International Performance Measurement and Verification Protocol (IPMVP®)

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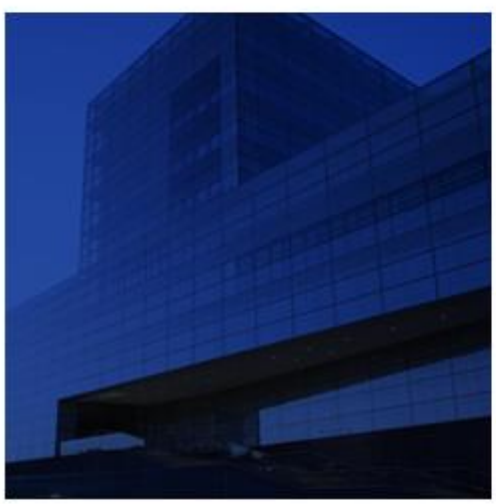
Core Concepts

MARCH 2022

EVO 10000 – 1:2022



INTERNATIONAL PERFORMANCE MEASUREMENT AND VERIFICATION PROTOCOL (IPMVP®)

CORE CONCEPTS

MARCH 2022

EVO 10000 – 1:2022

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FOREWORD

From the outset of the first publication of the ***International Performance Measurement and Verification Protocol (IPMVP®)***, the objective of its originators was to develop a consensus approach to measuring and verifying efficiency investments to facilitate a scaled-up global engagement into energy efficiency.

The purpose of the IPMVP is to reduce barriers to the energy and water efficiency industries. Adopted broadly by energy services companies initially, the IPMVP is now used by utilities and government agencies for their demand-side management incentive programs and by building, manufacturing, and industrial managers to assess and improve their facilities' performances. Increasingly, financial institutions understand the advantages of using the IPMVP as a risk reduction framework for their investments.

In the context of the global energy transition to a low carbon economy, the IPMVP also offers a consistent approach to measuring and verifying carbon emissions reduction in a broad range of energy sectors, including different types of facilities, industrial applications as well as renewable energy.

As primarily a non-prescriptive framework, the IPMVP provides an overview of M&V's current best practices while remaining flexible. It is also a living document whose methodologies and procedures enable the protocol to evolve and reflect current and new market needs.

The IPMVP is owned and maintained by Efficiency Valuation Organization (EVO®) is a non-profit organization whose products and services help people engineer and invest in energy efficiency projects. EVO's vision is to create a world that has confidence in energy efficiency as a reliable and sustainable energy resource. EVO's mission is to ensure that the savings and impact of energy efficiency and sustainability projects are accurately measured and verified.

EVO is the only organization globally with the exclusive focus on measurement and verification (M&V). EVO's activities span over three important fields: M&V protocol development, M&V training and education programs, and certification of industry professionals. To accomplish its mission, and vision, EVO relies on the vast knowledge and expertise of an international team of over one hundred M&V practitioners and instructors.

M&V Protocols

The IPMVP is the leading international protocol for M&V. It is maintained and updated by EVO's IPMVP Committee — a group of industry professionals who volunteer their time, and for whom we are indebted for keeping the protocol current and for undertaking regular reviews and updates.

In addition to the *IPMVP Core Concepts*, EVO also develops and publishes various IPMVP application guides on different topics such as non-routine events and adjustments, uncertainty assessments and statistics for M&V, M&V for energy performance contracting, water applications, evaluation measurement and verification, etc. EVO also publishes the International Energy Efficiency Financing Protocol (IEEFP).

M&V Training

EVO has many current training materials ranging from a one-hour introduction to M&V webinar to fully developed extensive courses. EVO's flagship training program is the *M&V Fundamentals and IPMVP* course deployed for over a decade. To date, around 15,000 individuals attended the training program worldwide. This training is delivered in multiple languages thanks to a network of local and national training partners in all continents. EVO recently added to its training portfolio the *M&V Planning in*

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Practice course. Successfully piloted in 2021, this course is also available through EVO training partners. These two training programs are foundational to the PMVA and PMVE certifications described below.

In addition to these certification courses, EVO also offers some advanced and thematic training covering a variety of M&V related topics such as ISO 50006, ISO 50015, ISO 50047, Advanced Option D for M&V Practitioners, Advanced Statistics, M&V and Metering, Interactive Effects, Energy Efficiency Financing, and many others. The development of these resources is assured by EVO's Training Committee and various ad-hoc and thematic sub-committees populated by EVO's approved M&V instructors.

M&V Certification

In 2019, EVO conducted a global survey to seek industry input to guide EVO's future M&V product development activities. One strong message coming out of this survey was for EVO to continually enhance the knowledge, skills, and abilities of M&V professionals. This message was in line with the views of our international team of M&V instructors that the *M&V Fundamentals and IPMVP* training program in place until then was not sufficient and that an advanced course and certification on M&V Planning was necessary.

To reflect on the survey's outcome, EVO created in 2022 two new certification programs for M&V professionals.

PMVA™ PERFORMANCE MEASUREMENT AND VERIFICATION ANALYST

The ***Performance Measurement and Verification Analyst (PMVA)*** certification establishes the IPMVP standard for individuals applying performance, measurement, and verification concepts to energy efficiency projects. This is the official IPMVP training and certification program for M&V fundamentals. PMVAs typically work in an analyst role for ESCOs, public administration, utilities, and financial institutions and are involved in designing and implementing energy efficiency programs and financing energy efficiency projects. They have demonstrated M&V capabilities, including a good understanding of applying the IPMVP to determine savings. PMVAs could be building technologists, HVAC specialists, engineers, architects, economists, financial analysts, etc.

PMVE™ PERFORMANCE MEASUREMENT AND VERIFICATION EXPERT

The ***Performance Measurement and Verification Expert (PMVE)*** professional certification establishes the IPMVP standard for individuals engaged in preparing or analyzing measurement and verification plans. PMVEs typically work as M&V specialists and design, elaborate, and implement M&V plans for comprehensive and complex energy efficiency projects. PMVEs also work as consultants and project facilitators for facility managers and building owners. PMVEs work as senior M&V analysts for public administration, utilities, and financial institutions. PMVEs typically have advanced applied expertise in various aspects of M&V and are capable of preparing/challenging M&V plans and reports. Most PMVEs will hold a technical degree and have a solid understanding of various energy efficiency measures.

EVO's PMVA and PMVE certifications are earned exclusively by demonstrated field M&V work achieved through M&V relevant education, professional expertise, and experiences.

For further details and updates on EVO's protocol, training, and certification activities and programs, visit EVO's website at: www.evo-world.org

ACKNOWLEDGEMENTS

This edition of the *International Performance Measurement and Verification Protocol* (IPMVP®) marks the 25th anniversary of the most recognized energy and water savings measurement and verification (M&V) protocols and relevant guidelines. The IPMVP is owned and maintained currently by the Efficiency Valuation Organization (EVO®).

This update of the IPMVP represents the outcome from a five-year statutory review process which gathered input from the IPMVP's Technical and Training Committees, EVO's approved instructors, and many other stakeholders worldwide. Hundreds of individual comments were received, analyzed, and discussed with the perspective of either inclusion into the *IPMVP Core Concepts* or in one of many IPMVP existing or upcoming application guides.

IPMVP Committee Members

The review work was coordinated under the auspices of EVO's IPMVP Committee under the direction of Tracy Phillips, Chair, Margaret Selig, Vice-Chair, and Lia Webster, a long-standing member of the committee. She served as the lead editor and coordinated the work of ad-hoc groups and sub-committees throughout the revision process. IPMVP Committee members who participated in this project include Todd Amundson, Jim Bradford, Gregory Bonser, Phil Combs, Luis Castanheira, Shankar Earni, David Jump, David Korn, Ken Lau, Eric Mazzi, Scott Noyes, Jesse Smith, Kevin Warren, and Jim Zarske.

Other Contributors

Thanks to the following individuals for their technical review and input at various stages of the review process: Zahra Abbasi, Chris Balbach, Paul Calberg Ellen, Donald Chu, Sandeep Dahiya, Alberto Escofet, Jon Feldman, Ignace de Francqueville, Daniele Forni, Dakers Gowans, Dolf Van Hattem, Nick Keegan, Eunjung Kim, Bill Koran, Steve Kromer, Daniel Magnet, Leo Mba, Rajvant Nijjhar, Cory Read, Bruce Rowse, Christo A van der Merwe, Vilnis Vesma, Hilary Woods.

Thank you to the Board of Directors of EVO for approving the resources necessary for this update: Mark Lister (Chair), Donal Gilligan (Vice-Chair), Thomas K. Dreessen (Treasurer), Laura Van Wie McGrory (Secretary), Pierre Langlois (Past-Chair), Phil Coleman (Member); and to EVO staff for managing the process over many years: Desislava Borisova, Monica Pérez Ortiz, and Denis Tanguay.

CHANGES IN THIS EDITION

This document supersedes previous versions of the IPMVP, including: *2016 IPMVP Core Concepts (EVO 10000 – 1:2016), IPMVP Measurement & Verification Issues and Examples (EVO 10300 – 1:2019)*, and *IPMVP Generally Accepted M&V Principles 2018.*

As a living document, every new version of the IPMVP incorporates changes and improvements reflecting new research, improved methodologies, and improved M&V data. The main changes in this edition are summarized below.

- Updated the name of Option A to Retrofit Isolation, Key Parameter Measurement(s) to be inclusive of multiple key parameters. Clarified Option B: Retrofit Isolation, All Parameter Measurement requires continuous measurement. Added discussions on sources of uncertainty in savings for each IPMVP Option.
- Added content to Section 13 – M&V Plan & Reporting Requirements on operational verification, additional requirements for Option A and Option C, and related to the accuracy of savings.
- Incorporated content from *Issues and Examples 2016* in Section 5 – M&V Process, Section 11 – Cost Savings, and Section 12 – Common M&V Issues.
- Consolidated content and added clarifications (e.g., measurement boundary, option selection, adherence with IPMVP, management of risk).
- Added and updated Figures, Tables, and Equations. Removed or updated Option-specific savings equations, added Simplified Equation for Normalized Energy Savings, updated simplified equations to 'routinely adjusted' where appropriate for consistency, and included names and numbers for equations.
- Included additional items in Terms & Definitions, primarily from IPMVP 2012. Updated definitions and checked for consistency across IPMVP Application Guides and other M&V related resources, including clarifying that impactful static factors may be outside the measurement boundary.
- Added or updated content including: Section 12.2 – Advanced M&V Methods, 12.3 – Demand Savings, Section 12.6 – Statistics for M&V, 12.7 – On-Site Energy Generation and Storage, 12.8 – Energy Services Performance Contracts (ESPCs), 12.9 – Utility & Governmental Programs, 12.10 – Water.

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1. SCOPE

The guidance provided throughout this document is focused on "energy savings" and can also be applied to demand, water consumption, related cost savings, emission reductions, or any other quantities being measured and verified. M&V is fundamental to energy efficiency financing, energy performance contracting, energy performance management, GHG accounting efforts, and many government and utility programs.

IPMVP provides a framework that is used to:

1) verify a project has the potential to perform and save energy, and

2) quantify site-level energy and cost impacts from a targeted project.

Both components are essential to the measurement and verification (M&V) of savings.

Energy savings in a facility cannot be directly measured because savings represent the absence of consumption or demand. Instead, savings are based on measurements of each fuel type or energy source impacted within a given measurement boundary before and after implementing a project, making suitable adjustments for changes in conditions.

IPMVP presents common principles and terms widely accepted as fundamental to any good *M&V* process. It does not define the M&V activities for all applications. Each project must be individually designed to suit the needs of all stakeholders in the reporting of energy or water savings. This individual design is recorded in the project's M&V Plan, and savings are reported as defined therein. Using the IPMVP's principles, framework, terms, and process to determine and report verified energy savings, facilitates reliable and translatable results.

2. TERMS & DEFINITIONS

For this document, the following terms and definitions apply.

Note: To maintain clarity in the text, although explicit references to energy are made throughout the document (e.g., energy efficiency measures), the methods described to measure and verify energy savings apply equally to demand reductions, water efficiency measures, GHG's emissions reductions, renewable energy, energy storage projects, or other targeted projects and their savings.

Term	Definition
Adjusted Baseline Energy	The Baseline Period Energy, modified by Routine and Non-Routine Adjustments, to account for changes in conditions in the Reporting Period or defined normal conditions.
Avoided Energy Consumption	Reduction in *Energy Consumption*, demand, or related cost that occurred relative to what measured energy (or demand) would have been without the Energy Efficiency Measure, most commonly determined under reporting period conditions. In some cases, avoided energy consumption may be determined under baseline conditions.
Backcasting	Rarely used method of determining Avoided Energy Consumption where reporting period energy is adjusted to baseline period conditions.
Baseline	Referring to (adjective) the systems, time period, energy use, or conditions that provide a reference to which performance of an *Energy Efficiency Measure or measures* can be compared.
Baseline Adjustment	See *Non-Routine Adjustment.*
Baseline Period	A defined period of time chosen to represent the operation of the facility or system before the implementation of *Energy Efficiency Measure(s)*.
Baseline Period Energy (or Demand)	Energy Consumption (or demand) used within a defined measurement boundary occurring during the *Baseline Period* without adjustments.
Commissioning	A quality-focused process for enhancing the delivery of a project which includes verifying and documenting that the facility and its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the design intent.
Confidence Level	Confidence level refers to the probability that the quoted range contains the true value.
Demand	A measure of the rate at which work is done or energy is used when applied to a load.
Energy Efficiency Measure (EEM)	An action or a set of actions designed to improve efficiency, reduce energy or water consumption, or manage demand, and sometimes referred to as an Energy Conservation Measure (ECM). In this document, the term EEM may include water, GHGs, energy generation, storage, or other targeted projects.
Energy Consumption	Quantity of energy applied to a load in a specific period of time.

Term	Definition
Energy Influencing Factors	Operating conditions that can affect the energy use within a measurement boundary, including static factors and independent variables.
Energy Performance Contract	An agreement between two or more parties where payment is based on achieving specified results, such as improvement in energy performance, reductions in GHG emissions, or energy costs, or the payback of investment within a stated period.
Energy End-Use	Application of energy for a specific purpose which is not the production, transformation, or storage of energy. (Examples*:* Ventilation, lighting, heating, cooling, transportation, industrial processes, production lines.)
Estimated Value	Parameter used in savings calculations determined through methods other than conducting measurements during the M&V period. The methods used to estimate values may range from engineering estimates derived from manufacturer ratings of equipment performance to measurements made during a different M&V period. Values derived from equipment performance tests or other measurements that are not made in situ are considered to be estimates for purposes of adherence with IPMVP.
Greenhouse Gas (GHG) Emissions	Carbon-containing gases such as carbon dioxide and methane which are emitted through the burning of fossil fuels in the production and distribution of energy. The emissions from within a measurement boundary can be expressed as weight units of carbon dioxide equivalent and are sometimes referred to generically as carbon emissions.
Installation Period	A defined period of time during which the planned EEMs are installed.
Independent Variable	A parameter that is expected to change regularly and has a measurable impact on Energy Consumption and/or Demand of a system or a facility.
Interactive Effects	Any energy impacts created by an *Energy Efficiency Measure* that occur outside of the *Measurement Boundary* of the EEM and are not captured in the energy measurements.
Key Parameter(s)	Critical variable(s) identified to have a significant impact on the energy savings associated with installing an *Energy Efficiency Measure*.
Measurement and Verification (M&V)	Process of planning, measuring, collecting, and analyzing data to verify and report energy savings within a facility or facilities resulting from the implementation of EEMs. Savings commonly quantified include electricity consumption, electric demand, natural gas consumption, carbon emissions, water consumption, and may include utilities such as steam, energy generated, or other item to be verified as part of a sustainability or efficiency project.
M&V Plan	A project-specific document detailing the methods, procedures, analyses, and reporting that will be conducted in the M&V periods to verify and report savings. IPMVP requirements for M&V Plans are described in Section 13.
M&V Periods	Time period of interest for an M&V project, including the baseline, installation, and reporting periods.

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Term	Definition
Measurement Boundary	Notional boundaries drawn around equipment, systems, or facilities to segregate those which are relevant to savings determination from those which are not. All *Energy Consumption* and/or *Demand* of equipment or systems used or generated within the boundary must be measured or estimated.
Metering	The process of using meters to collect energy consumption, demand data or key parameter data over time using measurements.
Non-Routine Adjustment	Individually engineered calculations to account for the energy effects within the Measurement Boundary due to changes in the Static Factors.
Non-Routine Event	Unexpected changes in energy use within the measurement boundary resulting from changes in static factors, which are not accounted for in the energy savings calculations and are not related to the targeted energy project.
Normalized Savings	Reduction in energy use, demand or cost that occurred in the reporting period, relative to what would have occurred if the facility had been equipped and operated as it was in the baseline period but under a fixed set of normal conditions. These normal conditions may be a long-term average or those of any other chosen period of time (other than the baseline or reporting period, which result in avoided energy use instead of normalized savings.) Normalization involves using a statistically valid means of adjusting baseline and reporting period energy to a common set of meaningful conditions.
Operational Verification	Verification that the *Energy Efficiency Measures* (EEMs) are installed and operating as intended and have the potential to generate savings. Operational Verification may involve inspections, measurements, functional performance testing, and/or data trending with analysis.
Performance Indicator	A measurable factor related to operating conditions, which is used to assess the function of an EEM or system.
Reporting Period	A defined period of time chosen to verify and quantify savings after the implementation of an *Energy Efficiency Measure(s)*. M&V may be performed over one or more reporting periods during which individual savings reports are prepared. The reporting period may be the total period on which the M&V is performed after EEMs are installed (e.g., the duration of a performance-based contract) or just the duration of time covered by an individual saving report.
Reporting Period Energy	*Energy Consumption* and/or *Demand* used within a defined measurement boundary occurring during the *Reporting Period* without adjustments.

Term	Definition
Routine Adjustment	An adjustment to the baseline or reporting period data using mathematical and statistical methods to account for expected changes in energy consumption or demand due to changes in the *Independent Variables* affecting energy consumption within the *Measurement Boundary*.
Savings	Value, in quantifiable units, of energy consumption, demand, water, greenhouse gas emissions, or related cost reductions, determined by comparing measured values before and after implementation of an *Energy Efficiency Measure(s)*, making suitable *Routine and Non-Routine Adjustments* to account for changes in conditions. Energy or other unit savings and any resulting cost savings may be reported in the form of *Avoided Energy Consumption or Normalized Savings.*
Static Factors	Those characteristics of a facility that affect *Energy Consumption* and/or *Demand* within the defined *Measurement Boundary*, that are not expected to change, and were therefore not included as *Independent Variables*. While not expected to change, these static factors should be recognized and monitored, and if they change, *Non-routine Adjustments* may need to be calculated to account for these changes. **Note:** These characteristics may include fixed, environmental, operational and maintenance characteristics.
Uncertainty in Savings	The range of savings values in which the true savings value is estimated to lie, often given a statistical confidence level. A single value does not adequately represent savings. Uncertainty in savings is reported either as a range of values (absolute uncertainty) or as a percent of the estimated savings (relative uncertainty).

3. DEFINITION AND PURPOSES OF M&V

"Measurement and Verification" (M&V) is the process of planning, measuring, collecting, and analyzing data to verify and report energy savings within a facility or facilities resulting from the implementation of EEMs. Savings commonly quantified include electricity consumption, electric demand, natural gas consumption, carbon emissions, water consumption, and may include utilities such as steam, energy generated, or other items to be verified as part of a sustainability or efficiency project process of using measurements to reliably determine savings. created within an individual facility through the application of *Energy Efficiency Measures* (EEMs). Savings cannot be directly measured since they represent the absence of energy consumption and/or demand. Instead, savings are determined by comparing measured consumption and/or 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:

- Evaluating energy flows and sources of savings.
- Meter installation, calibration, and maintenance.
- Data gathering, storage, and quality control.
- Development of a computation method and acceptable estimates.
- Computations with measured data.
- Planning and verifying completion of operational verification.
- Reporting, quality assurance, and third-party verification of reports.

M&V is not just a collection of tasks conducted to help a project meet IPMVP requirements. As shown in Figure 1, M&V activities often overlap with other project efforts related to the development and implementation of EEMs (e.g., collecting data to identify EEMs and establish energy baselines, commissioning, and operational verification of installed EEMs, installing monitoring systems to gather data, etc.). The M&V design and reporting process parallel the EEM design and implementation process, and their activities can often be integrated.

