group should have CMVP Introduction training (1 day).
- M&V Working Group Lead staff should have full CMVP training (3 days plus exam).
- Installers of electric submeters recommended to have electric power meter training or equivalent, such as offered by the Western Energy Institute (www.westernenergy.org/community-groups/northwest-electric-meter-school).
- Project managers for facilities or projects where M&V activity is being conducted should have 1-hour introductory M&V training (a custom introduction to M&V arranged by the M&V Working Group Lead).

6. References and Resources

1. ANSI/ASHRAE/ACCA Standard 211-2018 Standard for Commercial Building Energy Audits
2. ASHRAE (2014). Measurement of Energy and Demand Savings, Guideline 14. American Society of Heating, Refrigeration and Air Conditioning Engineers: Atlanta, GA. Available at www.ASHRAE.org.
3. Bonneville Power Authority (2018) Sampling for M&V: Reference Guide
4. CEATI (2008) Energy Savings Measurement Guide Following IPMVP
5. IPMVP Core Concepts [EVO 10000 – 1:2016]
6. IPMVP "Core Concepts – Addendum 1" [EVO 100000 - 1:2016]
7. IPMVP "Uncertainty Assessment for IPMVP" [EVO 10100-1:2019]
8. IPMVP "Issues and Examples" [EVO 10300 - 1:2019]
9. IPMVP (2017) “Renewables Application Guide” [EVO 10200 - 1:2017]
10. FEMP (2015). Federal Energy Management Program (FEMP) M&V Guidelines: Measurement and Verification for Federal Energy Projects. Federal Energy Management Program. Version 4.

Appendix A : Option A Sample Project

Source: CEATI (2008)

Project description:

- Office building lighting retrofit to replace all lamps and ballasts
- Wattage of existing lamps unknown, operating hours well established
- Option A chosen with measurement of power (kW) as key parameter
- 24 hours of power measurements for both baseline and reporting period
- Hours assumed or stipulated = 270 hr/month

Accounting for changes in energy outside the measurement boundary:

- Interactive effect for space cooling for 5 months/yr., using COP = 3.0
- Interactive effect for space heating for 7 months/yr., using efficiency = 80% for 50% of floor space
- Measurements (24 hours pre-retrofit and post-retrofit):
- Baseline power = 254 kW
- Reporting period power = 174 kW
- Power reduction = 80 kW

Interactive effects (outside the measurement boundary):

- Cooling: reduced power = 80 kW / 3.0 = 26.7 kW
- Heating: added thermal power = 0.50 * 80 kW / 0.80 = 50.0 kW
- Added thermal power is natural gas, not electricity

M&V Results:

- Electricity savings, including routine adjustment for cooling
  = 80 kW * 270 hr/mo.*12 mo./yr. + 26.7 kW *270 hr/mo. * 5 mo./yr.
  = 295,200 kWh/yr.
- Thermal fuel increase
  = 50 kW * 270 hr/mo. * 7 mo./yr.
  = 94,500 kWh/yr. * GJ / 277.78 kWh
  = 340 GJ/yr. increase in natural gas