Good practice involves the integration of the M&V efforts into the process of identifying, developing, procuring, installing, and operating energy efficiency measures (EEMs) whenever possible. Identifying 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. Properly integrated, each M&V task serves to enhance and improve EEM operations and persistence of savings.

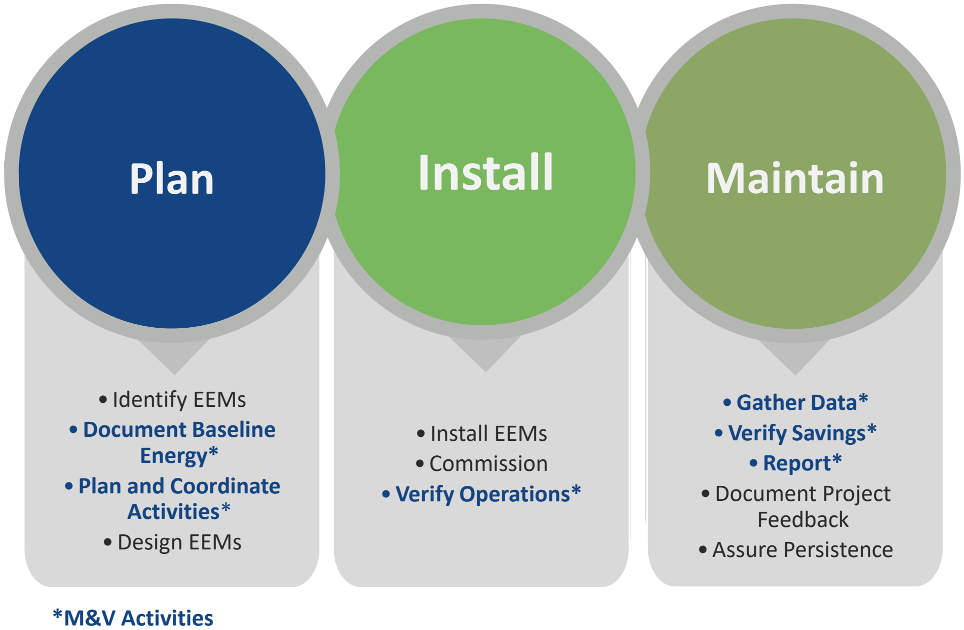

Figure 1: Example Project Timeline (M&V Activities in Bold)*

M&V is a fundamental part of many energy-focused efforts such as those involving:

- Energy performance contractors and their customers.
- Utility demand-side management program designers, managers, and evaluators.
- Energy users implementing EEMs and wanting to quantify savings.
- Facility managers properly accounting for energy budget variances.
- Existing building managers seeking recognition for the environmental quality of their building operations.
- New building designers wishing to account for the sustainability of their designs.
- Water efficiency project developers.
- Emission reduction trading program designers.
- Energy users seeking ISO 50001 certification.

Financial backers, project managers, and implementors of the above applications will find a use of this document to establish a shared framework and ensure key elements are addressed.

3.1. Purposes of M&V

M&V techniques can be used by facility owners or energy efficiency project stakeholders for multiple purposes, including risk management.

Table 1 – Purposes of M&V

M&V PURPOSES	APPLICATIONS
Manage Project-Related Risks	An M&V Plan is a risk mitigation tool used when implementing energy efficiency projects. A carefully crafted M&V Plan can manage project risks for the parties involved while ensuring performance goals are met. Balancing risks requires stakeholders to fully understand the potential impacts from variations in financial, operational, and performance-related parameters.
Provide Feedback on EEM Efficacy	Accurate determination of realized energy savings provides facility owners and managers valuable feedback on their energy efficiency measures (EEMs). This feedback helps them adjust EEM design or operations to improve savings and achieve greater persistence of savings over time.
Document Financial Transactions	For some projects, the energy efficiency savings form the basis for savings-based financial payments and/or a guarantee in a performance contract. A well-defined and implemented M&V Plan serves as the basis for documenting performance in a transparent manner. The M&V Plan and Reports should be subject to independent verification.
Enable Financing for Efficiency Projects	A good M&V Plan increases the transparency and credibility of reports regarding the outcome of efficiency investments. It also increases the credibility of projections for the outcome of these 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 that facilities can be run 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 to set proper budgets and account for budget variances.
Validate Emission Reduction Outcomes	Verifiable quantification of carbon emission reductions provides additional value to efficiency projects and greater benefit recognition for sustainability efforts.
Support Evaluation of Efficiency Programs	Utility- or government-sponsored programs for managing the use of an energy supply system can use M&V techniques to estimate the savings at specific energy user facilities. Using statistical techniques and other assumptions, the savings determined by M&V activities at selected individual facilities can be used at unmeasured sites to evaluate the performance of the entire program.

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4. PRINCIPLES OF M&V

The fundamental principles of good M&V practice described below provide the basis for assessing adherence to IPMVP. These principles should be considered and applied throughout the M&V process.

ACCURATE

M&V Reports should be as accurate as can be justified based on the project value and goals. M&V costs should normally be "small" relative to the monetary value of the savings being evaluated. M&V expenditures should also be consistent with the financial implications of over- or under-reporting of a project's performance. The M&V methodology's accuracy and cost should be evaluated as part of the project development. Accuracy trade-offs should be accompanied by increased conservativeness with increased use of estimated values and assumptions based on sound engineering judgment. Consideration of all reasonable factors that affect accuracy is a guiding principle of IPMVP.

COMPLETE

The reporting of energy savings should consider all effects of a project. M&V activities should use measurements to quantify energy use within the measurement boundary, document energy influencing factors, and detail any estimated values. By identifying key areas where judgment is required, IPMVP helps to avoid inconsistencies arising from a lack of consideration of important aspects.

CONSERVATIVE

Where judgments are made about uncertain quantities, M&V procedures should be designed to reasonably estimate savings such that they are not over- or under-stated. An assessment of a project's impact should be made to assure its energy-saving benefits are reasonable and conservative with due consideration to the level of statistical confidence in the estimation.

CONSISTENT

The reporting of a project's energy performance should be consistent and comparable across:

- Different types of energy efficiency projects
- Different energy management professionals for any project
- Different periods of time for the same project
- Energy efficiency projects and new energy supply projects

Consistent does not mean identical since it is recognized that any empirically derived report involves assumptions based on sound engineering judgment, which may not be made identically by all reporters.

RELEVANT

The determination of savings should be based on current measurements and information pertaining to the facility where the project occurs. This determination of the savings effort must measure the energy influencing factors and verify performance indicators that are of concern related to the EEM.

TRANSPARENT

All M&V activities should be clearly documented and fully disclosed. Full disclosure should include presentation of all of the elements of an M&V Plan and savings reports, and confirmation that the M&V Plan is agreed upon and understood by all stakeholders. Data and information collected, data preparation techniques, algorithms, spreadsheets, software, assumptions used, and analysis should follow industry standard best practices as closely as possible, be well formatted and documented – such that any involved party or independent reviewer can understand how the data and analysis conformed to the M&V Plan and savings reporting procedures. Transparency also means that any possible conflicts of interest are disclosed to all stakeholders in the project.

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5. M&V PROCESS

The M&V process usually involves the following 11 steps, although it may not always follow this step-by-step sequence and timeline.

Table 2: Overview of M&V Design and Reporting Process

Step 1: Determine Goals for M&V Efforts ***Step 2: Select IPMVP Option(s) and Approaches*** ***Step 3: Document Baseline Data*** ***Step 4: Develop M&V Plan*** ***Step 5: Set-up Metering and Ongoing Data Collection Processes***	***Baseline Period***
Step 6: Monitor for Changes in Site Conditions ***Step 7: Confirm Operational Verification***	***Installation Period***
Step 8: Ongoing Data Collection ***Step 9: Determine Savings for Period*** ***Step 10: M&V Report for Period*** ***Step 11: Track Energy Performance and Savings***	***Reporting Period***

Step 1 – Determine Goals for M&V Efforts

Consider the needs of the stakeholders using the planned M&V Report(s). Evaluate project risks and identify the goals of the M&V effort. If the stakeholders are focused on overall cost control, Whole Facility methods may be best suited. If the focus is on the performance of particular EEMs, Retrofit Isolation techniques may be best suited.

Step 2 – Select IPMVP Option(s) and Approaches

While developing the EEM(s), select the IPMVP Option(s) and define the measurement boundary that best suits the EEM(s) or overall project, the needs for accuracy and granularity in verified savings, the level of savings expected, and the budget for M&V. A combination of M&V Options may be best suited to some projects.

Decide whether adjustments of all energy quantities will be made to reporting period conditions or to some other meaningful set of conditions. Agree on the duration of the baseline period and the reporting period(s). These fundamental decisions will be written into the M&V Plan for the project.

Step 3 – Document Baseline Data

Assess the planned EEMs and the energy influencing factors. Collect relevant energy and operating data from the baseline period and record them in a way that can be accessed in the future and includes relevant details, as outlined in Section 13 – M&V Plan & Reporting Requirements.

Step 4 – Develop M&V Plan

Prepare an M&V Plan detailing the results of Steps 1 through 3 and meets the content specified in Section 9 – M&V Plan and Reporting Requirements. It should define the subsequent Steps 5 through 11.

Assess baseline energy, independent variables, and metering. Consider rigor in savings required. Establish any models that will be used to make planned adjustments to the baseline energy. Define energy calculations, provide a rationale(s) for the approaches used, define the expected level of effort or budget.

The final M&V Plan must be understood and approved by all stakeholders (e.g., owner/project sponsor and project developer/M&V agent) and may be adopted as terms and conditions for an energy performance contract or other agreement.

Step 5 – Set Up Metering and Ongoing Data-Collection Processes

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

Step 6 – Monitor for Changes in Site Conditions

During the EEM installation period, monitor for changes in conditions (i.e., static factors) at the site that could impact savings.

Step 7 – Confirm Operational Verification

After the EEM is installed, ensure it has the potential to perform and achieve savings by confirming appropriate operational verification is conducted as required by the project, which may include various methods from inspection and simple measurements to a full commissioning process depending on the complexity and savings of the EEM. Operational verification is conducted by the installing party and may be overseen by a third party such as a commissioning agent.

Step 8 – Ongoing Data Collection

Gather energy, operating data and details of other energy influencing factors from the reporting period, as defined in the M&V Plan.

Step 9 – Determine Savings for Period

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

Step 10 – M&V Report for Period

Report verified savings in accordance with the M&V Plan. Submit savings report to stakeholders after third-party review.

Step 11 – Track Energy Performance and Savings

Repeat Steps 8 through 11 throughout the M&V reporting period(s), as defined by the M&V Plan.

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5.1. Review by an Independent Verifier

Verification of savings can be performed by an independent party, by the owner, or the project developer. Where a project developer is hired by a facility owner to implement EEMs and report energy savings, the owner should consider an independent verifier to review the M&V Plan and 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 rigor in savings and mitigation of risks.

An independent verifier will help to ensure measurement validity and to prevent conflicts. If conflicts arise, this independent verifier can help to resolve the conflicts. Independent verifiers are typically engineering consultants with experience and knowledge in EEMs, M&V, and energy performance contracting.

When payments are contingent on proven performance, third-party verification should be required. This role should be stipulated in the contractual agreement. Additionally, consideration should be given in the contract to the circumstance where verification by the third party reveals unsatisfactory elements to the M&V Plan or Savings Reporting. The third-party review should be conducted by a reviewer that is wholly independent of the M&V Plan author (and their organization).

The inclusion of a third-party reviewer is part of conducting quality assurance activities. EVO recommends but does not require that a qualified professional be used to develop and oversee the implementation of M&V Plans and activities.

During an independent review, in addition to field verification of the installation, the reviewer should conduct activities needed to observe that the EEM is based on sound scientific principles and that independent evidence exists to support any claims made regarding its efficacy.

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6. ADHERENCE WITH IPMVP

The IPMVP represents a framework of terminology and methods to properly determine savings in energy or water and related costs. The IPMVP guides users in developing M&V Plans and M&V Reports for specific projects. The IPMVP is written to allow flexibility in creating and implementing M&V procedures while adhering to the principles of accuracy, completeness, conservativeness, consistency, relevance, and transparency (see Section 4).

Adherence with IPMVP means savings are determined and reported according to IPMVP's procedures and other details. Specifically, the following elements are required:

- The project's energy savings estimates and the scope of the EEMs are evaluated to help select appropriate M&V Options and strategies, and to evaluate the level of effort and costs required for the M&V process.
- Develop an M&V Plan that ensures the project uses the IPMVP's Framework, Principles, and adequately applies the IPMVP Option(s).
- Develop a complete M&V Plan as described in Section 13, which:
  - Defines the IPMVP Option(s) used and follows the requirements for that/those Option(s) detailed in Section 9.
  - Follows the current version of the IPMVP and clearly states the date of publication or the version number of the IPMVP edition being followed (i.e., *IPMVP Core Concepts, EVO 10000 – 1:2022*).
  - Uses terminology consistent with the definitions in the version of IPMVP cited.
  - Includes all information presented in Section 13 – M&V Plan & Reporting Requirements.
  - Defines the contents of saving reports and the frequency and duration that savings will be reported.
  - Is consistent with the Principles of IPMVP discussed in Section 4.
- The M&V Plan is reviewed for adherence to IPMVP Options, procedures, and principles. The review may be performed by a qualified third party, as described in Section 5.1.
- The Final M&V Plan is reviewed and approved by all stakeholders. Project stakeholders must understand and agree upon the M&V Plan for a project.
- Identify the person(s) responsible for executing the site-specific M&V Plan and for making sure that the M&V Plan is followed during the Reporting Period(s).
- Implement the agreed-upon IPMVP adherent M&V Plan and assure its procedures are followed. This may include conducting a quality assurance review of all M&V activities, including inspections, measurements, calculations, and reports. For each project, quality assurance procedures are described in the M&V Plan.
- The Savings Reports are developed per the M&V Plan and include all content specified in Section 13.
- The Savings Reports are reviewed for adherence with the M&V Plan and IPMVP methods, procedures, and principles. The review may be performed by a qualified third party, as described in Section 5.1.

7. IPMVP FRAMEWORK

Energy, demand, water, greenhouse gas emissions, or other savings in a facility cannot be directly measured because savings represent the absence of energy/water consumption or demand. Instead, savings are determined by comparing measured energy consumption or demand before and after implementation of an energy efficiency measure (EEM), making suitable adjustments for changes in conditions. The comparison of before and after energy consumption or demand must be made on a consistent basis, using the following general M&V equation shown in Equation 1.

Equation 1: General Equation for Determining Savings

Savings =		(Baseline Period Energy
	–	Reporting Period Energy)
	±	Adjustments

The Adjustments term in this general equation is used to restate the energy use or demand of the baseline and reporting periods under a common set of conditions. Adjustments are made using either mathematical models or physics-based models (e.g., simulations) of energy consumption and/or demand. The Adjustments term distinguishes proper savings reports from a simple comparison of cost or consumption before and after implementation of an EEM. Simple comparisons without such adjustments report only changes and fail to report the true performance of a project.

IPMVP's framework requires certain activities to occur at key points in this process and describes other important activities that must be included as part of IPMVP adherent M&V practice. This section describes such key elements of IPMVP's framework.

A general time-series graph representing Energy Consumption or Demand before and after the installation of an EEM is shown in Figure 2. The Adjusted Baseline Energy represents the Baseline Period Energy +/- Adjustments (from Equation 1) in the Reporting Period. The difference between Adjusted Baseline Energy and Reporting Period Energy results in Savings (i.e., Avoided Energy Consumption or Demand).

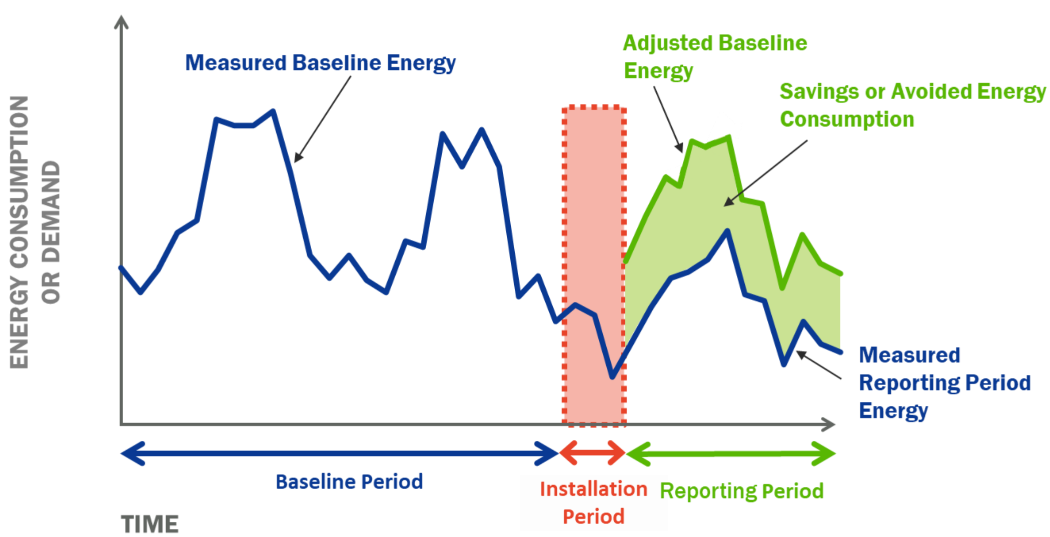

Figure 2: Savings or Avoided Energy Consumption or Demand

7.1. Measurement Boundary

Savings may be determined for an entire facility or a portion of a facility, depending upon the characteristics of the EEM(s) and the purpose of the reporting.

The measurement boundary is used to isolate the equipment and related energy use which are impacted by the EEM(s) from those unaffected by the EEM(s). All energy used or generated within the boundary must be measured or estimated using meters at the measurement boundary. Note that energy flows from all energy sources crossing the measurement boundary should be evaluated, and those impacted by the EEM must be measured. Note that in some cases, such as on-site solar generation, energy may flow in reverse.

The two basic types of measurement boundaries used are Whole Facility and Retrofit Isolation, as shown in Figure 3.

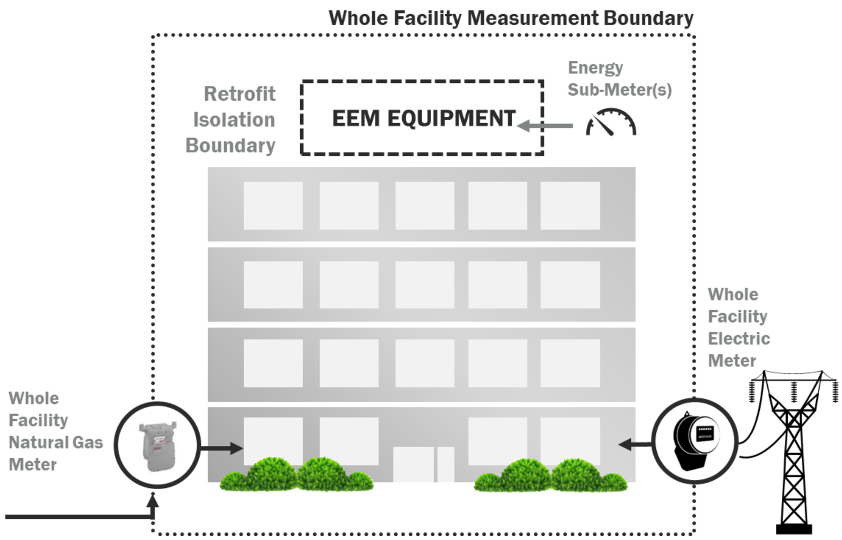

Figure 3: Whole Facility and Retrofit Isolation Measurement Boundaries

The type of measurement boundary selected generally aligns with one or more of the four IPMVP Options, shown in Figure 4 (detailed in Section 9), and impacts the granularity of the savings reported and the measurements required. The purpose(s) of the M&V reporting must be considered when selecting an Option.

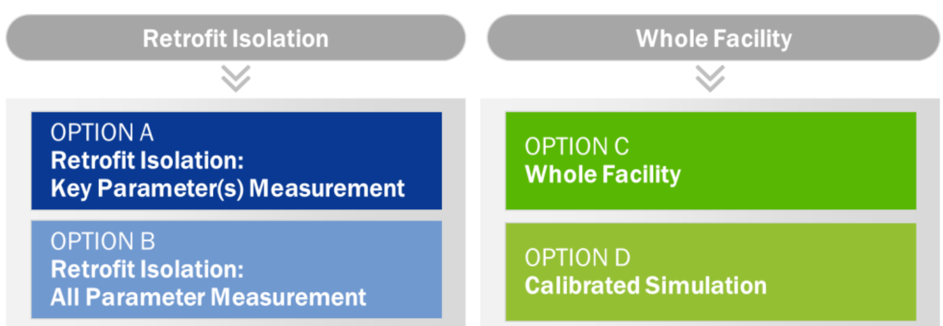

Figure 4: Overview of IPMVP Options

If the purpose of reporting is to verify the savings from equipment affected by the energy efficiency project, a measurement boundary should be drawn around that equipment, and measurement requirements for the equipment within the boundary can then be determined. Energy consumption and/or demand may be directly measured or determined by direct measurement of key variables that can be reliably used to calculate demand or energy consumption. The approach used is a **Retrofit Isolation Option** (Option A or B, discussed later in this Section and detailed in Sections Option A: Retrofit Isolation, Key Parameter(s) Measurement).