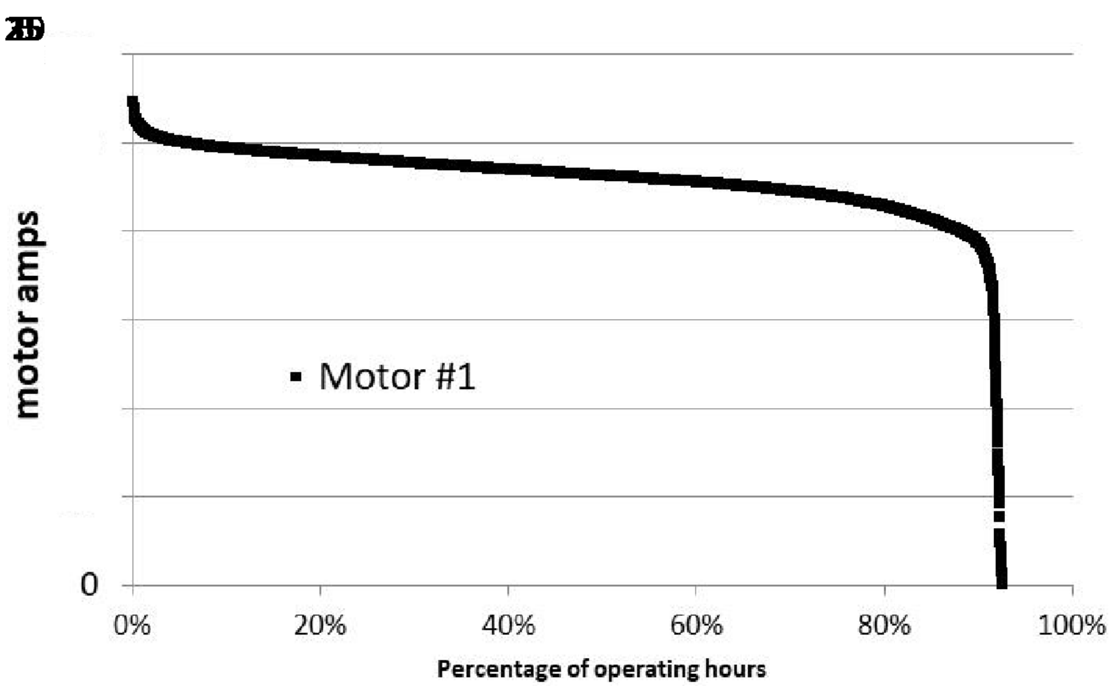
Appendix B : Option B Sample Project

Project description:

- Trim impellers for two large water pumps. Each 50 hp motor.
- Option B chosen based on isolation retrofit and ability to use building motor amp meters at low cost
- M&V measurements:
- Hourly motor amps for baseline and reporting period
- Power (kW) calculated using manufacturer power factor for 3 motor load points.

M&V Results:

- Baseline measurements for 3 weeks.
- Shortened baseline period due to project initiation timing and building shutdown schedule.
- 12 months post-retrofit measurements
- Reporting period "on time" determined using Load Duration curve (e.g. ≥ 20 amps is "on")



M&V energy savings:

- #1 pump =7,973 hr/yr., 10.94 kW reduction
- #2 pump =7,962 hr/yr., 15.77 kW reduction
- No adjustments required
- 87,463 + 125,561 = 213,000 kWh/yr.

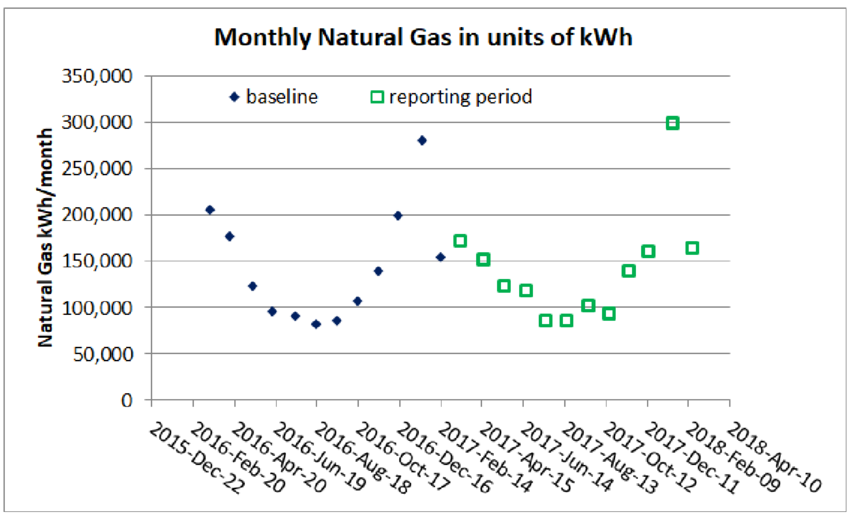
Appendix C : Option C Sample Project

Project description:

- Medical office building
- Natural gas savings due to two programs: behavior change program and recommissioning
- Option C (whole facility) chosen because multiple systems affected
- Monthly natural gas data from utility meter

M&V Analysis:

- Build baseline model
  kWh/month = 94,292 + 257.0 * HDD/month
- Model statistics (outside scope of CEM):
  Cv(RMSE) = 0.18 (< 0.20 or 20%)
  Bias Error <0.005%
  R^2 = 0.84 (> 0.70)
  Model coefficient p-values < 0.01



M&V Results:

- Reporting period predicted consumption using Baseline Model = 1,836,000 kWh/yr. (or 6,610 GJ/yr.)
- Reporting period actual consumption = 1,689,000 kWh/yr. (or 6,080 GJ/yr.)
- M&V Savings = 147,000 kWh/yr. (or 530 GJ/yr.) is 8% of baseline
- Routine adjustments: heating degree days (HDD)

Appendix D : Option D Sample Project

Project description (a case study published in the IPMVP Issues and Examples, 2019):

- EEMs were planned and implemented for a library building on a university campus including lighting, HVAC, operator training, and behavioural/awareness interventions.
- The building was supplied with electricity and steam, but had no building-level meters as utility bills were based on main meters for the whole campus.
- The EEM upgrades included installation of new steam and electricity meters. Due to project logistics and the goal to realize savings as soon as possible, EEMs were implemented as soon as the new systems were commissioned.
- Therefore there were no baseline energy data sets available. The baseline steam, electric demand, and electric consumption were to be determined with simulation modelling using IPMVP Option D methodology, and using a U.S. Department of Energy software.