If the purpose of reporting is to verify and/or help manage total facility energy performance or verify the savings from multiple EEMs with interactive effects, the meters measuring the supply of energy to the whole facility can be used to assess performance and savings. The measurement boundary, in this case, encompasses the whole facility. The approach used is **Option C: Whole Facility** (defined later in this Section).

If the Baseline Period or Reporting Period data are unreliable or unavailable (e.g., new construction), energy data from a calibrated simulation model can be applied for either a portion or all of the facility. The measurement boundary can be drawn accordingly. The approach used is **Option D: Calibrated Simulation** (defined in Section 9.4).

Energy effects created by EEMs occurring beyond the selected measurement boundary are called interactive effects. The magnitude of any interactive effects needs to be estimated or evaluated to determine savings associated with the EEMs. Although not preferred, interactive effects may be ignored in some cases provided the M&V Plan includes discussions of each effect, its likely magnitude and that the magnitude is small compared to the savings from the primary effects. Option selection is detailed in Section 8.

7.2. Measurement Periods

7.2.1. Baseline Period

Care should be taken in selecting the baseline period over which the baseline period energy measurements are taken and energy influencing factors documented. The baseline period should:

- Represent all operating modes of the facility or the equipment during a normal operating cycle. The period should span a full operating cycle from maximum energy consumption and demand to a minimum.
- Include only time periods for which factors that impact energy use of the facility are known. These include independent variables and static factors (i.e., energy influencing factors).
    - The extension of baseline periods backward in time to include multiple cycles of operation requires equal knowledge of factors that impact energy use throughout the longer baseline period to properly derive routine and non-routine adjustments after EEM installation.
- Coincide with the period immediately before implementing the energy efficiency measures.
    - Periods further back in time may not necessarily reflect the conditions existing before the retrofit and, therefore, may not provide a proper baseline for measuring the effect of just the EEM.
- Support EEM planning.
    - EEM planning may require the study of a longer or different time period than the one chosen for the baseline period.

Baseline Energy Data Considerations

- 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 if the full range of weather conditions is included.
- The energy consumption and demand of a compressed air system may only be governed by plant production levels, which vary on a weekly cycle. In this case, several weeks' data may be all that is needed to define baseline performance across a full range of operating conditions.
- The collection and documentation of static factors such as scheduled hours of operation can be critical to applying adjustments in the M&V reporting period.

7.2.2. Installation Period

The length of the installation period depends upon the project and EEMs. Measurements and site inspections during this period may be used to monitor for changes in static factors that could impact savings from the EEMs and necessitate the need for non-routine adjustments.

Depending on the M&V Option(s) and measurement boundary selected, reporting period measurements on individual EEMs may begin after operational verification is complete. In some instances, specific contractual provisions may be needed to accommodate staggered completion of EEMs over time. Installation periods vary by project and, in some cases, may include all or part of the reporting period (e.g., continuous improvement programs).

7.2.3. Reporting Period

The developer of the M&V Plan should recommend the length of the overall reporting period for the project over which measurements will be taken, and the period each saving report will cover. Energy data collected during this period will be compared to the baseline period energy to develop verified savings (as described in the following sections).

The reporting period should encompass at least one complete normal operating cycle of the equipment or facility to fully characterize the savings effectiveness in normal operating modes. The reporting period should encompass long-term performance monitoring for some projects, while other projects may cease reporting verified savings after a shorter measurement period (ranging from spot readings to measurements taken over one or several months). The length of any reporting period should be determined with due consideration of the life of the EEM(s), the likelihood of degradation of originally achieved savings over time, costs or resources required to perform M&V activities, and the purposes of ongoing savings reporting. The frequency and level of detail reported may change over time, if needed.

If the frequency of performance measurements after initial proof of savings are reduced, other on-site monitoring activities can be intensified to ensure savings remain in place and operational verification activities are repeated. The M&V Plan should specify when this represents a change in IPMVP Options. Regardless of the length of the reporting period, metering may be left in place to provide feedback of operating data for routine ongoing management purposes and to detect subsequent adverse changes in performance.

Measurements or verified savings from a past reporting period may not be used as a basis for assuming future savings. (See *Section 6* of this document for more information on adherence.)

7.2.4. Adjacent Measurement Periods (“On/Off” Test)

When an EEM can be turned on and off easily, baseline period and reporting periods may be selected that are adjacent to each other in time. A change in the control logic for a system is an example of an EEM that can often be readily removed and reinstated without adversely affecting the facility's operation. Such on/off tests involve energy measurements with the EEM in effect and then immediately thereafter with the EEM turned off so that pre-EEM (baseline) conditions return. This procedure is often used when there is not enough time prior to the implementation of the EEM to collect sufficient data.

After the EEMs are installed and verified, the baseline period energy can be established when the EEM is “Off” by measuring the energy consumption within the measurement boundary and the related variables over a full range of operating conditions. Similarly, the reporting period is when the EEM is “On” and should be long enough to cover the range of normal facility operations, but measurements may be ongoing.

This technique can be applied under retrofit-isolation and whole-facility options. However, measurement boundaries must be located so that it is possible to readily detect a statistically significant difference in measured energy consumption or demand when EEMs are turned on and off. To cover the normal range of operating conditions, the on/off test may need to be repeated under different operating modes such as various seasons or production rates (e.g., on for one week, off for one week over a period of a year). Routine adjustments should be used to ensure the operating conditions and measurement durations during the assessed periods are equivalent, and non-routine adjustments can also be required.

EEMs that can be turned off for such testing may be at risk of being accidentally or purposely turned off when intended to be on. Efforts should be made to ensure the persistence of such EEMs, such as periodically repeating operational verification activities.

7.3. Baseline Period Conditions

Baseline period conditions include details of the facility and systems before the implementation of Energy Efficiency Measure(s). These conditions must be well documented because they are a critical element of the M&V process and become unavailable once an EEM is implemented.

Data related to the systems and equipment impacted by the EEM(s), as well as the independent variables and static factors, need to be documented corresponding to the time period for which baseline energy consumption data are collected. The extent of the information required is determined by the planned EEM, selected M&V Option, measurement boundary chosen, and the energy influencing factors.

This information may include variables such as production data, ambient temperature, equipment or system operating pressures, or other variables collected through spot measurements, short-term or long-term metering, or site inspections.

Similarly, the prevailing facility conditions during the baseline period need to be documented. These conditions (i.e., static factors) are normally assumed to remain constant over the baseline, installation, and reporting periods. If static factors change and substantially impact the savings, the impact will have to be addressed using non-routine adjustments. Examples of static factors are multiple and may include:

- Facility size installed equipment and systems.
- Occupancy details of type, occupancy density, equipment loads, and equipment run times.
- Operating conditions (e.g., equipment control sequences and set points, lighting levels, ventilation levels) for each operational mode and season.

It is important to identify past and planned changes to conditions (i.e., static factors) that may affect the baseline or reporting period energy. Changes may include any number of items such as an increase in occupancy levels, adding a shift, changing the size of the facility served, adding equipment, or increasing lighting levels. This information can impact the selected measurement boundary and help plan for non-routine adjustments (described in Section 7.4.2).

In some cases, existing systems or facilities may not function properly, meet code, or otherwise may not be reflective of the appropriate baseline conditions. In these cases, the baseline energy may be adjusted using non-routine adjustments so that it reflects the operation while meeting code or operation after needed repairs, as described in Section 12.1 – Non-Routine Events and Adjustments.

7.4. Methods of Adjustment

The adjustment terms in the IPMVP savings equations should be computed from identifiable physical facts about the characteristics that impact equipment energy use within the measurement boundary. Two types of adjustments are possible: Routine Adjustments and Non-Routine Adjustments.

7.4.1. Routine Adjustments

Any energy influencing factors expected to change routinely during the reporting period which have a statistically significant impact on energy use in the baseline period and are expected to remain variable in the reporting period should be considered to define the routine adjustment methodology or model. Influencing factors such as weather or production volume should be evaluated for statistical significance to energy consumption or demand.

Adjustment techniques may be as complex as using several multiple parameter equations which correlate energy with one or more independent variables or as simple as applying an established energy value to an EEM known to be at constant load as indicated by a proxy variable (e.g., fan energy consumption during heating mode as indicated by recorded operating parameters). Valid mathematical techniques must be used to derive the adjustment method for each M&V Plan.

7.4.2. Non-Routine Adjustments

For those energy influencing factors that are not usually expected to change (e.g., the facility size, the design, and operation of installed equipment, the number of weekly production shifts, or the type or number of occupants), the associated static factors must be monitored for change throughout the reporting period.

When a change to one or more static factors which significantly impacts energy use within the measurement boundary is identified, this becomes a potential non-routine event. When analysis of the non-routine event indicates a significant impact on the magnitude of energy savings, this then warrants making a non-routine adjustment

Note: See *Section 12.1 – Non-Routine Adjustments*.

Non-routine adjustments can potentially have a significant impact on reported savings; the rationale and calculation for non-routine adjustments should be agreed upon between the parties and documented.

Therefore, savings can be expressed as shown in Equation 2 below, which is the primary IPMVP equation.

Equation 2: Primary IPMVP Savings Equation

Savings =		(Baseline Period Energy
	–	Reporting Period Energy)
	±	Routine Adjustments
	±	Non-Routine Adjustments

Note that baseline data consist of real facts about energy and independent variables as they existed during the baseline period.

The mechanism of the adjustments made in calculating savings depends upon whether savings are to be reported based on the conditions of the reporting period, reported on the basis of the conditions of the baseline period, or normalized to some other fixed set of conditions.

7.5. Savings Accounting Approaches

The operating conditions that affect energy consumption often differ between the baseline and reporting periods. It is important that reliable adjustments are made to account for these changes in operating conditions. The basis of adjustment specifies the operating conditions under which saving will be evaluated using routine and non-routine adjustments and is defined in the M&V plan.

The basis of adjustment selected determines how the measured energy consumption and demand will be adjusted. Depending on the basis of adjustment used, energy savings are categorized as either **Avoided Energy Consumption** or **Normalized Energy Savings**, as shown in Figure 5.

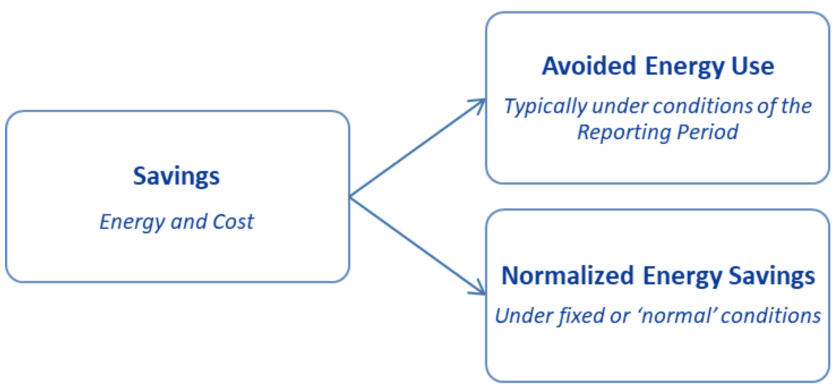

Figure 5: Types of Savings

7.5.1. Avoided Energy Consumption or Demand

Savings stated as avoided energy consumption or demand quantifies reductions relative to what measured energy or demand would have been without the EEM, most commonly under reporting period conditions.

Avoided energy consumption or demand:

- Requires routine adjustments to the baseline period energy to reflect reporting period conditions, OR less commonly, routine adjustments are made to the reporting period energy to reflect baseline period conditions.

- Depends upon the reporting period's operating conditions or baseline period's operating conditions. Even though energy can be properly adjusted using independent variables such as weather or production, verified savings reported depend upon the actual energy use and independent variable data collected during the period selected as the basis for adjustment.

The term forecasting is used to describe the adjustment of baseline period energy to reporting period conditions. This common style of estimating savings can be stated as shown in Equation 3.

Equation 3: Fundamental Equation for Avoided Energy Consumption using Forecasting

Avoided Energy Consumption =		(Baseline Period Energy
	±	Routine Adjustments to Reporting Period Conditions
	±	Non-Routine Adjustments to Reporting Period Conditions)
	−	Reporting Period Energy

The adjusted baseline energy is frequently found by first developing a mathematical model that correlates actual baseline period energy data with appropriate independent variables in the baseline period. Each reporting period's independent variables are then inserted into this baseline mathematical model to produce the adjusted baseline energy. This procedure is called forecasting.

This equation is often simplified to Equation 4.

Equation 4: Simplified Equation for Avoided Energy Consumption using Forecasting

Avoided Energy Consumption =		Routinely Adjusted Baseline Energy
	–	Reporting Period Energy
	±	Non-Routine Adjustments to Reporting Period Conditions

This process of calculating savings may be used in reverse, where the reporting period energy is adjusted to baseline period conditions and savings are determined under baseline conditions. The term backcasting is used to describe this adjustment of reporting period energy to baseline period conditions. Although rare, it can make sense to use this approach when more data are available in the reporting period than in the baseline period to develop mathematical models of energy consumption or demand (e.g., utility meter is upgraded to provide more frequent data). Since backcasting may introduce risk due to the unknown accuracy of modeling future energy consumption, it is best practice to use it as an optional method to forecasting. For this style of savings, savings can be reported as shown in Equation 5 and Equation 6.

Equation 5: Fundamental Equation for Avoided Energy Consumption using Backcasting

Avoided Energy Consumption =		Baseline Period Energy
	−	(Reporting Period Energy
	±	Routine Adjustments to Baseline Period Conditions
	±	Non-Routine Adjustments to Baseline Period Conditions)

This equation may be simplified to Equation 6.

Equation 6: Simplified Equation for Avoided Energy Consumption using Backcasting

Avoided Energy Consumption =		Baseline Period Energy
	−	Routinely Adjusted Reporting Period Energy
	±	Non-Routine Adjustments to Baseline Period Conditions

Another less common method of determining Avoided Energy Consumption may be considered when reporting period conditions are out of range of the baseline conditions and hinder making routine adjustments as planned. In these cases, the basis of adjustment may need to shift to some interim period conditions that include the full range of conditions (chaining)[1].

7.5.2. Normalized Energy Savings

Normalized energy savings use conditions other than those of the reporting or baseline periods as the basis for adjustment. The conditions may be those of an agreed-upon representative period or a typical, average or normal set of conditions as the basis of adjustment. Adjustments to a fixed set of conditions such as typical meteorological year (TMY) weather data provide a type of savings called normalized energy savings. In this method, the reporting period energy and the baseline period energy are adjusted from their actual conditions to the common fixed or normal set of meaningful conditions, as shown in Equation 7 and Equation 8.

Normalized energy savings:

- Require routine adjustments to the reporting period energy and the baseline period energy to a fixed set of conditions that are established once and are not changed.
- Can be directly compared with savings from other time periods and EEMs where savings are predicted under the same set of fixed conditions.
- Can only be reported after a full cycle of reporting period operating conditions so that the mathematical correlation between reporting period energy and operating conditions can be derived.

Equation 7: Fundamental Equation for Normalized Energy Savings

Normalized Energy Savings =		(Baseline Period Energy
	±	Routine Adjustments to Fixed Conditions
	±	Non-Routine Adjustments to Fixed Conditions)
	−	(Reporting Period Energy
	±	Routine Adjustments to Fixed Conditions
	±	Non-Routine Adjustments to Fixed Conditions)

[1] Chaining is further described in IPMVP's *Application Guide on Non-Routine Events and Adjustments*.

Equation 8: Simplified Equation for Normalized Energy Savings

Normalized Energy Savings =		(Routinely Adjusted Baseline Period Energy to Fixed Conditions
	±	Non-Routine Adjustments to Fixed Conditions)
	−	(Routinely Adjusted Reporting Period Energy to Fixed Conditions
	±	Non-Routine Adjustments to Fixed Conditions)

The calculation of the reporting period routine adjustment term usually involves the development of a mathematical model correlating reporting period energy with the independent variables of the reporting period. This model is then used to adjust reporting period energy to the chosen fixed conditions. Further, a mathematical model of baseline energy is also used to adjust baseline period energy to the chosen fixed conditions.

7.6. Operational Verification

Operational verification consists of a set of activities intended to ensure that the EEM is installed, commissioned, and performing its intended function. Confirmation that Energy Efficiency Measures are installed and operating as per the design intent and have the potential to perform and generate savings is required. This may involve inspections, measurements, functional performance testing, and/or data trending with analysis.

While operational verification activities may not be the responsibility of the M&V agent, the operational verification activities proposed and the party responsible should be documented in the M&V Plan and results reported. Developing the operational verification requirements provides an opportunity to review the engineering design to ensure that the savings estimates are realistic and achievable.

Operational verification serves as a low-cost initial step for assessing savings potential and should be conducted prior to other post-installation saving verification activities. Operational verification can be integrated with commissioning efforts. Both data collection and analysis tasks can be used to support the M&V quantitative efforts and determine the proper performance of the EEMs.

A range of operational verification methods is outlined in Table 3. As noted in the table, the selection of the best approach to operational verification depends on the EEM's characteristics and the magnitude of the savings at risk compared to the cost of verification.

Planning the operational verification activities can vet savings claims and ensure sufficient baseline data has been collected. The M&V Plan requires some details on operational verification, including:

- What data will be collected to confirm the EEM is properly installed and meets the EEM's Intent.
- Who is responsible for conducting these verification activities.

Additional details which can be helpful to specify are the data needed from operational verification, such as the dates of the implementation period, when operational verification was completed, and when energy impacts from EEMs should be present. It may also be appropriate to detail how testing and data collection will be coordinated with any third-party commissioning efforts.

Table 3: Operational Verification Approaches

Operational Verification Approach	Typical EEM Application	Activities
Visual Inspection	**EEM** will perform as anticipated when properly installed. Direct measurement of EEM performance is not possible.	View and verify the physical installation of the EEM (e.g., windows, insulation, passive devices).
Sample Spot Measurements	Achieved **EEM** performance can vary from published data based on installation details or component load.	Measure single or multiple key parameters for a representative sample of the EEM installations (e.g., electric demand of non-dimmable lighting fixtures, motor power with constant load).
Short-Term Performance Testing	**EEM** performance may vary depending on the actual load, controls, or interoperability of components.	Tests for functionality and proper control. Measure key parameters. May involve conducting functional tests designed to capture the component or system operating over its full range or performance data collection over a sufficient period of time to characterize the full range of operations (e.g., demand control ventilation, variable speed fan, control algorithms).
Data Trending and Control-Logic Review	**EEM** performance may vary depending on actual load and controls. Component or system is being monitored and controlled through a Building Automation System (BAS) or can be monitored through independent meters.	Set up trends and review data or control logic. The measurement period may last for a few days to a few months, depending on the period needed to capture the full range of performance (e.g., chiller, boiler, heat pump, evaporative cooler).

Over time, as the M&V effort continues into later years of the reporting period, the operational verification efforts can be repeated to assess the performance of the EEMs and to identify and correct any performance deficiencies, helping to ensure persistence of savings year after year. Specifying in the M&V Plan how often these activities will be repeated is recommended when continuous measurements are not used during the reporting period.

8. IPMVP OPTION SELECTION CONSIDERATIONS

IPMVP provides four Options for determining savings (A, B, C, and D). Each Option is appropriate in different circumstances and utilizes different methods. The selection of an IPMVP Option is a recommendation that is made by the developer of the M&V Plan and agreed upon by the stakeholders for each project, based on the full set of project conditions, analysis, budgets, and professional judgment. The key considerations in selecting IPMVP Option(s) are discussed in this section, and each of the four IPMVP Options are detailed in Section 9.

As highlighted in Section 7.1 and in Table 3 below, IPMVP's Options are generally delineated by the measurement boundary used – either a retrofit-isolation or a whole-facility approach. Determining the IPMVP Option(s) and measurement boundary (boundaries) that best suits the EEM(s) or project requires consideration of the physical properties of how the EEM(s) save energy, the level of savings expected, the measurements required, the need for accuracy and granularity in verified savings reported, the context of the project, and the budget for M&V.

Table 4: Key Elements of IPMVP Options

IPMVP Options	Type of Measurement Boundary	Measurements Required and Savings Reported
OPTION A: Key Parameter(s) Measurement **OPTION B:** All Parameter Measurement	**RETROFIT ISOLATION**	Measures the energy impacts at the equipment or system level
		Usually requires one or more dedicated meters
		Savings are determined for each EEM, and any impacts beyond the measurement boundary are estimated
OPTION C: Whole Facility **OPTION D:** Calibrated Simulation	**WHOLE FACILITY**	Measures ALL energy effects in a facility or portion of a facility
		Often uses energy data from the utility meter(s)
		Savings include impacts from all EEMs and any other changes in energy use

Each project's circumstances will largely dictate if a retrofit isolation approach or a whole facility approach should be used. Note that "whole" facility approaches can also be applied to only a portion of a facility (for example, a sub-metered portion of a building). Moreover, the requirements for performance verification and reporting may be adjusted during the reporting period and can involve changing to a different IPMVP Option.

8.1. Typical Project Characteristics for IPMVP Options

It is impossible to generalize on the best IPMVP Option for any situation. However, some key project characteristics can be helpful indicators of the best approach. When selecting a method, all types of energy sources impacted by the EEMs must be considered.

RETROFIT ISOLATION OPTIONS A AND B ARE BEST APPLIED WHEN:

- The physical properties of the EEM allow the impacted energy flows to be separately measured.
- Any interactive effects of the EEM on the energy consumption and demand of other facility equipment can be reasonably estimated or assumed to be insignificant.
- Only the performance of the systems affected by the EEM is of concern, or savings from each EEM need to be reported.
- Expected savings from the EEM(s) are too small to be detected using Option C or to justify the expense of using Option D.
- Sub-meters already exist to isolate energy consumption and demand of affected systems, or adding sub-meters would be feasible.
- The energy influencing factors (i.e., independent variables and static factors) which affect energy consumption and demand are not excessively difficult or expensive to monitor.
- There is no need to directly reconcile savings reports with changes and payments to energy suppliers.

WHOLE FACILITY OPTIONS C AND D ARE BEST APPLIED WHEN:

- There is a high level of interactive effects from the EEM or energy interactions between EEMs.
- The energy flows impacted by the EEM(s) cannot be separately measured.
- The level of savings expected is high enough to use Option C and reporting a facility's overall performance, rather than EEM performance, is preferred.
- There are many unique EEMs whose energy flows would be difficult to measure individually.
- Baseline period energy data are not available (Option D).

Some project characteristics and commonly favored Options are shown in Table 5.

Table 5: Typical Project Characteristics and Commonly Favored IPMVP Options

EEM PROJECT CHARACTERISTIC	Favored Options			
	A	B	C	D
NEED TO ASSESS EEMS INDIVIDUALLY	✖	✖		✖
NEED TO ASSESS ONLY TOTAL FACILITY PERFORMANCE			✖	✖
EXPECTED SAVINGS ARE LESS THAN 10% (MONTHLY ENERGY USE DATA) OR 5% (DAILY OR HOURLY ENERGY USE DATA) OF WHOLE FACILITY BASELINE ENERGY CONSUMPTION	✖	✖		✖
THE ENERGY INFLUENCING FACTORS FOR THE EEMS ARE NOT WELL KNOWN		✖	✖	✖
LONG TERM PERFORMANCE ASSESSMENT NEEDED	✖	✖	✖	
INTERACTIVE EFFECTS OF EEM ARE SIGNIFICANT OR UNMEASURABLE			✖	✖
RECENT OR FUTURE CHANGES ARE EXPECTED TO IMPACT ENERGY USE WITHIN THE MEASUREMENT BOUNDARY	✖			✖
BASELINE PERIOD ENERGY DATA ARE NOT AVAILABLE				✖

8.2. Granularity of Savings

Retrofit isolation allows the narrowing of the measurement boundary to reduce the effort required to monitor independent variables and static factors when EEMs affect only a portion of the facility. This allows reporting savings a the EEM level. However, boundaries smaller than the total facility usually require additional meters at the measurement boundary and introduce the possibility of significant unmeasured interactive effects.

Since in this case measurement is less than the total facility, the results of retrofit isolation approaches may not be fully apparent in utility bills if the savings are small compared to total facility energy use. Facility changes beyond the measurement boundary and unrelated to the EEM will not be reported by retrofit isolation approaches but will be included in the utility's metered consumption and/or demand. Otherwise, savings determined through whole facility approaches can be related to utility bills.

8.3. Level of Interactive Effects

Isolated metering is placed at the measurement boundary between equipment the EEM affects and equipment it does not affect. When drawing a measurement boundary, care should be taken to consider all energy flows affected by the EEM which are beyond the boundary. A method must be derived for estimating such interactive effects. However, if the measurement boundary can be expanded to encompass interactive effects, there is no need to estimate them.

Apart from small estimated interactive effects, the measurement boundary defines the metering points and the scope of any adjustments which are used in the IPMVP savings equations. Only changes affecting energy systems within the measurement boundary, related static factors, and operating variables must be monitored to prepare the adjustment term(s) of the main IPMVP equation (Equation 2).

Interactive Effects – Example

For an EEM, which reduces the power requirements of electric lights, the measurement boundary includes only 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 that may have to be estimated rather than included within the measurement boundary.

8.4. Energy Measurements Required

The energy quantities required in the IPMVP's savings equations can be measured by one or more of the following techniques:

- Utility or fuel supplier meter data and invoices or data directly from the utility meter including any adjustments to the readings that the utility makes.
- Special meters isolating the energy flows to an EEM or portion of a facility from the rest of the facility. These measurements may be periodic or continuous throughout the baseline and reporting periods and may use temporary or permanent meters.
- Separate measurements of the key parameters used in computing energy consumption and/or demand.

    - The sample rate of the measurements should be adequate given the rate of variation in the value of the parameters to be measured, and measurement intervals coordinated across measured parameters, including independent variables.
- Measurements of proxy variables after validating their relationship with energy consumption or demand. In some cases, a measured proxy variable may be substituted in place of direct measurement of energy consumption or demand where the relationship between the two has been proven in situ.
    - For example, if a consistent relationship has been proven via measurements between the output signal from a variable-frequency drive controller and the power draw of the controlled fan, then the output signal may be used as a valid proxy measurement for fan motor power.
- Energy simulation that is calibrated to actual energy consumption and demand data for the system or facility being modeled during either the baseline or reporting period.
- Where a key parameter needed to estimate savings is already known with adequate accuracy or when it is more costly to measure than justified by the increase in certainty of savings, then direct measurement may not be necessary or appropriate. In these cases, estimates may be made of some of the EEM's key parameters, but others must be measured (Option A).

Additional considerations related to measurements are included in Section 12.

8.5. Stability of Operations

Past or future changes in energy use patterns within the measurement boundary due to changes unrelated to the EEMs can influence the Option selected. The need for non-routine adjustments can sometimes be avoided by using a smaller measurement boundary, reducing the number of static factors which may impact the performance of the EEM.

8.6. M&V Cost Limitations

The cost of the M&V effort must be aligned with the value of the project, the level of energy variation within measurement boundary, and the expected savings. The related costs and accuracies of the Options are discussed in Section 10 – M&V Cost & Uncertainty in Savings. Generally, average M&V costs should be less than 10% of the cost savings being assessed.

Table 6: General Guidelines for Balancing Cost and Uncertainty in M&V

Energy Variation and Savings	Description	Choice of Options
Low Energy Variation, Low-Savings EEM.	EEMs with low savings cannot typically afford much M&V, based on the 10%-of-savings guideline, especially if there is little variation in the measured energy data.	**The use of Option A is favored**. A short reporting period may be considered, 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-Savings EEM.	Low-saving EEMs cannot generally afford much M&V, as noted 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 accuracy in savings reporting.	**Option B is preferred if feasible**. Keeping M&V costs low and appropriate relative to the level of savings expected can be a challenge, and sampling techniques may sometimes reduce Option B costs. Option C may not be suitable based on the general guidance that savings should generally exceed 5% to 10% of a facility's metered use to be quantifiable.
Low Energy Variation, High-Savings EEM.	With low variation in energy consumption and demand, the level of uncertainty is often low. However, since a high level of savings is expected, small improvements in accuracy may have monetary rewards large enough to merit more precise metering and data analysis.	**Options B and C are generally most suitable**. A high-savings EEM may be measurable with Option C but requires a means to monitor static factors to detect the need for non-routine adjustments. Using Option B, in some cases, may reduce the number of static factors to track without reducing accuracy. Additional costs may be justified to enable accurate reporting. For example, if the savings from an EEM are $1,000,000 annually, an annual M&V cost of $20,000 (2% of savings) may be reasonable.
High Energy Variation, High-Savings EEM.	High-saving EEMs allow for high level of rigor which may include extensive data collection and analysis. The baseline and reporting periods may have to span multiple normal cycles of facility operation to capture variations in savings.	**Consider using Options B, C, or D**. However, savings are likely to show in the utility records, so Option C techniques may be used with careful monitoring of static factors to detect the need for non-routine adjustments

8.7. Context of Project and Stakeholder Responsibilities

The context of a project and the responsibilities of the individual stakeholders and their risks should be considered when evaluating IPMVP Options and other details in the M&V Plan, especially where verified savings are the basis for financial transactions.

It is important to consider what the stakeholders are responsible for relative to an EEM. For example, lighting retrofits selecting Option A where the contractor's risks and responsibilities involve reducing power draw of lights and not affecting the operating hours, which are controlled by the building owner. Similarly, a building owner may not have control over all of the loads in a facility, and therefore prefers the use of Retrofit Isolation Options A or B over a Whole Facility Approach using Option C.

In a project where the contractor is responsible for EEM performance but is not performing EEM operation and maintenance, the length of measurements in the reporting period may be limited. For subsequent periods where re-inspections are used rather than measurements to validate the value of a key parameter, the reported energy savings are not IPMVP adherent.

8.8. Using Retrofit Isolation Methods

Retrofit Isolation Options A and B have similar measurement boundaries but use different methods to determine savings, and each is more appropriate for different applications and types of EEMs.

The fundamental difference between these Options involves what measurements are needed, as highlighted in their names:

- Option A: Retrofit Isolation with Key Parameter(s) Measurement
- Option B: Retrofit Isolation with All Parameter Measurement

Often, the key parameters required to determine energy consumption are the rates of energy use (e.g., demand or load) and the corresponding hours of use. In other instances, key parameters may include items such as power factor, volts, and amps (used to determine kW), run hours, equipment load, flow rates, temperature differentials, thermal content, etc., depending upon the application and the EEM.

Key Parameters - Examples
Key parameters are critical variable(s) identified to have a significant impact on the energy savings associated with the installation of an EEM. In retrofit isolation methods, key parameters may be combined to define energy demand and consumption of the load, which is subject to the EEM. For an EEM involving upgrading lighting equipment, electrical demand (kW) can be determined from amps, volts, and power factor, and consumption (kWh) determined from the corresponding hours operated. For an EEM such as replacing a gas-fired boiler, thermal energy performance may be determined by measuring gas flow rates, system operating temperatures, and hot water flow rates over time.

Option A allows the use of both measured and estimated values to calculate baseline and reporting period energy, whereas Option B requires the direct measurement of demand and energy consumption OR the concurrent measurement of all the parameters necessary to determine demand and energy consumption. Generally, the accuracy in verified savings reported by Option B is higher than those using Option A.

When planning a retrofit isolation procedure, evaluate:

- The amount of variation in the baseline period's energy use and related key parameters (e.g., loads and hours of operation),
- How the EEM will impact those key parameters,
- Level of rigor required in reported savings, and
- Any risk management agreements between stakeholders.

Conditions of variable load or variable operating hours require more rigorous measurement and computations than constant loads, constant hours, or scheduled hours of operation. Generally, where a key parameter varies during the baseline period or when that parameter will be impacted by the EEM, that parameter should be measured.

The following simplified examples show a range of scenarios that may arise.

Table 7: Retrofit Isolation Option Selection – Examples Based on Load and Operating Hours

#	Scenario	Preferred Approach
1	EEM reduces a constant rate of consumption without changing its operating hours	Option A or B
2	EEM reduces operating hours without changing a constant load	
3	EEM impacts both loads and operating hours	Option B
4	EEM impacts equipment with variable loads and variable operating hours	

These equations are conceptual in nature, and the exact savings equations will be more complex because savings are the sum of the conditions over time, the hours at a specific rate.

Equation 9: Option A/B Savings when Adjustments Are Not Required

$$
\begin{aligned}
\text{Savings} = \quad \Sigma_{\text{time}} \quad & \text{(Baseline Period Rate of Energy Consumption} \\
\times \quad & \text{Baseline Hours of Use)} \\
- \quad & \text{(Reporting Period Rate of Energy Use} \\
\times \quad & \text{Reporting Period Hours of Use)}
\end{aligned}
$$

Generally, using Option A: Key Parameter(s) Measurement would be appropriate for Scenarios 1 and 2, but not for Scenario 3 or 4. Option B: All Parameter Measurement is more suitable for EEMs impacting variable loads or EEMs impacting both loads and operating hours.

RETROFIT ISOLATION MEASUREMENTS

A retrofit isolation approach usually requires the addition of special meters or data logging equipment on either a short-term or permanent basis to measure energy use or the key parameters needed to calculate energy use. These meters may be installed during an energy audit to help characterize energy consumption and demand while designing the EEM(s), or meters may be installed to measure baseline performance for an M&V Plan. Generally, measurements of key parameters, or energy use, and independent variables should be made concurrently. When verifying demand savings, significant care should be taken to establish load profiles or otherwise properly account for the diversity in equipment operations coincident with the utility's peak demand period.

Where key parameters and energy use are variable, measurements should be made to capture values across a full range of expected values and operating conditions whenever possible. The measurements required may be short-term over a portion of the baseline and reporting periods or continuous, depending on the variability of the parameter and if it is impacted by the EEM. Where a parameter may change periodically, the occasional measurements of the parameter at times representative of normal variations in system behavior may be appropriate.

Where a key parameter is shown to be a constant value, measurements may be of short duration and conducted periodically. Parameters not measured in both the baseline and reporting periods, however, are considered estimates. Where a parameter is not expected to change, it may be measured immediately before and after EEM installation and occasionally checked throughout the reporting period. The frequency of this checking can be determined by beginning with measurements sufficient to verify that the parameter remains constant for the baseline and reporting periods. Once proven constant, the frequency of measurement may be reduced to a minimum of once during any reporting period. To maintain control on savings as measurement frequency drops, more frequent inspections or other tests might be undertaken to verify proper operations.

Table 8: Constant Values Establish Based on Measurements

Constant Values
▪ A parameter may be considered “constant” where measured values do not change within a defined range (e.g., +/- 10%) during a period of interest. ▪ Minor variations may be observed in the parameter while still describing it as constant. The magnitude of variations that are deemed to be “minor” must be reported in the M&V Plan. ▪ Once proven constant, the frequency of measurement may be reduced to a minimum of once during any reporting period. Otherwise, it should be treated as an estimated value.

Where a parameter may vary daily or hourly, as in most building heating or cooling systems, continuous metering may be the simplest. For weather-dependent loads, measurements may be taken over a long enough period to adequately characterize the load pattern through all parts of its normal annual cycle (i.e., each season and weekday/weekend operating modes) and repeated as necessary through the reporting period. These measurements are often used to make routine adjustments.

Continuous metering provides greater certainty in reported savings and more data about equipment operation. This information can be used to improve or optimize the ongoing operation of the equipment, potentially improving the benefit of the EEM itself. If the measurement is not continuous and meters are removed between readings, the location of the measurement and the specifications of the metering device(s) should be recorded in the M&V Plan, along with the meter’s accuracy and the procedures for validating readings and calibrating the meter being used.

Where multiple versions of the same EEM installation are included within the measurement boundary, statistically valid samples may be used as valid measurements of the total parameter.

9. IPMVP OPTIONS

Additional details related to applying the IPMVP Options are discussed in Section 12 – Common M&V Issues. Option-specific M&V Plan and Reporting requirements are included in Section 13 – M&V Plan & Reporting Requirements.

9.1. Option A: Retrofit Isolation, Key Parameter(s) Measurement

Under Option A, Retrofit Isolation: Key Parameter(s) Measurement, energy quantities can be derived from a computation using a combination of measurements of some key parameters and estimates of the others. Such estimates should only be used where it can be shown that the combined uncertainty from all such estimates will not significantly affect the overall confidence in reported savings, or the uncertainty from all estimates is agreeable by all parties.

9.1.1. Measured and Estimated Values

Decide which parameters to measure and which to estimate by considering the impacts of the EEM, the cost of measurements, and each parameter's contribution to the overall uncertainty of the reported savings. The selection of which factor(s) (i.e., key parameters and any required performance indicators) to measure may also be considered relative to the objectives of the project or the duties of a contractor undertaking some EEM performance risk**. Where a factor is significant to assessing the performance of the EEM, it must be measured while other factors can be estimated.**

When estimating parameters, a range of plausible values should be determined, and a value selected which results in a conservative savings estimate. The estimated values and analysis of the significance of these estimated parameters to the total savings uncertainty should be included in the M&V Plan. Estimates may be based on historical data such as data recorded during an energy audit, operating hours established from whole building energy data, equipment manufacturer published ratings, laboratory tests, or typical weather data.

If a parameter, such as hours of use is shown to be constant and not expected to be impacted, the reporting period determination of a parameter can be assumed to be equal to the baseline value or vice versa, but the values would be considered estimates. Wherever a parameter is not measured in the facility during both the baseline period and reporting period, the parameter should be treated as an *estimated value*.

The largest source of uncertainty in savings reported using Option A is typically from estimated values. The plausible range of values for any estimated values should be evaluated, and a rationale for the use of the estimated value provided.

Engineering calculations or mathematical modeling should be used to assess the significance of the errors in estimating any parameter in the reported savings to the extent possible. The combined effect of estimations should be assessed before determining whether sufficient measurement is in place and the assessment included in the M&V Plan.

Other sources of savings uncertainty for Option A may include sampling error where measurements are made on statistical samples instead of all equipment impacted and from errors based on measurement equipment used. Where statistical sampling is used for measurements, the statistical results of the sampling and their impact on verified savings should be considered.

Values estimated for use in IPMVP Option A are often chosen to reduce costs or to eliminate the need for adjustments when changes happen affecting energy use within the measurement boundary. Therefore, the need for non-routine adjustments may be reduced using Option A. For example, a chiller plant's cooling load profile (ton-hours/day) was estimated rather than measured, and the performance of the plant (kW/ton) was measured periodically to determine Option A savings created by a chiller efficiency EEM. 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 unaffected (provided the chillers' periodic performance measurements). In this case, the use of Option A avoided the need for a non-routine adjustment.

9.1.2. Installation Verification

Since some values may be estimated under Option A, great care is needed to review the engineering design and installation of these EEMs to ensure that the estimates are realistic, achievable, and based on equipment that should truly produce savings as intended. Proper specification and installation of each EEM must be confirmed using appropriate operational verification strategies.

At defined intervals during the reporting period, it is recommended that the installation be re-inspected to verify that the equipment is installed, maintained, and functioning properly and the equipment is operating as intended. Such re-inspections can ensure the continuation of the potential to generate predicted savings and validate estimated and measured values. The frequency of these re-inspections is determined by the likelihood of performance changes and should be detailed in the M&V Plan as described in Section 13.

9.1.3. Calculations

Under Option A, there may be no need for adjustments, routine or non-routine, depending upon the location of the measurement boundary, the nature of any estimated values, the length of the reporting period, the time between baseline measurements and reporting period measurements, or the terms of the contract or requirements of the program associated with the project.

Similarly, baseline period energy and reporting period energy measurements may involve measurement of only one parameter under Option A, and estimation of the other parameters, although multiple parameters may be measured.

9.1.4. Best Applications

Option A is best applied where:

- The level of savings is low and cannot justify the cost of measurements needed for Option B or simulation for Option D.
- Estimation of parameters may avoid possibly difficult non-routine adjustments when future changes are likely to happen that affect energy use within the measurement boundary.
- Uncertainty created by estimations is acceptable.
- Interactive effects are limited or easily estimated.
- The continued effectiveness of the EEM can be assessed by simple routine re-testing or re-inspection of key parameters.
- Key parameter(s) used to judge a project's performance in computing savings can be readily identified.