M&V Analysis:

- Following the project M&V plan, an energy simulation model of the building was developed including the EEMs, and calibrated to the first year of post-retrofit data based on monthly consumption and peak demand data from the newly-installed and calibrated building-level meters.
- The calibration initially revealed large differences in predicted and actual consumption, which required investigation and assessment of building systems. It was determined that the thermal mass design parameters in the model needed to be changed to more accurately match the existing building, and subsequently calibration achieved the M&V plan criteria.
- The model was then adjusted to a normalized outdoor weather data to determine reporting period steam consumption, electricity consumption (kWh), and peak demand (kW). This was described as the “post-retrofit normal-conditions model.”
- The simulation model was modified to remove EEMs and include the pre-retrofit design conditions. Baseline energy and demand were simulated using the same occupancy, operating schedules, and weather data as for the reporting period. This was described as the “baseline normal-conditions model.”

M&V Results:

- M&V savings were determined based on the difference between the “baseline normal-conditions model” and the “post-retrofit normal-conditions model” as summarized in the table below.

	Baseline normal-conditions model	Reporting period 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 (1000’s pounds)	12,222	5,942	6,280

Appendix E : Using Sampling Methods for Lighting

The following sections specify suggested M&V procedure and calculations for lighting projects using IPMVP Option A approach:

'Basic' M&V Option A is recommended for lighting EEMs that involves lighting fixtures or lamps upgrade only and 'Enhanced' M&V Option A is recommended for lighting EEMs that involves installation of new lighting controls with the existing or new lighting fixtures.

- 'Lighting Retrofit – Basic' M&V:
    - Measure hours of operation of a sample of the new lighting fixtures (sampled lighting fixtures in accordance with usage groups). Usage group is grouping of lighting fixtures which are identified based on the space functionality and/or estimated annual hours of operation (schedules) listed in an inventory of lighting fixtures.
    - Use stipulated baseline and post-retrofit power rating (watts) information from the manufacturer's specification sheets.

  The following equations can be used to determine the annual rate of energy savings using the trended and logged data and the equipment specifications:

    - Baseline Energy Consumption, when baseline hours of operation are equal to post-operating hours:

$$Baseline\ Energy\ Consumption_{(Usage\ Group\ i)} = [Baseline\ Total\ kW_{(Usage\ Group\ i)}]\times[Post\ Retrofit\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$$

Where: $Baseline\ kW_{(Usage\ Group\ i)} = \sum(kW\ for\ baseline\ lighting\ fixtures)_{Usage\ Group\ i}$

- $Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)} = [Post\ Retrofit\ Total\ kW_{(Usage\ Group\ i)}]\times[Post\ Retrofit\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$

Where: $Post\ Retrofit\ kW_{(Usage\ Group\ i)} = \sum(kW\ for\ Post\ Retrofit\ lighting\ fixtures)_{Usage\ Group\ i}$

- $Annual\ Energy\ Savings_{(Usage\ Group\ i)} = [Baseline\ Energy\ Consumption_{(Usage\ Group\ i)}]\times[Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)}]$

  Adjustment term is less commonly applied to lighting measures (or adjustments are inherent in algorithms for calculating savings).

- 'Lighting Retrofit and Controls – Enhanced 1' M&V:
    - Measure hours of operation of a sample of the existing and new lighting fixtures (sampled lighting fixtures in accordance with usage groups).
    - Use stipulated baseline and post-retrofit power rating (watts) information from the manufacturer's specification sheets and/or perform spot measurements (true Root Means Square, RMS) wattage readings of a sample of lighting fixtures of each type of lamp/ballast combination.