9.2. Option B: Retrofit Isolation, All Parameter Measurement

Option B: Retrofit Isolation, All Parameter Measurement requires measurement of energy and/or demand quantities, or the key parameters needed to compute energy and/or demand. The savings created by most types of EEMs can be determined with Option B. The degree of difficulty and costs associated with Option B increase as metering complexity and comprehensiveness increase. However, Option B will produce accurate savings determination where load or savings patterns are variable, as described in Section 8.8.

Sampling error where statistical samples are measured, and estimated values. These errors should be evaluated and included in the M&V Plan, as detailed in Section 13.1 – M&V Plan Requirements.

9.2.1. Calculations for Option B

Equation 2: Primary IPMVP Savings Equation is used in IPMVP adherent computations. When energy consumption or demand within the measurement boundary varies based on independent variables, routine adjustments may be required.

However, in some cases under Option B, there may be no need for adjustments, routine or non-routine, depending upon the location of the measurement boundary, the variability of the measured energy consumption, and demand. Where energy use is variable and independent variables need to be considered, modeling strategies described in Option C should be used.

Sources of savings uncertainty for Option B result from error based on measurement instrumentation used, the model (for a discussion on statistical error where mathematical models are used, see Option C), the sampling error where statistical samples are measured, and estimated values. These errors should be evaluated and included in the M&V Plan, as detailed in Section 13.1 – M&V Plan Requirements. For a discussion on statistical error where mathematical models are used, see Option C.

9.2.2. Best Applications

Option B is best applied where:

- The energy consumption of EEM can be isolated.
- EEM impacts equipment with variable loads and variable operating hours. Baseline energy consumption within the measurement boundary is variable.
- Interactive effects are limited or easily estimated.
- The EEM affects more than one key parameter.
- The EEM’s outcome will benefit from monitoring.
- Meters for isolation purposes exist or will be used for other purposes such as operational feedback or tenant billing.
- Measurement of the key parameters is less costly than simulation in Option D.

9.3. Option C: Whole Facility

Option C involves the use of energy data from utility meters, whole facility meters, or sub-meters, and independent variables to assess the energy performance of a total facility. The measurement boundary encompasses either the whole facility or a major section. This option determines the collective savings of all EEMs applied within the measurement boundary. As such, savings reported under Option C include the positive or negative effects of any non-EEM changes made in the facility.

Option C is intended for projects where expected savings are large relative to the random or unexplained energy variations which occur at the whole facility level. Mathematical models are developed to describe how the independent variables explain the variations in energy consumption but do not account for all variations between the independent variables and the actual consumption data.

Typically, baseline models, and sometimes reporting period models, are developed using regression analysis to make routine adjustments to energy consumption and calculate savings. Statistical results of a model describe how well the variations in energy consumption are explained, and statistical metrics are used to validate using a model. As discussed in Section 12.6 – Statistics for M&V, the expected savings must be greater than twice the standard error in the model for the use of a model to be valid. Models with lower levels of error can identify lower levels of savings, and confidence in savings will be higher.

Option C may be based on monthly utility billing data or short time-interval energy consumption data (e.g., hourly, daily). Using interval meter data with Option C typically involves creating a series of multivariate 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, considerations on independent variables, selecting software tools, and applying models. (See Section *12.2* – Advanced M&V Methods).

When short-time-interval data is available, the number of data points is much greater, and advanced mathematical models (e.g., multiple linear change-point models) are more accurate than the simple linear models used for monthly analysis. Consequently, methods using short-time-interval data and advanced modeling algorithms can often verify, with confidence, expected savings that are 5% or less of annual energy consumption, whereas if only monthly utility billing data are available, savings often need to consistently exceed 10% of the baseline period energy. These examples are rules-of-thumb, and an assessment of the baseline model's accuracy compared with expected savings is required.

Care should be taken to ensure the baseline period energy represents normal operations relevant to the expected reporting period conditions and does not include non-routine periods. The baseline period selected should be screened for non-routine events (NREs) through interviews, site inspections, and a review of data. Where NREs are identified, a limited amount of data may be excluded, or the baseline period selected may need to be adjusted.

Identifying non-routine events (i.e., facility changes) that will require non-routine adjustments represents a fundamental component of the Option C approach, particularly when savings are monitored for long reporting periods. Therefore, periodic inspections of all equipment and operations in the facility should be performed during the reporting period. These inspections identify changes in the static factors from baseline period conditions. Such inspections may be part of regular monitoring to ensure that the intended operating methods are still being followed. A lower-cost alternative, most applicable to smaller projects or facilities, can be to track energy performance over time, normalize for operating conditions, and inspect the facility for changes when adjusted performance shows a marked unexpected variance or persistent change as a means to identify non-routine events. Since non-routine changes can either increase or decrease savings, they must be treated equally.

Note: the longer the reporting period, the more data are available, and the less significant is the impact of short-term unexplained variations.

9.3.1. Utility Meter Data

Whole facility energy measurements can use the utility's meters. Utility-meter data are typically considered 100% accurate for determining savings because the data defines the payment for energy. Utility-meter data are subject to local commercial accuracy regulations for the sale of energy commodities.

Utility meters do not always cover the entire building, and multiple meters may be present. The main meter may include only a portion of the energy supplied to a facility, and care must be taken to understand the measurement boundary of any utility meter.

The energy supplier's meter(s) may be equipped or modified to provide an electrical pulse output that can be recorded by the facility's monitoring equipment. The energy-per-pulse constant of the pulse transmitter should be calibrated against a known reference such as similar data recorded by the utility meter.

Separate meters installed by the facility owner can measure whole facility energy consumption or that of a portion of the facility. The accuracy of these meters should be considered in the M&V Plan, together with a way of comparing its readings with the utility meter readings.

9.3.2. Energy Data Issues

Where utility supply is only measured at a central point in a group of facilities, sub-meters are needed at each facility or group of facilities for which individual performance is assessed. Several meters may be used to measure the flow of one energy type into a facility. If a meter supplies energy to a system that interacts with other energy systems, directly or indirectly, this meter's data should be included in the whole facility saving determination.

Meters serving non-interacting energy flows, for which savings are not to be determined, can be ignored. Determine savings separately for each meter or sub-meter serving a facility so that performance changes can be assessed for separately metered parts of the facility. However, where a meter measures only a small fraction of one energy type's total use, it may be totaled with the larger meter(s) to reduce data-management tasks. When electrical meters are combined this way, it should be recognized that small consumption meters often do not have demand data associated with them so that the totaled consumption data will no longer provide meaningful load information. Additionally, if the interval of the data is different, the combined data will be in the longest interval.

If meters are read on separate days, then each meter having a unique billing period should be separately analyzed. The resultant savings can be combined after analysis of each individual meter if the dates are reported. For some applications (e.g., industrial process), metering of sub-areas may be effective. For determining demand savings, however, the sub-meter's readings should be synchronized with the utility demand meter.

If any of the energy data are missing from the reporting period, a reporting period mathematical model can be created to fill in missing data as defined in the M&V plan. However, the reported savings for the missing period should report these savings as missing data and as a source of uncertainty in savings.

ENERGY INVOICE ISSUES

Energy data for Option C are often derived from utility meters, either through a direct reading of the meter or from utility invoices. Where utility bills are the source of data, it should be recognized that a utility's need for regular meter reading is not usually as great as the needs of M&V. Utility bills sometimes contain estimated data, especially for small accounts. In some cases, it cannot be determined from the utility bill whether the data came from an estimate or an actual meter reading. Unreported estimated meter readings create unknown errors for the estimated month(s) and also for the subsequent month(s). However, the first invoice with an actual reading after one or more estimates will correct the previous errors in energy quantities. Savings reports should note when estimates are part of the utility data. When an electrical utility estimates a meter reading, no valid data may exist for the electrical demand of that period. Recorded energy use values that are known to be estimates should not be included in the baseline energy.

Energy consumption can either be metered directly (e.g., electricity, natural gas) or measured by some other means (e.g., weight or volume of oil, wood chips, manure, etc.). When energy is supplied indirectly to a facility through on-site storage facilities, such as for oil, propane, or coal, the energy supplier's shipment invoices do not represent the facility's actual consumption during the period between shipments. Ideally, a meter downstream of the storage facility measures energy consumption. However, where there is no downstream meter, inventory-level adjustments for each invoice period should supplement the invoices.

9.3.3. Independent Variables

Common independent variables include weather, production volume, and occupancy. The weather has many factors, but for whole facility analysis, weather data is often limited to just outdoor dry-bulb temperature. Production has many dimensions, depending upon the nature of the industrial process, but is typically expressed in mass units or volumetric units of each product, and may have additional weather dependencies. Occupancy is defined in many ways, such as hotel-room occupancy, office-building occupancy hours, average motor speeds, occupied days (weekdays/weekends), restaurant-meal sales, or other metrics.

Mathematical modeling can assess independent variables if they are cyclical. Regression analysis and other forms of mathematical modeling can determine the number of valid independent variables to consider in the baseline period data. Parameters that have a significant effect on the baseline period energy should be included in the routine adjustments when determining savings, as shown in Equation 2. This translates to Equation 4 for Avoided Energy Use and

Equation 8 for Normalized Energy Savings. Independent variables must be measured and recorded during the same period as the energy data. The range of values for the independent variables used to develop the model must be noted to ensure it is valid for making adjustments.

9.3.4. Calculations & Mathematical Models

For Option C, the routine adjustments term in Equation 2 is calculated by developing a valid mathematical model of each meter's energy-use pattern.

A model may be as simple as an ordered list of twelve measured monthly energy quantities without any adjustments. However, a model can also be based on interval data – and often includes factors derived from regression analysis, correlating energy to one or more independent variables such as outdoor temperature, degree days, metering period length, production, occupancy, or operating mode. Models can also include a different set of regression parameters for each range of conditions, such as summer or winter in buildings with seasonal energy variations.

Option C usually uses complete years (e.g., twelve, twenty-four, or thirty-six months) of continuous data during the baseline period and continuous data during the reporting period. For short time interval data, fewer months of data may be used; however, care should be taken to ensure that the data range is representative of the entire baseline year. Models, which use other numbers of months (e.g., nine, ten, thirteen, or eighteen months), can create statistical bias by under or over-representing unusual modes of operation. Such models should be checked for bias.

Metered data can be hourly, daily, or monthly whole facility data. Hourly data may be combined into longer time intervals, such as daily, to limit the number of independent variables[2] required to produce a reasonable baseline model without significantly increasing the uncertainty in computed savings.

Many statistical model types are appropriate for Option C. To select the one most suited to the application, consider statistical-evaluation indices, such as Coefficient of Variation of the Root Mean Squared Error (C_V{RMSE}), Mean Bias Error (MBE) defined in published statistical literature which can help demonstrate the statistical validity of the selected model. (See related discussion in Section 12.6 – Statistics for M&V.)

Sources of savings uncertainty for Option C include the statistical error in mathematical models used and any error from measurement instrumentation used. These errors should be evaluated and included in the M&V Plan, as described in Section 13.2.2. Quantifying savings uncertainty for Option C can be complex and depends on how "well-behaved" a building is, and the resultant scatter in the data and similarly in the reporting period model, if used. The resulting uncertainty in savings can be calculated using statistical parameters from the models, the number of points included, and the length of the reporting period. (See the *IPMVP Application Guide on Uncertainty* for suitable methods.)

9.3.5. Best Applications

Option C is best applied where:

- An assessment of the energy performance of the whole facility is of interest rather than the individual EEMs.
- There are many types of EEMs in one facility.

[2] Both continuous and categorical variables may be included.

- EEMs involve activities whose individual energy consumption and demand are difficult to measure separately.
- Savings are large compared to the variance in the baseline and reporting period energy data.
- Retrofit isolation techniques (Option A or B) are excessively complex and costly.
- Significant future changes to the facility are not expected during the reporting period.
- A system of tracking static factors can be established to enable possible future non-routine adjustment.
- Reasonable correlations can be found between energy consumption or demand and independent variables.
- Utility data or sub-metered energy data is available in frequent intervals.

9.4. Option D: Calibrated Simulation

Option D: Calibrated Simulation uses facility energy simulation software to predict facility energy use, typically when baseline energy data does not exist. Savings determined with Option D are based on computer simulation models of physical systems which are used to predict facility or process energy consumption and demand. These types of models are based on engineering equations that capture the physics and details of the systems included in the measurement boundary. The accuracy of the savings depends on user proficiency, model robustness, and the level of calibration achieved.

Option D may be used to assess the performance of EEMs for the whole facility or for a specific system, akin to Option C. However, the whole facility simulation model can also be used to estimate the savings attributable to each EEM within a multiple EEM project.

Option D may also be used to assess just the performance of individual systems within a facility, akin to Options A and B. For this application, the system's energy consumption and demand should be isolated from that of the rest of the facility by appropriate meters so that these metered data can be used for the calibration of the simulation model.

9.4.1. Types of Simulation Programs

Energy simulation programs usually use hourly calculation techniques. Utilizing simulation software packages that are widely used and have been evaluated (e.g., ASHRAE Standard 140) are preferred where simulations are used for buildings. The software used must be well understood by the user, capable of simulating the system, the space types, and the project EEMs. Due to the wide variety of available software, it is recommended to include details of the proposed software in the M&V Plan and to receive acceptance by the project stakeholders on the proposed modeling program before commencing analysis.

For industrial applications, there is not a single standard for simulation software that is industry or process specific. Special-purpose software may be used to simulate energy use associated with the operation of devices or industrial processes. Proprietary simulation software may be used if algorithms, calculations, and statistical treatments are transparent and well documented. System-level simulation models must account for significant EEM interactions.

When savings for individual EEMs are determined by re-running the model after each EEM is included, the stacking order of the EEMs needs to be determined if the EEMs impact one another (e.g., EEMs that reduce loads are typically modeled before those that reduce the equipment's operating hours). The order used will affect the saving estimated for the individual EEMs but will not change the savings for the project.

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MODEL CALIBRATION

When metered data for the baseline or existing conditions are available, the simulation model is calibrated by the modeler so that the energy and load shapes approximately match the actual metered data. Otherwise, the model should be calibrated to reporting period conditions. There is typically no need to recalibrate a model that has been calibrated with baseline data. The requirements for the model calibration should be included in the M&V plan, and should consider the level of savings expected, energy and other data available, and needed granularity in results[3].

When calibrated, the simulation model should reasonably predict the load shapes and energy use of the facility or system. This is determined by comparing model results to measured energy consumption and demand data, independent variables, and static factors and iteratively altering the model until predicted energy consumption and demand, as well as key operating conditions, agree with measured data within acceptable limits. The changes made to the model's input parameters to calibrate the model should be documented, as described in Section 13.2.3 - Option D - Additional Requirements

Calibration of whole-facility energy simulations is performed with twelve consecutive months of utility billing data over a range of weather conditions and a stable operating period. Using shorter time interval energy data, however, to determine load profiles is common and can provide for better calibrated models.

Additional calibration data might include operating characteristics, schedules, occupancy metrics, weather, process or other loads, and equipment efficiencies. Parameters should be measured at an appropriate interval, day, week, month, or extracted from operating logs or trend data logs. The accuracy of meters should be verified for critical measurements. The level of calibration should be established in the M&V Plan and reflect the level of effort and accuracy justified for the project.

In a new facility, model calibration may not occur until several months after completion when occupancy and operations stabilize. For industrial processes or other facility subsystems, system-level data should be collected for a sufficient time period to capture a full range of operating conditions, including all significant process cycles and variations. Ensure data is of sufficient granularity and frequency to capture variations. The time period and the data to be utilized to calibrate the model should be documented in the M&V Plan. Collect and record any data that will be used if evaluating normalized energy savings (e.g., average production rates, weather conditions for a standard year).

After developing the M&V Plan, collect data and perform the Calibration Steps described in Table 9. It is important to note that the creation and calibration of simulation models are iterative processes that can be time-consuming. Accurate computer modeling and model calibration are the major challenges associated with Option D implementation. For example, models for new buildings are based on full occupancy and stable operations but the calibration period used occurs during the period required to ramp up to full-building occupancy and loads.

Using monthly or daily rather than hourly energy data helps to limit the effort and cost of performing model calibration. However, if the simulation is used to estimate demand savings or to determine savings at the EEM level, calibration using hourly data (or sometimes shorter time interval data) may be required for the impacted end-uses/systems and/or equipment.

To balance costs with accuracy, the following points should be considered:

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[3] ASHRAE 90.1 Appendix G provides useful example calibration requirements.

- Simulation analysis should be conducted by trained personnel experienced with the software, calibration techniques, the equipment and process being modeled, and IPMVP savings concepts.
- Record survey data, monitoring data, and assumptions used to define input values. The calibrated simulation model should be saved with the secure backup of all files. The simulation software release version should be recorded and saved to support quality assurance reviews.
- Document the specific changes made to the simulation model to represent each EEM's impact.
- When possible, for new construction projects, retain the facility or process energy model personnel that created the as-designed model to create the calibrated reporting period model and the adjusted baseline model (described below).

Table 9: Calibration Steps for Simulation Model

Step	Model Calibration Activity
1	Develop necessary input parameters and model assumptions, and document their values and sources.
2	Gather data from the calibration period and document their values and sources. Data needed includes energy consumption and demand data as well as details on other energy influencing factors (e.g., measured system pressures, temperature set points, material flows, operating hours, occupancy levels, etc.). Where estimates are used, document the range of likely values.
3	Run the simulation model and verify that systems meet performance requirements (e.g., loads for each end-use, zone set points (temperature and humidity) for buildings, production rates, and product quality parameters for industrial applications).
4	Compare the simulated energy results with the metered energy data from the calibration – on an hourly, daily, or monthly basis to account for differences in the weather.
5	Compare results to detailed operating and measured performance data to ensure they represent actual facility and system operation.
6	Evaluate consistency in load shapes and other end-use patterns and calibration data, e.g., bar charts, monthly percent difference time-series graphs, and monthly XY scatter plots, help to identify discrepancies.
7	As needed, revise input data values established in Step 1. Repeat Steps 3 – 5 to bring predicted results within the project calibration requirements which were specified in the M&V Plan. Collect more operating data from the facility if necessary.

9.4.2. Calculations

Avoided energy consumption can be determined using the measured reporting period energy and demand along with the calibrated simulation results from models representing the baseline period and the reporting period.

EXISTING FACILITIES

For existing buildings, an energy model representing existing building conditions can be developed to predict the impact of the EEMs and/or assist with the selection of the best combination of EEMs to meet client expectations and/or to meet code requirements. After EEMs are installed, the reporting period energy consumption and demand are used to develop the reporting period model. Once calibrated (i.e., when the differences are negligible between actual and model predicted values), the EEMs are removed from the reporting period model to construct the baseline model. The baseline model represents the existing building under the reporting period conditions.

Normalized energy savings can also be determined. If it is desired to report savings under normal conditions, the reporting period calibrated model would be modified to represent normal conditions (e.g., normal weather conditions or normal variables) then the EEMs would be removed to develop the baseline model.

NEW CONSTRUCTION

If the baseline period does not exist or baseline data are not available (e.g., new construction or repurposing of a building), the calibrated reporting period model can be used to develop the baseline model. For projects that develop a hypothetical baseline model (e.g., code-compliant baseline energy for a new construction project), the baseline model for M&V must be developed from the calibrated reporting period model with EEMs removed, as described above. In all situations, the models' input parameters and measured energy data must be under the same set of operating conditions, similar to Option C.

Since the model is only calibrated to one period, the calibration error is assumed to equally affect the baseline period and reporting period models. For new construction, the calibration error is the actual reporting period energy minus the energy predicted by the calibrated model for the reporting period, which can be either positive or negative.

Equation 10: Simplified Equation for Avoided Energy Consumption Using Option D in New Construction

Avoided Energy Consumption =		Baseline Period Energy from the Calibrated Model updated to Baseline Conditions
	−	Reporting Period Energy from the Calibrated Model

ONGOING SAVINGS

If a multi-year performance evaluation is required, models should be recalibrated each year of the reporting period. As an alternative, Option D may be used for the first year after the EEMs are installed. In later years, Option C may be applied with the baseline period based on the metered data from the reporting period's first year of steady operation. In this case, Option C is used in subsequent years to track savings persistence.

SAVINGS UNCERTAINTY

Sources of savings uncertainty for Option D include inaccurate assumptions used in the development of the simulation model, error in estimated values used, sampling uncertainty, and measurement error due to instrumentation in any sub-metered energy data.

As detailed in 13.2.3, the M&V Plan should discuss the sources of uncertainty in savings and requirements for model calibration. The variables measured and those estimated as part of the model development and calibration efforts should be identified, and the possible impact of estimated values on the uncertainty in savings. This should include the values used, the range of probable values, and sources of estimated values.

9.4.3. Best Applications

In general, Option D is best applied where:

- Baseline period energy data are unavailable or unreliable, such as:
  - New construction project
  - Facility expansion needing to be assessed separately from the rest of the facility
  - Centrally metered campus of facilities where no individual facility meter exists in the baseline period, but where individual meters will be available after EEM installation.
- There are too many EEMs to assess using Options A or B.
- The performance of each EEM will be estimated individually within a multiple EEM project, but the costs of Options A or B are excessive.
- Interactions between EEMs are complex and significant, making the isolation techniques of Options A and B impractical

Table 10 Summary of IPMVP Options

IPMVP Option	Definition	How Savings are Calculated	Typical Applications
A. **Retrofit Isolation: Key Parameter(s) Measurement**	Savings are determined by field measurement of the key parameter(s), which define the energy consumption and/or demand of the EEM's affected system(s). Performance indicators may also be defined and measured to ensure the success of the project. Measurements range from periodic short-term to continuous long-term, depending on the expected variations in the key parameter(s). Parameters not selected for field measurements are estimated values. Estimates can be based on historical data, manufacturer specifications, or engineering judgment. Documentation of the source and justification of the estimated value is required. The plausible savings error arising from estimation rather than measurement is evaluated and is acceptable to stakeholders.	Calculation of baseline period energy and reporting period energy from periodic short-term energy measurements, or from periodic short-term or continuous measurements of key parameter(s) and from estimated values. Routine and non-routine adjustments as required. Key parameter(s) must be measured during both baseline and reporting period.	A lighting retrofit where the change in power drawn by the lighting system is the most uncertain parameter and is measured, and secondly, lighting operating hours are estimated based on facility schedules and occupant behavior. Notes: Multiple key parameters often exist, and selection of key parameters to measure is an important consideration.
B. **Retrofit Isolation: All Parameter Measurement**	Savings are determined by continuous field measurement of the energy consumption and/or demand or validated proxy variables and the related independent variables of the EEM affected system. Measurements range from periodic short-term to continuous long-term, depending on the expected variations in the key parameters.	Determination of baseline period energy based on short-term or continuous measurements of baseline and reporting period energy, or on engineering computations using measurements of proven proxies of energy consumption or demand. Routine and non-routine adjustments as required.	Installation of a variable-frequency drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power demand every minute. In the baseline period, this meter is in place for a month and system testing was conducted to verify constant loading across a full range of operating conditions. The meter remains in place throughout the reporting period to measure energy consumption and demand.

IPMVP Option	Definition	How Savings are Calculated	Typical Applications
C. **Whole Facility**	Savings are determined by measuring energy consumption and/or demand at the whole facility or sub-facility level, often using utility meter data. Continuous measurements of the entire facility's or sub-facility's energy consumption and/or demand are taken throughout the baseline period and the reporting period.	Analysis of the whole facility or sub-facility baseline and reporting period energy data (e.g., utility meter) and independent variables. Routine adjustments as required, typically using models based on regression analysis techniques. Non-routine adjustments as required.	Multifaceted energy management programs affecting many systems in a facility. Measure energy consumption and/or demand with the gas and electric utility meters for a twelve-month baseline period and throughout the reporting period.
D. **Calibrated Simulation**	Savings are determined through simulation of the energy consumption and demand of the whole facility, or of a sub-system in the facility and comparing results with actual energy consumption and demand. Simulation models are demonstrated to adequately model actual energy performance in the facility. This option requires considerable skill in calibrated simulation and experience with the equipment and processes being modeled.	Actual energy consumption and demand and results from simulation model(s). Energy consumption and demand from the simulation, calibrated with hourly, daily or monthly energy data. Energy sub-metering and metered performance data including processes may be used in further model calibration. Non-routine adjustments as required.	Multifaceted energy management programs affecting many systems in a facility but where no meter existed in the baseline period. Energy consumption and demand measurement, after installation of natural gas, electric or other energy meters, is used to calibrate a simulation model.

10. M&V COST & RIGOR IN SAVINGS

10.1. Cost of M&V

M&V costs should be appropriate for the level of expected savings, the level of rigor needed in the reported savings, the level of investment and benefits of the EEMs, as well as the stakeholders' interests in the frequency and duration of the reporting process. It is difficult to generalize about costs for the different IPMVP Options since each project will have its 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 EEMs. The level of effort may be increased to improve confidence in savings.

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

- IPMVP Option selected and measurement boundary used.
- The number of EEMs and their complexity.
- The number and type of energy flows within the measurement boundary (or boundaries) which require measurement.
- Required accuracy in reported savings (i.e., the acceptable level of savings uncertainty).
- The level of effort associated with the Option and approaches selected, such as:
  - amount and complexity of the measurement equipment needed as compared to existing instrumentation available. (Consider design, installation, calibration, reading, removal, maintenance or re-installation, etc.),
  - level of effort needed to make the baseline and reporting period measurements,
  - sample sizes specified (if used) for metering representative equipment based on confidence level and precision required in measured parameter(s),
  - amount of engineering required,
  - complexity in collecting independent variables used in mathematical models, and
  - number and type of static factors impacting energy use within the measurement boundary that need to be documented and tracked.
- Operational verification activities required for each EEM.
- Inclusion of third-party commissioning agent for installed EEMs.
- Duration of the reporting period.
- Frequency of savings reports and level of detail required.
- Ongoing verification activities required.
- The methods used to review M&V plans and savings reports.
- Experience and professional qualifications of the people conducting the savings determination.

The costs to add meters at the measurement boundary may be justified for EEM(s) with high-energy savings to ensure a high level of rigor in the reported savings (see Section 8.6). Sometimes, metering expenses may be shared with others when they can be used for additional purposes such as operational feedback or tenant billing.

Expect M&V costs to be highest at the beginning of the reporting period. At this stage in a project, new metering may be required, measurement processes are being refined, and accurate performance monitoring helps to optimize EEM design and operation. Ultimately, the cost for savings determination should be in proportion to the magnitude of the expected savings and other related stakeholder goals.

- **Option A** methods usually have lower costs and higher uncertainty than **Option B** methods. Since new measurement equipment is often involved in **Options A or B**, the cost of installing and maintaining this equipment may make **Option C** less costly for longer reporting periods, but this must be compared to the costs for tracking static factors, managing data, and making non-routine adjustments. Cost planning for **Options A and B** should consider all elements: analysis, meter installation and calibration, the ongoing costs to read and record data, and to perform verification activities. When multiple EEMs are installed at one site, it may be less costly to use **Options C** or D than to isolate and measure multiple EEMs with **Options A or B**.
- **Option C**'s cost depends on the source of the energy data and the difficulty of tracking static factors impacting energy use within the measurement boundary to enable non-routine adjustments during the reporting period. Utility meters work well, or existing sub-meters if calibrated, and the data are properly recorded. This choice requires no extra metering cost. However, the cost of tracking changes in static factors depends on the facility's size, the likelihood of static-factor changes, the difficulty of detecting changes on-site, the availability of frequent utility data (i.e., hourly or daily), and the surveillance procedures already in place.
- An **Option D** simulation model is often time-consuming and costly because it requires the development of an often complex building energy simulation that considers all parts of the building envelope, systems, loads, schedules, or industrial process. Energy modeling and calibration efforts can take a substantial amount of specialized engineering time and will require updates to account for changes in static factors during the reporting period.

10.2. Managing Uncertainty

The determination of savings is uncertain because savings represents the absence of energy use and cannot be directly measured. In an M&V process, uncertainties in parameters used to determine savings prevent the exact determination of savings. We use the term *error* to compare a measurement or forecast when the true value is known, whereas the term *uncertainty* is used when the true value is not known.

Our goal is to minimize uncertainties in the determination of savings. Minimizing uncertainty can be done by minimizing the uncertainty of individual parameters in a savings determination process and conducting a thorough savings uncertainty analysis for the resulting savings.

Characteristics of a savings determination process that should be carefully evaluated to manage uncertainty in reported savings are:

» **Instrumentation error** – The measurement of any physical quantity includes errors because no measurement instrument is 100% accurate. Measurement equipment errors are due to calibration, the accuracy of the instrument, inexact measurement, and improper meter selection or operation. Verifying instrument specifications and accuracy relative to a calibrated instrument is typical.

» **Modeling error** – Mathematical forms from regression analysis or other techniques do not fully account for all variations in energy consumption or demand. Limited modeling error (uncertainty due to scattering in the data beyond what is characterized by appropriate independent variables) is expected and allowable within appropriate bounds. High levels of modeling error can be due to unusual variations in data, inappropriate functional form, the inclusion of irrelevant variables, or the exclusion of relevant variables. Evaluating modeling error using statistical parameters to ensure model validity is required and quantifying uncertainty is possible.

- **Sampling error** – 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 from biased sampling. Sampling[4] 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). Quantifying the actual precision of statistical sampling strategies to evaluate the viability of the sample is typical.
- **Estimated values** – Error introduced from using any non-measured parameters in savings computation method. Evaluating the potential impact on savings from estimated values using the range of the expected values is typical.
- **Interactive effects** – Energy impacts beyond the measurement boundary of the EEMs that are not fully included in the savings computation methodology. Any estimated interactive effects should be small compared to overall savings and conservatively estimated to limit impacts on reported savings.
- **Data collection and analysis** – The inherent errors arising from the (e.g., erroneous or missing data) must also be managed when developing and implementing the M&V Plan. Implementing rigorous quality assurance procedures can reduce these errors.

Methods of quantifying, evaluating, and reducing some of these sources of errors and uncertainties should be used in the development of the M&V Plan to reduce the uncertainty associated with determining savings. Assessing optional M&V program characteristics can establish the level of rigor used and support stakeholder confidence in the reported savings.

Establish the stakeholders' expectations in managing uncertainty and the methods that will be used to meet these expectations. This may include a broad range of methods from the specification of accuracy requirements for measurement equipment, sensitivity analysis of calculation parameters, the requirement of calculation methods, or even complete mathematical determination of savings uncertainty.

In savings determination, it is feasible to quantify many uncertainty factors but usually not all. Therefore, when developing an M&V Plan or Report, recognize and report all uncertainty factors, either qualitatively or quantitatively. The *Uncertainty Assessment for IPMVP* presents methods of quantifying uncertainty, combining several components of uncertainty, along with examples.

10.3. Balancing Rigor and Cost

In an M&V process, the level of effort or rigor in establishing an appropriate savings determination process, collecting and preparing data, and calculating savings can be more or less thorough depending on the level of savings and economic benefit expected. A best practice is to minimize the cost associated with the level of data collection and analysis rigor in comparison with the expected economic benefit.

The acceptable level of uncertainty expected reported in savings is related to the cost of improving the level of rigor to an appropriate level for the value of the savings and risk tolerance of the stakeholders. M&V planning can provide a rough cost-benefit analysis of alternative M&V scenarios, but stakeholders must decide how much to spend and if the expected level of rigor used in determining the savings is acceptable.

[4] Best practices for using sampling are addressed in *Uncertainty Assessment for IPMVP EVO 10100–1:2018*.

Typically, average annual M&V costs should be less than 10% of the average annual cost savings being assessed, although higher levels may sometimes be appropriate (e.g., new measurement equipment required). Costs associated with the M&V effort tend to increase as the level of complexity of the M&V process increases. The quantity of savings at stake, therefore, places a limit on the M&V budget, which in turn may determine how much accuracy is achievable.

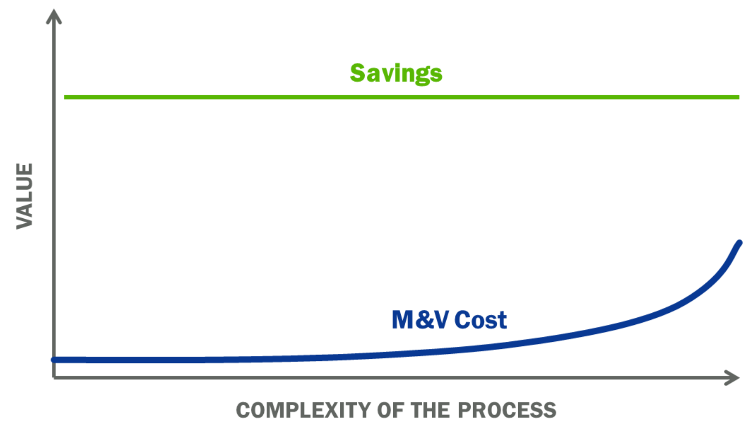

Figure 6: Level of Savings Generally Limits the Costs of M&V

The required level of rigor in a savings-reporting process is often a matter for project stakeholders, which depends on their desire for confidence in savings. However, improving accuracy usually requires more or better operational data, which may increase the level of effort and costs but has additional benefits. Enhanced operational data enables better insight of EEMs' effectiveness which can lead to adjustments that increase savings. Such data can be developed into performance indicators that can be used to manage EEM performance over time. More operational information may also help to size equipment for plant expansions or for the replacement of old equipment.

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 and the value of the resulting savings, as shown in Section 8.6. For example, scheduled indoor lighting loads 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.

Examples of Balancing Rigor and Cost
Consider a project where stakeholders agree savings uncertainty will be determined, with an expected savings of $100,000 per year and $5,000 per year cost for an Option C M&V approach based on one independent variable (outside air temperature). At 90% confidence, an uncertainty of no better than ± $25,000 (± 25% of savings) per year is possible. The expected uncertainty in reported savings can be reduced to ± $7,000 (± 7% of savings) by including an additional variable, but additional site visits would be required to collect the data. In this case, it may be seen as reasonable to increase M&V expenditures up to $10,000 per year (10% of savings), but not $20,000 per year (20% of savings).

11. COST SAVINGS

Determining the monetary value of the verified savings reported is not always within the scope of an M&V effort. When it is included, all related details on how cost savings computations will be made should be defined in the M&V Plan.

Although utility price schedules vary from monthly block tariffs to those with multiple time-of-use periods each day, cost savings are typically determined by one of two methods:

1) Determining the difference in the total costs of energy consumption and demand in the reporting period and what costs would have been without the EEM(s).
2) Valuing savings directly from energy unit savings based on marginal or time-of-use prices.

When planning for and reporting savings under a performance contract (or any contract where payments are contingent on proven energy/cost-saving performance) the parties should consider and agree on what to do with the uncertainty (if calculated) in reported savings in the context of financial reconciliation.

11.1. Total Costs

To calculate the difference in total costs of energy consumption and/or demand, the appropriate price schedule is applied to the energy consumption and/or demand. The same price schedule should be applied in computing both C_b and C_r using Equation 11.

Equation 11: Cost Savings Using Total Costs Method

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

Where:

C_b = Cost of the baseline energy plus any adjustments (i.e., cost of adjusted baseline energy)

C_r = Cost of the reporting period energy plus any adjustments (i.e., cost of adjusted reporting period energy)

The costs used in the equation are determined for the adjusted reporting period energy, including all routine and non-routine adjustments, and the adjusted baseline period energy, including all routine and non-routine adjustments.

This method can be best when actual costs are based on complex rate schedules, includes demand costs, or includes rate changes resulting from reduced consumption due to the installation of EEMs.

11.2. Marginal and Time-of-Use Prices

Alternately, cost savings may be calculated directly from energy unit savings using actual unit prices. This method for valuing savings applies per-unit prices of energy directly to energy unit savings. This involves multiplying energy units saved by the actual prices of the units of energy saved, which may vary. The actual per-unit price may be the marginal price, which is the cost of one additional unit of a commodity billed under a complex rate schedule such as block rates, which charge a certain price for the first defined amount used, with a different price for each additional block used. Similarly, determining cost savings under time-of-use rates requires tracking the energy savings during each pricing period.

Be careful to ensure that the marginal price(s) determined is valid for the level of consumption and demand of both the baseline and reporting periods. Similarly, care is required when applying time-of-use rates which charge different prices per unit of energy used based on time-of-day and season. The concept of establishing base prices and associated reporting period escalation factors, as discussed below, can apply to marginal price valuation procedures. Use of the actual price schedule is required in establishing the proper marginal prices for the future valuation of the project-specific savings.

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

11.3. 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, transmission fees, early payment discounts, and taxes.

The selected price schedule may be fixed or changed as prices change. (Increasing prices will shorten the EEM payback period, and decreasing prices will lengthen the payback period though total energy costs will drop when prices drop). When the conditions of the reporting period are used as the basis for reporting energy savings (i.e., avoided energy consumption or demand), the price schedule of the reporting period is normally used to compute “avoided cost.”

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.

Price schedules may change at points in time different from meter reading dates. Therefore, C_b and C_r in Equation 11 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.

11.4. Estimating Future Values

Defining how energy savings will be valued in future years requires significant consideration of potential risks that actual costs are more or less than those used in the M&V Plan.

Estimating future energy values may be complicated by the use of time-of-use rates and facilities with renewable energy, energy generation, and energy storage systems. In these cases, using hourly data is often necessary, and sub-hourly data can be required to assess peak demand cost impacts.

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 establishing energy prices. If the EEM 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’s M&V Plan and agreed to between the owner and contractor.

These contractually defined energy prices would then be used in reported savings rather than the actual reporting period energy prices. This lowers the risk to the owner 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 similarly lowers the risk to the contractor of meeting the energy performance guarantee in consumption and demand but still not meeting the associated cost savings due to a factor out of the contractor's control.

The determination and stipulation of an annual escalation rate to be applied to the base price schedule (to reflect projected reporting period prices) for each year of the reporting period may be agreed to in order to value energy savings. There are industry tools available to assist with the energy price 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).

11.5. Fuel Switching and Price Schedule Changes

The general strategy of applying the same price schedule to baseline and reporting period energy introduces some special considerations when the EEM 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 EEM 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 11. 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 the use reporting period prices is intended. 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 EEM(s) being assessed. For example, if the utility changed its price structures for no reason related to the EEM(s) being assessed, the general principle of using the same price schedule for valuing the adjusted baseline period energy and the adjusted reporting period energy (e.g., C_b and C_r) still applies.

12. COMMON M&V ISSUES

This section provides guidance on issues that commonly arise when conducting M&V, often independent of the IPMVP Option chosen.

12.1. Non-Routine Events and Adjustments

As described in Section 7.4.2 – Non-Routine Adjustments, when unexpected changes in conditions (including atypical operations) which are otherwise static (i.e., static factors) affect energy use within the measurement boundary, non-routine adjustments must be made, as indicated in the IPMVP savings equations. Non-routine adjustments are made in addition to any routine adjustments made with the mathematical model used to account for predictable changes in conditions.

Non-routine adjustments are determined from actual physical changes in the facility, equipment, or operations (i.e., 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 use of advanced data analytics-based tools (see Section 12.2 – Advanced M&V Methods) can help with the tracking and quantification of non-routine adjustments. Methods for identifying non-routine events and making non-routine adjustments are detailed in the *IPMVP Application Guide on Non-Routine Events & Adjustments*.[5]

Non-routine adjustments are needed where a change occurs in equipment or operations that affect the energy use within the measurement boundary. Such change occurs to a static factor, not to independent variables. These types of changes or non-routine events may occur during any M&V period, and changes may include facility size, equipment efficiency, capacity, operating sequence, or any other element that results in changes in energy use within the measurement boundary.

For example, an EEM improved the efficiency of a large number of light fixtures. When additional light fixtures were installed after the EEM installation period, a non-routine adjustment was made. The energy of the extra fixtures was determined and added to the baseline energy so that the EEM's savings were still reported.

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. Tracking of conditions may be performed by one or more parties, including 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.

[5] *IPMVP Application Guide on Non-Routine Events & Adjustments* is available through www.evo-world.org.

Examples of Changes in Static Factors Requiring Non-Routine Adjustments
Significant equipment problems or outages, facility shutdowns, or atypical operations
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 standards (e.g., light levels, temperature, ventilation rate)
Occupancy type, or operating schedule

12.1.1. 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, industrial process managers, or other stakeholders. Key user conditions may include light levels, space temperatures, ventilation rates, compressed air pressure, steam pressure, water flow rates, production rates, etc. The M&V Plan should record the agreed minimum operating conditions that will be maintained.

If minimum operating conditions are not met in the baseline period but are required in the reporting period, non-routine adjustments should be used where impacts to energy savings are significant. For example, equipment problems that are present in the baseline but are resolved by the installed EEM's (e.g., inoperable lighting fixtures replaced) may require non-routine adjustments to report savings accurately.