  The following equations can be used to determine the annual rate of energy savings using the trended and logged data and the equipment specifications:

    - Baseline Energy Consumption, when baseline hours of operation are different from post-installation operating hours:

$$Baseline\ Energy\ Consumption_{(Usage\ Group\ i)} = [Baseline\ Total\ kW_{(Usage\ Group\ i)}]\times[Baseline\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$$

Where: $Baseline\ kW_{(Usage\ Group\ i)} = \sum(kW\ for\ baseline\ lighting\ fixtures)_{Usage\ Group\ i}$

- $Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)} = [Post\ Retrofit\ Total\ kW_{(Usage\ Group\ i)}] \times [Post\ Retrofit\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$

  Where: $Post\ Retrofit\ kW_{(Usage\ Group\ i)} = \sum (kW\ for\ Post\ Retrofit\ lighting\ fixtures)_{Usage\ Group\ i}$

- $Annual\ Energy\ Savings_{(Usage\ Group\ i)} = [Baseline\ Energy\ Consumption_{(Usage\ Group\ i)}] \times [Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)}]$

- <u>'Lighting Retrofit and Controls – Enhanced 2' M&V:</u>
  - Perform continuous power measurements (15-minute or hourly interval readings – average power) of a sample of lighting fixtures or circuits in order to calculate the baseline and post-retrofit on-time average power (kW) and annualized hours of operation per luminaire. Continuous power measurements are recommended for lighting EEMs with adaptive or multi-level lighting controls.

  The following equations can be used to determine the annual rate of energy savings using the trended and logged data and the equipment specifications:

  - Baseline Energy Consumption, when baseline hours of operation are different from post-installation operating hours:

$Baseline\ Energy\ Consumption_{(Usage\ Group\ i)} = [Baseline\ Total\ kW_{(Usage\ Group\ i)}] \times [Baseline\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$

  Where: $Baseline\ kW_{(Usage\ Group\ i)} = \sum (kW\ for\ baseline\ lighting\ fixtures)_{Usage\ Group\ i}$

- $Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)} = [Post\ Retrofit\ Total\ kW_{(Usage\ Group\ i)}] \times [Post\ Retrofit\ Annualized\ Hours\ of\ Operation_{\ (Usage\ Group\ i)}]$

  Where: $Post\ Retrofit\ kW_{(Usage\ Group\ i)} = \sum (kW\ for\ Post\ Retrofit\ lighting\ fixtures)_{Usage\ Group\ i}$

  - For each lighting load (fixture or circuit) measured using a temporary power meter, the baseline and/or reporting period calculations using power (kW) interval data can be performed using the following equations:
    - $Energy\ Consumption\ (kWh) = \sum_{Start\ of\ Period}^{End\ of\ Period} \frac{kW}{No.\ of\ Intervals\ per\ hour}$
    - $Average\ Operating\ Power\ (kW) = Average\ (All\ intervals\ where\ kW > Minimum\ Operating\ Load)$

      Where: the minimum operating load in kW is determined using visual inspection of the time series and load duration curves.
    - $Operating\ Hours = \frac{Energy\ Consumption}{Average\ Operating\ Power}$
    - $Metering\ Hours = \sum_{Start\ of\ Period}^{End\ of\ Period} \frac{No.\ of\ metering\ intervals}{No.\ of\ Intervals\ per\ hour}$
    - $Percent\ Operating\ Time = \frac{Operating\ Hours}{Metering\ Hours}$
    - $Annualized\ Operating\ Hours = Percent\ Operating\ Time \times Annualized\ Operating\ Hours$

- $Annual\ Energy\ Savings_{(Usage\ Group\ i)} = [Baseline\ Energy\ Consumption_{(Usage\ Group\ i)}] \times [Post\ Retrofit\ Energy\ Consumption_{(Usage\ Group\ i)}]$

Sampling for usage groups:

Sampling is to be distributed across the facility and measured data should be obtained for a sample of loads (sample size determination is typically 10% precision at 90% confidence for similar population) for each type of lighting fixtures. The following statistical equations will be used for estimating sample populations:

$$n = \frac{Z^2 C_v^{\ 2}}{p^2} \quad ; \quad n^* = \frac{Nn}{N+n}; \quad ; \quad C_v = \frac{\sigma}{x}$$

Where:

- Confidence = 90% (or alternately chosen level, such as 80%)
- Standard normal distribution value (@90% confidence) = 1.64
- Z = Z statistic for desired confidence interval
- P = desired precision (normally 10%)
- C_v = coefficient of variation (typically set to 0.5)
- N = population of usage group or fixtures
- n = sample size assuming infinite population size
- n^* = sample size corrected for population size

The sample size n and n^* need to be rounded up to the nearest integer value.

- σ = standard deviation
- x = average measured value

Metering Sample Sizes for Lighting Usage Groups

Population of Lines in Usage Group (N)	Sample Size (n)
1 < n < 4	~ 3
5 < n < 8	~ 5
9 < n < 12	~ 6
13 < n < 20	~ 7
21 < n < 70	~ 8
71 < n < 300	~ 10
> 300	> 11