Similarly, when a certain condition or 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. (In some cases, this is referred to as a second or dual baseline.) Non-routine adjustments could be made, for example, on systems that are not providing adequate ventilation in the baseline period. All non-routine adjustments must be reported in the savings reports and should be tracked for the life of the project.

12.2. Advanced M&V Methods

Advanced M&V methods are characterized by the use of energy data in short time increments, typically daily, hourly or sub-hourly data collected from whole building utility meters, and the use of software tools that allow advanced data analysis and modeling strategies to be applied.

The increased prevalence of advanced utility meters, inexpensive computing power, and the development of data analysis methodologies have encouraged the use of these M&V methods. Adoption of these methods is supported by the development of open-source and proprietary software tools that include advanced data analyses and M&V analyses capabilities. These software tools use a variety of analysis platforms (e.g., R, Python) and rely upon regression analyses, machine learning, and other methods. These tools, which continue to evolve, can semi-automate M&V analyses and retain or improve the accuracy of results. Proprietary simulation software may be acceptable if algorithms, calculations, and statistical treatments are transparent and well documented.

The use of frequent data provides more accurate feedback on energy performance and savings achieved than traditional monthly data methods. More granular data can provide actionable insights for optimizing savings and allows Option C approaches to be credibly applied often when expected savings are lower than is reasonable with monthly billing data. Increased resolution in savings allows for time-of-use rates to be accurately applied and peak demand impacts to be evaluated. Additionally, it enables the ongoing assessment of energy performance and detection of changes in energy-use patterns, which may indicate a change in EEM performance or the occurrence of a non-routine event.

These methods directly impact the application of IPMVP Whole Building Option C and may also influence the implementation of other M&V Options. For example, these analysis methods may be applied to interval energy and independent variable data collected from building subsystems under an Option B approach. Interval energy meter data can be used to confirm operating schedules used in Option A or B applications and provides the basis for improved calibration of simulation models used in Option D.

Currently, information on advanced M&V is summarized in an *IPMVP white paper*[6] , and EVO has a tool testing portal[7] for testing the accuracy of software tools used for Option C assessments.

12.3. Demand Savings

Demand savings at a facility can provide capacity savings for the providing utility and cost savings to the facility. Demand savings are determined and valued differently under different circumstances, and details must be defined in the M&V Plan. Demand savings are typically realized when EEM's reduce the facility's overall demand during specific periods defined by the providing utility but can be based on other criteria such as site-level demand management goals.

Whole-facility electricity demand measurement usually requires continuous recording of the demand at the utility meter or a sub-meter, sometimes by logging the pulse outputs directly from the utility's meter. From this record, the meter's demand can be evaluated according to defined periods. In some cases, peak demand may be defined as the average demand reduction over specified hours of the year or corresponding to certain weather conditions. In other cases, peak demand may be defined as the highest value over a moving 15-minute average. Not all rates include demand charges, and some utilities may not identify the time of their peak demand in advance.

Electricity demand measurement methods vary amongst utilities. The method of measuring electric demand on a sub-meter should replicate the method the power company uses for the relevant billing meter. Care should be taken to ensure that the facility's load is metered following the utility's metering methodology, and any sub-meters are synchronized with the utility's readings so that high yet short-duration peak loads which may show up differently in a moving time interval than in a fixed time interval are represented properly. Where Option C methods are used, care must be taken to ensure the models used adequately predict demand, which in weather-dependent facilities may require using the maximum

[6] See IPMVP's Snapshot on AM&V, January 2020.

[7] EVO Tool Testing Portal is available https://mvportal.evo-world.org/. The EVO Tool Testing Portal was designed by Berkeley Lab to compare the predictive accuracy of any tool or model, independent of whether it is open source or proprietary.

or minimum ambient temperatures during the measured interval instead of the average temperature as an independent variable.

When determining peak demand impacts from Retrofit isolation methods which involve multiple installations of similar equipment with variable loads or schedules, demand savings will vary over time. For this reason, the demand savings realized at the whole building level need to be considered based on the actual equipment operations during the defined period. Where all loads are not measured, a coincidence factor that represents the ratio of the EEM's operating demand during the peak demand period to the full power draw of the equipment when operating, is needed to properly account for the diversity in equipment operations and the actual coincident impact during the utility's peak demand period.

Utilities often request demand reductions from customers with little notice or use automated controls to achieve short-term site-level demand reductions. In these demand response scenarios, short-term baselines may be defined by the utility, which uses only selected previous days of similar weather conditions. These baselines are typically more simplistic and use different routine-adjustment methods than those used in Option C.

12.4. Sub-Metering Issues

It is important to follow good measurement practices to enable the calculation of energy savings with reasonable accuracy and repeatability. Measurement practices are continually evolving as metering equipment improves. Therefore, use the current best practices in measurement instrumentation and data management to support determining the savings. Where meters are used for additional business value, it may be possible for those business functions to bear some of the metering costs.

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*.[8]

12.4.1. Electricity Measurements

To measure electricity accurately, measure the voltage, amperage, and power factor, or true Root Mean Squared (RMS) wattage with a single instrument. RMS power meters and data loggers should be used wherever possible. RMS measurements account for normally occurring distortions in alternating current as well as changes in power factor.

In rare cases of purely resistive loads, such as incandescent lamps and resistance heaters without blower motors, the measurement of amperage and voltage and spot measurement of Power Factor may be adequate to determine the wattage. It may also be possible to use only amperage data where a load is demonstrated to be constant, and spot power measurements of voltages and power factor have been conducted and are believed to be reasonably consistent. When not measuring RMS power, make sure that a resistive load's electrical waveform is not distorted by other devices in the facility. RMS values can be reported by solid-state digital instruments properly accounting for the net power wave distortions existing in alternating current circuits and should be used except in rare cases.

[8] *ASHRAE Guideline 14-2014, Measurement of Energy, Demand, And Water Savings*

12.4.2. Meter Calibration

Meters readings should be verified, and meters calibrated as needed following recommended procedures by the equipment manufacturer and of recognized measurement authorities. Traceable calibration equipment should be utilized wherever possible. Sensors and metering equipment should be selected based in part on the ease of calibration and the ability to hold calibration. An attractive solution is the selection of equipment that is self-calibrating. Modern solid-state power meters typically require less frequent recalibration once initially calibrated.

Volumetric measurements of natural gas may need to be temperature and pressure compensated, and the caloric value of the fuel may vary. For natural gas sub-metering, the actual caloric values used for utility billing purposes should be adopted.

12.5. Data Issues

12.5.1. Missing or 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 handled and when interpolation may be allowed. 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.

12.5.2. Use of Monitoring and Control Systems for Data Collection

Many facilities have computerized systems to monitor or control a facility’s equipment or processes. These are commonly referred to as either energy management and information systems (EMIS) or building automation systems (BAS), and can provide much of the monitoring and data collection for some M&V efforts. However, the system’s hardware and software must be capable of performing the intended monitoring control and data gathering simultaneously, without slowing computer processing, consuming excess communication bandwidth, or overfilling storage. The frequency of the data recorded as well as data communication and management methods should also be considered.

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 or other energy governing factors. Control systems can record energy consumption and demand with their trending capability, similar to EMIS systems which typically log the energy consumption of various equipment or systems.

Great care should be exercised to:

- Control access and/or changes to the system's trend log from which the energy or key parameter data are extracted.
- Develop post-processing routines for changing any control-system change-of-value data into time-series data for performing the analysis.
- Validate specifications of sub-meters are appropriate for the application, properly located, mapped, and calibrated. Get from the system supplier:
  - standard traceable calibrations of all meters and sensors used
  - evidence that proprietary algorithms for counting and/or totaling pulses and units are accurate, and the commitment that there is adequate processing and storage capacity to handle trending data while supporting the system's control functions

12.6. Statistics for M&V

Statistics are used when summarizing, analyzing, interpreting data, and when evaluating results. They are therefore often required in M&V, including when evaluating measured data, validating any mathematical models developed to routinely adjust energy consumption, when using measurements from a sample of equipment, and when considering uncertainty in savings.

Many statistical metrics may be used in M&V, and some (but not all) of the fundamental terms and concepts are outlined here. Details and related examples are available in *IPMVP's* Application Guide on Uncertainty Assessment[9].

12.6.1. Using Confidence Levels & Confidence Intervals

Statistical results are based on underlying assumptions along with specified analysis criteria. Where estimated values are based on mathematical analyses, a confidence level is specified, and the resulting measurement uncertainty is reported – together they express the accuracy of a result. These values are often specified as (confidence level required)/(uncertainty or half confidence interval desired), such as 95/10 or 80/15. Increased levels of rigor are indicated by higher levels of confidence with lower uncertainty (e.g., a result at 95/10 is more accurate than 80/15).

- ***Confidence level*** (or level of confidence) refers to the probability that the quoted range contains the true value.
- ***Confidence Interval*** (or precision[10]*)* is the range within which the true value is expected to occur at a specified confidence level (equivalent to twice the savings uncertainty).[11]

[9] Key statistical metrics include, but are not limited to, Mean, Sample Variance, Standard Deviation, RMSE or Standard Error of the Estimate, Degrees of Freedom, t-statistic, Coefficient of Variation of RMSE, Fractional Savings Uncertainty. See *Uncertainty Assessment for IPMVP, 2018.*

[10] Note use of the term precision can be counter-intuitive. Low-precision values correspond to tighter estimates (lower uncertainty).

[11] Confidence intervals are determined by multiplying the standard error of the estimate by a t-statistic, which increases with higher levels of confidence.

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Expressing Savings Uncertainty

The uncertainty in any reported savings value is properly expressed as the range within which we expect the true value to fall, with some level of confidence.

For example, a savings calculation may result in savings of 5,000 units with an uncertainty of ±200 units, with a confidence of 95%. Such a statement means that we are 95% confident that the true value of savings is between 4,800 and 5,200 units or are 5,000 units +/- 4%. The confidence interval is 5,200 – 4,800 = 400 units, and the savings uncertainty is 200 units.

12.6.2. Evaluating Results

Different levels of uncertainty may be acceptable. However, the accuracy of any specific model used should be agreed upon by stakeholders, including the mathematical models often used in Options B and C, and the simulation models used in Option D. To this end, specific threshold metrics may be used to assure reasonably accurate models. The level of confidence to be used in analyses is specified, and the resulting metrics which describe the goodness of fit of a model compared to actual data are reported (e.g., net mean bias error – NMBE, coefficient of variation of root mean squared error – Cv(RMSE), and Fractional Savings Uncertainty – FSU). Similarly, it is important to verify the significance of all independent variables included in a model using statistical metrics (e.g., t-statistic >2).

Statistical regression models may be required to meet certain minimum criteria to ensure the validity of reported savings results. Such assessments are necessary to 1) validate the significance of independent variables, 2) ensure a model is of sufficient accuracy to determine savings, and 3) to validate the assumptions of regressions.[12] The independent variables used in models to determine savings may be confirmed using a statistical metric (e.g., p-value, t-statistic) based on the specified confidence level and the quantity of data observed.

For a model to be considered valid, its accuracy must be considered relative to the level of savings expected. Specifically, the standard error of the estimate must be less than 50% of the expected savings at a specified confidence level, typically no lower than 68%, although these are modest thresholds. Lower levels of error at confidence levels of 80% to 90% are often preferred in M&V analyses, and these levels should be included in the M&V plan.

These are minimum threshold values required to ensure the expected level of savings can be determined using a given model. If this threshold is not met, reported savings may not be valid. Similarly, savings may not be fully evident (e.g., "lost in the noise") when uncertainty levels are too high. The total uncertainty in savings, however, includes the propagation of uncertainty from each component in the IPMVP savings equation (described below).

PROPAGATION OF ERRORS

To ensure that the resulting uncertainty in the reported savings is acceptable, the total uncertainty in savings must be managed and assessed when developing an M&V Plan. Propagation of errors is an

[12] Ordinary Least Squares (OLS) is a commonly used linear regression technique. OLS analyses are based on key assumptions including linearity in the coefficients, normal distribution of data, independence of variables (no multicollinearity), independence of data (no autocorrelation), and equal variances (homoscedasticity).

important concept and is needed to make this assessment. As discussed in Section 10.2, the values used in determining savings each have errors or uncertainties. The total uncertainty in savings is the combined uncertainties (or errors) in the values used in IPMVP Equation 2, including baseline period energy, reporting period energy, and whatever error exists in the computed adjustments. Note that error values may only be combined (using quadratic calculations described below) when they have the same confidence level.

Since energy savings are typically summed over time, the error in each value included must be considered. The total uncertainty, however, may not be a simple sum of errors but is usually less (according to probability theory, the sum of independent errors[13] may be simplified to a quadratic sum: the square root of the sum of the individual error components squared). Additional rules apply, but total uncertainty decreases somewhat over time as the total number of data points increases. Note that special considerations are needed to determine uncertainty when using frequent time-series energy data (e.g., hourly) affected by autocorrelation in the data, as the simplification in the combination of uncertainty components is no longer applicable.

12.6.3. Significant Digits & Rounding

Care must be taken to recognize the numbers of significant digits used in M&V calculations since misuse may compromise the acceptance of the result. Limiting significant digits and conservatively rounding the calculated savings to the nearest significant digit are best practices that support the M&V principle of conservatively estimating savings.

When performing arithmetical calculations, the inherent accuracy of the data must be considered, so the result does not presume greater accuracy than is defendable. For this reason, engineers have adopted a standard of rules related to the use of significant digits and rounding that limits the resolution of a result to that which is supported by the data.

Each value used in a savings calculation may have a different level of accuracy, which is usually indicated by the number of significant digits or its known measurement uncertainty. The resolution of calculated savings generally equals the smallest number of significant digits of any one of the values used, although treatment varies by analysis.

Note that including exact values with infinite significant digits does not affect the results of calculations since the results are limited by the value included with the least significant digits. To ensure consistency and repeatability, all calculations should be carried out by an arithmetic operation before applying rounding rules. It may be advisable to define these rules and how they will be applied in determining savings.

Example of Significant Digits Using a Utility Rate
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 rounding rule. This is because the utility rate is exact; it can be represented as $\$0.0600\bar{0}$ per kWh.

[13] With fully covariant errors, propagation of error is equivalent to their arithmetic sum.

12.7. On-Site Energy Generation and Storage

On-site renewable energy, energy generation, and energy storage systems are commonly found at facilities conducting the M&V process. Energy from these systems will need to be accounted for if they impact the energy consumption, generation, or costs within the measurement boundary.

Often, on-site sources are used to offset whole building energy and demand provided by a utility and, in some cases, provide excess energy to the utility. Energy and demand from these types of systems should typically be measured continuously. In these cases, projects using Options C or D need to include the on-site energy when establishing the baseline and reporting period energy. This may include considering multiple energy sources, including any energy provided to a utility.

In some cases, an on-site energy generation or storage system may be installed as an EEM. In these cases, direct measurement of the net energy and demand provided by the on-site system may be needed. Requirements for adjustments and calculations will vary based on the selected measurement boundaries, relevant variables, and reporting requirements.

Note in cases where multiple measurement boundaries are used to account for the whole building and energy storage and/or generation systems, the measurement boundaries should be disparate, and the energy measurements on each system should be made concurrently to determine the net energy for each. Care is required in applying the IPMVP savings equations in these instances, especially where energy flows may reverse.

When determining avoided energy consumption, the actual consumption and/or demand provided by generation and storage systems during the reporting period, the measured values can be used directly and may need to be aligned with the utility. If consumption and/or demand provided by the on-site energy system needs to be normalized to fixed conditions, independent variable data related to the system needs to be collected and used to routinely adjust the measured energy or demand to the selected fixed conditions.

In some cases, utilities have demand response or other programs where demand reductions are requested from customers with little notice and may use automated controls to achieve short-term site-level demand reductions. Facilities with energy generation and storage systems can provide supplying utilities additional flexibility in their demand levels and are sometimes referred to as Grid Enabled Buildings (GEB).

The value of the energy savings and the energy provided to the utility can be determined using the strategies for valuing savings in Section 11. Note that utility price schedule changes are likely to result from the installation of on-site energy systems, and time of use rate structures will usually apply.

12.8. Energy Services Performance Contracts (ESPCs)

An energy services performance contract (ESPC) is a contractual agreement between an energy services company (ESCO) and a facility owner. The ESCO installs EEMs at the facility, and the owner pays the ESCO back for their investment over a period of years from the energy cost savings generated from the project. The ESCO typically monitors the performance of the project for the life of the contract and reports verified energy savings periodically.

Contracting arrangements vary, but the M&V results are the basis for these financial transactions. In these instances, the M&V Plan must be carefully crafted to ensure sufficient cost savings are generated to cover contracted cash-flows for the duration of the contract term, and to properly allocate savings risks (i.e., savings are lower or higher than expected) between stakeholders. Since the details in the M&V Plan effectively allocate risks, M&V approaches used should consider the responsibilities of each stakeholder.

Different types of contract arrangements may be selected due to the project's funding source, the ESCO selected, the risk tolerance of the stakeholders, or other considerations.

In guaranteed savings arrangements, such as in municipal projects, the primary goal of the project may be to perform facility upgrades or acquire equipment. M&V efforts may be used to ensure savings meet fixed financial performance thresholds based on ensuring a minimum level of savings is achieved. In shared savings arrangements, however, payments may vary and are based on actual performance. In other cases, the ESCO owns, operates, and maintains the energy-using equipment related to the EEMs, and the facility owner buys the end-use (e.g., steam, chilled water) for agreed-upon rates over a specified period of time.

Under any of these, there are several issues that must be addressed. Typically, these include financial, operational, and performance-related considerations such as, but not limited to:

- Interest rates, construction costs, schedules, future energy costs.
- Future operating conditions, managing non-routine adjustments.
- Long-term EEM performance and related operations, maintenance, and repairs.

12.9. Utility & Governmental Programs

Utility and government agencies create and manage energy reduction programs for a number of reasons, including regulatory mandates requiring the cost-effective acquisition of energy savings. In these cases, M&V is often conducted by the program and then furthered by additional evaluation, measurement, and verification (EM&V) activities conducted on a sample of the program's projects to assess cost-effectiveness and overall savings achieved.

Goals of energy and demand savings programs vary widely, although many programs must achieve a minimum level of energy or demand savings from a portfolio of projects while meeting cost-effectiveness criteria, as determined by a qualified third-party program evaluator.

These programs include those focused on above-code performance in new construction projects, supply-chain incentives offered to manufacturers and equipment suppliers, rebates to customers based on equipment installed, custom energy projects with stringent site-level M&V, and demand flexibility programs (e.g., demand response) using near-real-time data.

Programs usually have their M&V guidelines, which are often based on IPMVP and may include the application of all IPMVP Options (e.g., Option A – lighting retrofits, Option B – custom equipment upgrades, Option C – comprehensive facility upgrades, and Option D – new facility construction).

In many instances, however, the procedures for each of IPMVP Options are generally followed but other elements of the IPMVP are not incorporated. Program-level M&V may not adhere to IPMVP requirements for any number of reasons, including, but not limited to:

- Lack of site-level measurements in the baseline and reporting periods.
- Not establishing a project-specific M&V Plan.
- Lacking data on baseline operating conditions.
- Using statistically invalid mathematical models.
- Ignoring non-routine events and corresponding adjustments needed in site-level savings.

- Site inspections are performed, but energy or key parameters are not measured.
- Mis-stating the IPMVP Option being used.

Site-level energy savings that are not based on IPMVP's requirement for performance measurements made in situ before and after implementation of an EEM may be inaccurate. In aggregate, however, these savings estimates may be sufficient for planning and tracking overall program progress where the savings values are updated through a third-party EM&V effort.

12.9.1. Evaluation Measurement & Verification (EM&V)

Program evaluations are made subsequent to, or concurrent with, program-level M&V efforts. EM&V efforts hope to validate and potentially improve the rigor in the energy savings reported by a Program, and may also estimate the ongoing energy savings from the Program's EEMs in future years.

Utility and Governmental programs have specific EM&V guidelines, which often claim adherence with IPMVP and can include additional criteria for assessing a Program's savings. EM&V efforts may use any of the IPMVP M&V Options. IPMVP adherent strategies effectively used by evaluators include, but are not limited to:

- Supplementing the evaluator's in situ data collection efforts with data collected by the Program, especially data from the baseline period.
- Using adjacent measurement periods and utilizing on-off control strategies to evaluate conditions with and without the EEM (described in Section 7.2.4).
- Lowering the baseline period energy used in savings determination to code-required conditions, effectively using a second or dual baseline.

In many cases, full adherence with IPMVP is not possible due to the third-party evaluator's access to site-specific baseline data. However, like the Programs being evaluated, EM&V efforts may generally follow but not fully adhere to IPMVP's requirements for any number of reasons. The examples listed above for program-level M&V may apply, and additional reasons may include but are not limited to:

- Lacking data on baseline conditions and any subsequent changes in static factors.
- Using comparison groups to make non-routine adjustments in savings instead of project-specific data.
- Predicting future savings based on generalized assumptions regarding the life of EEMs.
- Using terminology which conflicts with IPMVP's terms and definitions.
- Using a small sample of projects which may not effectively represent the actual projects.

Even where the procedures used in a program evaluation are not fully adherent with IPMVP, EM&V efforts generally follow the IPMVP principles, such as making conservative savings estimates. However, where energy savings are not based on IPMVP adherent M&V procedures applied at each individual project, the results can be unreliable.

12.10. Water

Water-efficiency M&V is analogous to energy-efficiency M&V and uses similar M&V techniques. The relevant technique for any project depends upon the nature of the change being evaluated and upon the site-specific conditions and water-metering available.

Water-consuming equipment is often in the control of facility users (building occupants or production managers). Therefore, it can be difficult to monitor user behavior as needed to make adjustments to total-facility water use for the application of Option C methods. Retrofit isolation methods are often more easily applied, using a sample of the retrofits to demonstrate the performance of an entire group of changes.

Water used by mechanical systems may be affected by evaporative cooling loads, operating setpoints, level of blow-down required for hydronic systems, system leaks, the integrity of steam and condensate systems, and variations in boiler loads.

Where outdoor water use is being evaluated, the adjustment term in IPMVP Equation 2 may be related to parameters that drive water use, such as rainfall and evaporation rates. Liquid flow measurement devices are most commonly applied in M&V for water efficiency projects, and a combination of sampling may be appropriate.

12.11. Greenhouse Gas (GHG) Emissions Reduction Quantification

IPMVP methods quantify energy savings in energy units saved at the site level by energy source and do not consider the impacts of site-level energy savings at the energy source, which may be different due to generation, transmission, and distribution losses. This is a key consideration in quantifying GHG emissions reduction quantification. Additionally, the level of greenhouse gas emissions associated with each energy source is different and may change over time.

To verify an emission-reduction commodity, the IPMVP and the project's M&V Plan should be used in conjunction with the appropriate emissions certificate scheme's accounting protocol's (e.g., ISO 14064–2) specific guidance related to converting energy savings into equivalent emissions reductions and to ensure compliance with any methods required.

The following should be considered when designing the process for determining the units of energy saved, in accordance with the relevant emission-trading program:

- Electrical savings should be split into peak periods and off-peak periods or further delineated as required.
- Self-generation at the facility should be metered separately.
- The adjusted baseline energy may need to change to suit the program's requirements.
- Energy savings should be tracked by individual site, by fuel type, and combustion device as needed.
- The GHG emissions conversion factors and their source for valuing the energy savings should be referenced in the M&V Plan and M&V Report. Factors may vary by fuel type, location, and time-of-use.
- When reporting verified energy savings and corresponding GHG Emissions, clearly indicate the scope of the verified energy savings, which may not represent an absolute quantification of GHG reductions for the stated boundary and reporting period.

12.12. Persistence of Savings

Persistence of energy savings can be achieved beyond the M&V reporting period by performing follow-on efforts that build on M&V. One approach is "Monitoring, Targeting, and Reporting" (MT&R), which can seamlessly follow the M&V process. If Options B and C have been used for verifying savings, the project will have metering in place for the routine measurement of consumption. More importantly, models will also have been developed that correlate energy use with driving factors such as weather. These same models can be "re-tuned" to estimate energy consumption that accounts for EEM installation. This enables a periodic comparison of actual and expected consumption, which will readily reveal and quantify any loss of EEM effect (or unrelated waste), enabling prompt remedial action to be taken in cases where the unexpected avoidable cost is deemed significant.

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13. M&V PLAN & REPORTING REQUIREMENTS

The guidance provided in this section may be used by a project engineer or M&V specialist to develop or review an M&V Plan or report for IPMVP adherence. This section describes content required in an M&V Plan and M&V Report. For an M&V Plan or Report to be considered adherent, it must include all of the suggested content presented in this section.

A key component in IPMVP adherence involves the development and implementation of a clear and transparent project-specific M&V Plan that describes all of the measurements and data to be gathered, analysis methods employed, and verification activities that are conducted to evaluate the performance of a measure or a project.

An adherent M&V Plan will help ensure that the measure or the project can realize its maximum potential and that the savings can be verified with adequate certainty. For performance contracting projects where the M&V Plan defines how savings will be verified to ensure the contractual savings guarantee has been met and to validate associated payments, an adherent M&V Plan needs to be developed and agreed to as part of the final contract approval and/or before the installation of the project EEMs.

13.1. M&V Plan Requirements

An adherent M&V Plan addresses all of the criteria presented in the items below and also meets adherence requirements specified in Section 6. Note specific additional adherence requirements for projects using Options A, Option C, and Option D, and These items are also required in the M&V Reports.

Headings for each of the Sections below can be used as a guide for setting up headings/sections in an M&V Plan[14]. Although there is a logical/recommended flow to the order of the topics to be included in the M&V Plan, this specific order is not a requirement for adherence. It is only required that all these points are addressed in the M&V Plan.

13.1.1. Facility and Project Overview

An M&V Plan should provide an overall description of the facility and the proposed project along with a list of all the EEMs that are included as part of the project. This section should also include references to any relevant energy audit reports or other analyses used to develop the project.

13.1.2. Intent of Energy Efficiency Measure

This section of the M&V Plan should provide a clear understanding of each measure's scope and intent. At a minimum, this section should include:

- A detailed description of the measure.
- How the measure saves energy, demand, or other resources (e.g., improves efficiency, reduces operating hours, etc.).
- The measure's effect on operational factors such as temperature set points, hours of operation, etc., and if the measure will correct any operational deficiencies.
- An inventory of impacted equipment.
- Expected savings estimated in energy units and the source of the estimate.

[14] An M&V template that corresponds to this format is available from www.evo-world.org.

13.1.3. Selected IPMVP Option and Measurement Boundary

Specify the IPMVP option(s) that will be used to evaluate savings.

Clearly identify the measurement boundary for saving determination. The boundary may be as narrow as the flow of energy through a pipe or wire or as broad as the total energy consumption and demand across many facilities.

This section should also describe the nature of any interactive effects beyond the measurement boundary together with their possible effect on project savings. Quantified interactive effects should also be included in this section with appropriate justification.

13.1.4. Baseline Period Energy and Conditions

This section of the M&V Plan documents the facility's or system's baseline energy and demand and consumption within the measurement boundary along with corresponding energy influencing factors (e.g., independent variables, operating conditions, and static factors), and must be consistent with the Option selected and data required to perform specified analyses.

Baseline documentation should include the following information:

Identification of the Baseline Period

Identify the specific time period over which the operation and conditions of the facility or system are assessed and documented prior to the implementation of EEMs. This baseline period is often a year but can be any period depending on the specific M&V needs.

Baseline Energy Consumption and Demand Data

Include the actual baseline data and how it was collected (including technical details). If the baseline energy data does not yet exist, the M&V Plan should include exactly how the baseline will be established and used.

Baseline energy consumption and demand data may include utility billing data and/or meter interval data if Options C or D are used, or meter interval data, spot measurements, or short-term measurement data if Options A or B are used. This includes the energy data collected over the baseline period. These data are normally considered to be the dependent variable.

Energy Influencing Variable Data

Data collected of the energy influencing variables corresponding to the time period of the energy consumption data. This may include variables such as production rates data, ambient temperature, baseline equipment speeds, pressures, or any other variable collected through spot measurements, short-term or long-term metering. These data are normally considered to be the independent variables that affect the dependent variable discussed above

Operating Conditions

Document the prevailing facility conditions during the baseline period corresponding to the dependent and independent variable data. These conditions (i.e., static factors) are normally assumed to remain unchanged over the baseline, installation, and reporting periods but must be documented to assess the need for non-routine adjustments. Examples of baseline conditions may include, but are not limited to:

- Facility size, installed equipment, and systems.
- Occupancy type, occupancy density, equipment loads and equipment run times.
- Operating conditions (e.g., equipment control sequences and set points, lighting levels, ventilation levels) for each operational mode and season.
- Significant equipment problems or operational changes during the baseline period.

The M&V Plan should record the agreed minimum operating conditions that will be maintained. Specified conditions may include light levels, space temperatures, ventilation rates, compressed air pressure, steam pressure, water flow rates, production rates, etc.

Note: See discussion in Section 7.3 – Baseline Period Conditions.

13.1.5. Operational Verification Requirements

Specify the operational verification activities that are required after EEM installation to confirm the installation is complete, meets specifications, and has the potential to save energy as expected. This section should include:

- What data will be collected to confirm the EEM is properly installed and meets the EEM's Intent.
- Who is responsible for conducting these verification activities.
- If these activities are to be repeated during the reporting period, when and by whom.
- What will be reported regarding the verification activities conducted.

13.1.6. Reporting Period(s)

The reporting period is a selected interval for evaluating and quantifying the post-installation performance of the measure. The M&V Plan shall identify the reporting period(s) for which the measure or a project is being evaluated. This may be for a short period of time right after the installation of the measure to ensure that it is performing as intended, or it could be for a longer time at periodic intervals such as a year, multiple years, or other time periods.

In cases where the baseline period and reporting period are not of the same length, it is important to explain how the time frames are normalized so the baseline and reporting period energy consumption and demand are compared evenly and reliably.

In a performance contract, the performance period refers to the duration of the project guarantee and is made up of numerous reporting periods. Normally the ESCO must report on the performance of the project and the EEMs regularly for the entire duration of the performance period. Note that once M&V activities cease or are concluded, the reporting period would no longer be considered IPMVP adherent.

13.1.7. Basis for Adjustment

The operating conditions that affect energy consumption may differ between the baseline and reporting periods. It is important to make reliable adjustments to account for these changes in operating conditions. The conditions for the basis for adjustment determine whether savings are reported as avoided energy use or as normalized energy savings.

The M&V Plan should provide details on how the baseline and/or reporting period energy consumption and demand will be adjusted to allow for valid saving calculations as described in Section 4.3. The method for making routine adjustments (e.g., forecasting, backcasting, or adjusting to standard conditions), the conditions selected for the basis for adjustment, and the type of savings to be reported (i.e., avoided energy use or normalized energy savings) should be specified.

Table 11: Basis of Adjustment and Type of Savings

Type of Savings	Basis of Adjustment	Routine Adjustment Method	Description
Avoided Energy Consumption	Reporting Period Conditions	Forecasting	Baseline period energy is adjusted to reporting period conditions
	Baseline Period Conditions	Backcasting	Reporting period energy is adjusted to baseline period conditions
Normalized Energy Savings	"Normal" or Fixed Conditions	Normalizing	Both the baseline and reporting period energy are adjusted to standard conditions, e.g., Typical Meteorological Year (TMY) conditions

NON-ROUTINE ADJUSTMENTS

Detail any non-routine adjustments required to the baseline to adjust for deficiencies in the baseline operating conditions.

The M&V Plan should provide a description of the criteria and methods for identifying and validating non-routine events and for making relevant non-routine adjustments to account for unexpected changes in static factors during the reporting period. State criteria for when non-routine events will be evaluated and adjustments will be required to properly determine savings. Since non-routine changes can either increase or decrease savings, they must be treated equally.

Describe methods that will be used in making any non-routine adjustments, including how cost impacts will be estimated. Referencing specific procedures from *IPMVP's Application Guide on Non-Routine Events and Adjustments* may be effective.

13.1.8. Calculation Methodology and Analysis Procedure

The M&V Plan needs to specify data analysis procedures, model descriptions, and assumptions that are used to calculate savings for each of the reporting periods. The IPMVP savings equation(s) used should be included.

For each model used, identify and define all independent variables, dependent variables, and other model-related terms. Report all coefficients and constants, as well as statistical metrics (CV{RMSE}, MBE, R^2, t-statistics) for independent variables and other model elements or terms. Report the range of independent variables over which a model is valid.

13.1.9. Cost Savings

The M&V Plan should state if assigning a monetary value to savings is required. If so, the utility prices or tariffs that will be used to calculate the cost savings associated with the measure or project and how the monetary value of savings will be adjusted if prices change during the life of a measure or a project should be specified. The plan should clearly define and report how utility/resource price changes or other variables that affect the valuation of the M&V results will be handled, and details of any inflation and/or escalation rates assumed or contractually stipulated.

There are many considerations to be made when stating the relevant prices, and the reader should refer to Section 9.1 – Applying Energy Prices for further details.

If quantification of equivalent Greenhouse Gas Emissions is required in the reported M&V results, then the applicable GHG equivalence factors are determined for the measurement boundary and measurement period. Equivalence factors vary over time and location, and as such, it is important to reference the source of these factors (e.g., internal reporting values, the utility reported, legislated by the applicable government).

13.1.10. Metering Details

The plan should specify the details for collecting each point that will be used as M&V data, including spot and continuous metering of energy or key parameters. For non-utility energy meters, the M&V Plan should specify:

- Meter specifications including – type, make, model, as well as the range, resolution, accuracy, and precision of readings.
- Data to be collected, formats, and related responsibilities.
- Meter reading and witnessing protocol if required.
- The installation procedures for new or temporary meters.
- Meter calibration requirements and procedures.
- Details for data collection and transfer.
- Method of dealing with lost or missing data.

13.1.11. Monitoring and Reporting Responsibilities

The plan should state responsibilities for collecting, analyzing, archiving and reporting the data. Management of M&V data should be assigned to the party that is qualified to efficiently and effectively access, manage, and provide data sets. Responsibilities should include as a minimum:

- Acquisition of Energy and Independent Variable data.
- Management of measurement equipment and systems.
- Monitoring of Static factors impacting energy use within the measurement boundary.
- Operational verification and periodic inspections.
- Analysis and retention of acquired data.
- Preparation and publication of M&V Reports.

13.1.12. Expected Accuracy

The M&V Plan should include the expected accuracy of the reported energy savings. Describe sources of uncertainty in the savings such as measurement, data capture, sampling, modeling and data analysis, and describe uncertainty assessment to be used in the planned savings report.

This assessment should include qualitative and any feasible quantitative assessment related to the level of uncertainty in the savings. Report all sources of uncertainty in savings, information on the source of uncertainty, the expected direction, and the magnitude of impact on savings. In some cases, estimates of uncertainty in savings may be required.

13.1.13. M&V Budget

The M&V Plan should include the budget and the resources required for M&V activities, including saving determination and the costs associated with both the initial setup and ongoing tasks for evaluating, documenting the baseline period conditions, and reporting the estimated savings and other performance metrics required for each of the reporting periods.

13.1.14. M&V Report Format

The plan should detail the agreed format and content for reporting the M&V results during the reporting period, including the frequency of reporting. Refer to Section 13.3 – M&V Reporting for further details.

The distribution of the report/s and any requirements for formal review and issuance should be stated.

13.1.15. Quality Assurance

The M&V Plan should include quality-assurance procedures and processes that will be used in baseline and post-retrofit data collection, calculations, saving reports, and any interim steps in preparing reports.

Quality assurance procedures should include:

- Inspections at regular frequencies to ensure that the measure and equipment continue to be operated as intended
- Methods of dealing with lost or missing data

Other activities may include:

- Requirements for third-party oversight or review
- Peer review of savings calculations
- Assessing the accuracy of measurement methods
- Calculating uncertainty in savings

13.2. Additional M&V Requirements

13.2.1. Option A - Additional Requirements

JUSTIFICATION OF ESTIMATES

The M&V Plan should clearly identify the variables to be estimated as part of the savings calculation and their impact on the uncertainty in savings. This must include the actual values used and the source of the estimated values. Although not required, it is best practice to show the overall significance of these estimates to the total expected savings by reporting the range of possible savings associated with the range of plausible values of the estimated parameters.

PERIODIC INSPECTIONS

The plan should specify the periodic inspections that will be performed in the reporting period to verify that equipment is still in place and operating as assumed. This can include the measurement of key parameters and checking any estimated values to ensure that they are still valid.

13.2.2. Option C – Additional Requirements

METERS INCLUDED

All fuels used within the measurement boundary should be included in analyses. Justification for excluding any fuels should be provided.

SOFTWARE IDENTIFICATION

The M&V Plan should include the name and the version number of any software or data analysis package that is used to calculate savings.

ENERGY AND INDEPENDENT VARIABLE DATA

The M&V Plan should describe the source of all energy and independent variable data and the processes used to obtain and manage the data. The data used should be reported, and raw data should be archived and made available as needed. This may include interval data, utility invoices, weather data, and data on other independent variables.

The M&V Plan and Report should provide copies of the energy, weather, and other data used in the analyses, including any input and output files and/or reports. Details on any data post-processing used, including analysis methods, tools, and calculations should be provided.

MODEL FIT METRICS

The M&V Plan should include the goodness of fit statistics from the selected model (e.g., confidence level, Standard Error, CV(RMSE), R^2, Net Mean Bias Error, t-statistic for independent variables), and the goodness of fit criteria required for the baseline energy model to be acceptable given the level of savings expected. Include the range of the independent variables covered by the model and the range for which it will be considered valid in the reporting period.

The M&V Reports should similarly detail the goodness of fit metrics for reporting period models. Although not required, it is best practice to calculate uncertainty in savings and to report the range of possible savings values.

13.2.3. Option D - Additional Requirements

SOFTWARE IDENTIFICATION

The M&V Plan should report the name and the version number of the simulation software that is used to calculate savings.

INPUT/OUTPUT DATA

The plan should provide copies of the input files, output files and/or reports, and weather files or weather file identification, used for the simulation, including any post-processing or presentation development methods and calculations.

MEASURED DATA

The M&V Plan should describe the process of obtaining any measured data, including which input parameters were measured and which input parameters were estimated. The actual measured data should also be reported and raw data should be archived and made available as needed. This may include interval data or utility-provided bills.

MODEL CALIBRATION

The plan should report the energy and operating data that will be used for calibration, including the calibration requirements (e.g., CV{RMSE}, MBE, etc.) and the accuracy with which the simulation results must match the calibration energy data and actual facility conditions. Supporting data should be provided at a minimum of one month (i.e., billing period) intervals, but more resolution is preferred, and include a description of the steps taken to calibrate the simulation model. M&V Reports should also include model calibration results, as specified in Section 9.4.2.

JUSTIFICATION OF ESTIMATES

The M&V Plan should clearly identify the variables estimated as part of the savings calculation and their impact on the uncertainty in savings. This must include the actual values used and the source of estimated values. Although not required, it is best practice to show the overall significance of these estimates to the total expected savings by reporting the range of possible savings associated with the range of plausible values of the estimated parameters.

13.3. M&V Reporting Requirements

Periodic M&V Reports are prepared to document and communicate the findings of the measurement and verification project using procedures outlined in the M&V Plan. The frequency and the format for these M&V Reports must be defined 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 an appropriately qualified person.

The report should include, as a minimum, the following information:

13.3.1. Overview of M&V Report

- Date of M&V Report.
- Author and Reviewer of the M&V Report.
- Reference to the relevant M&V Plan.
- Key parties included in the distribution of the published report.
- Entities/individuals involved in the reporting period activities.
- Quality assurance procedures and actions taken.

13.3.2. Project Background

- M&V Option chosen for the EEM or project as part of the M&V Plan.
- Description of EEM(s).
- Reporting period start and end dates and frequency of M&V Reports.

13.3.3. M&V Data Collection Activities Conducted During Current Reporting Period

- Start and end time for the measurement period.
- Energy and key parameter data collected.
- Data for independent variables and static factors.
- Description of and findings from inspection activities conducted.
- Installation period activities including details related to operational verification activities conducted, if not yet reported.

13.3.4. Savings Calculations and Methodology

- Provide a detailed description of data analysis and methodology.
- Provide an updated list of assumptions and sources of data used in the calculations.
- Provide details of any baseline or saving adjustments, including routine and non-routine adjustments to account for changes. Previous non-routine adjustments should be included if they impact reported savings.

13.3.5. Verified savings

- Include a clear presentation of all energy and demand savings, cost savings, and a comparison to the expected savings.
- Discuss sources of uncertainty. If required, provide estimated uncertainty in reported savings.
- Provide details of values used to calculate the value of reported savings, if required, and the source of the values (e.g., utility rate or contract details).

13.3.6. Additional Information Required

All additional items required for the M&V Plan for a specific Option should also be included in the M&V Reports, including those specified above as 'Additional Requirements' for Options A, C, and D.

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