BPA Custom Project Measurement and Verification Training

October 29, 2024

Your Instructor: Todd Amundson, P.E.

- Currently BPA EE's Industrial Engineer Technical Lead. For the past 23+ years, he has primarily focused on energy management, Energy Smart Industrial, Strategic Energy Management (SEM), US DOE 50001 Ready and SEP (CPEnMS, SEP PV), custom project M&V Plans, and development / maintenance / training of BPA M&V Protocols and Guidelines, plus PMVA training.

How about you?

- Please take a minute and tell us about yourself, and your activities related to:
  - Energy management retrofit and new construction/major renovation projects
  - M&V:
    - your experience
    - your expectations for today

Today's Webinar

What will be learned:

– Familiarity with present (recently updated) BPA's M&V resources and general background/history

– Familiarity with general overview of the relationship of BPA M&V Protocols to RTF, to IPMVP

– Understand the major differences in BPA's M&V Protocols

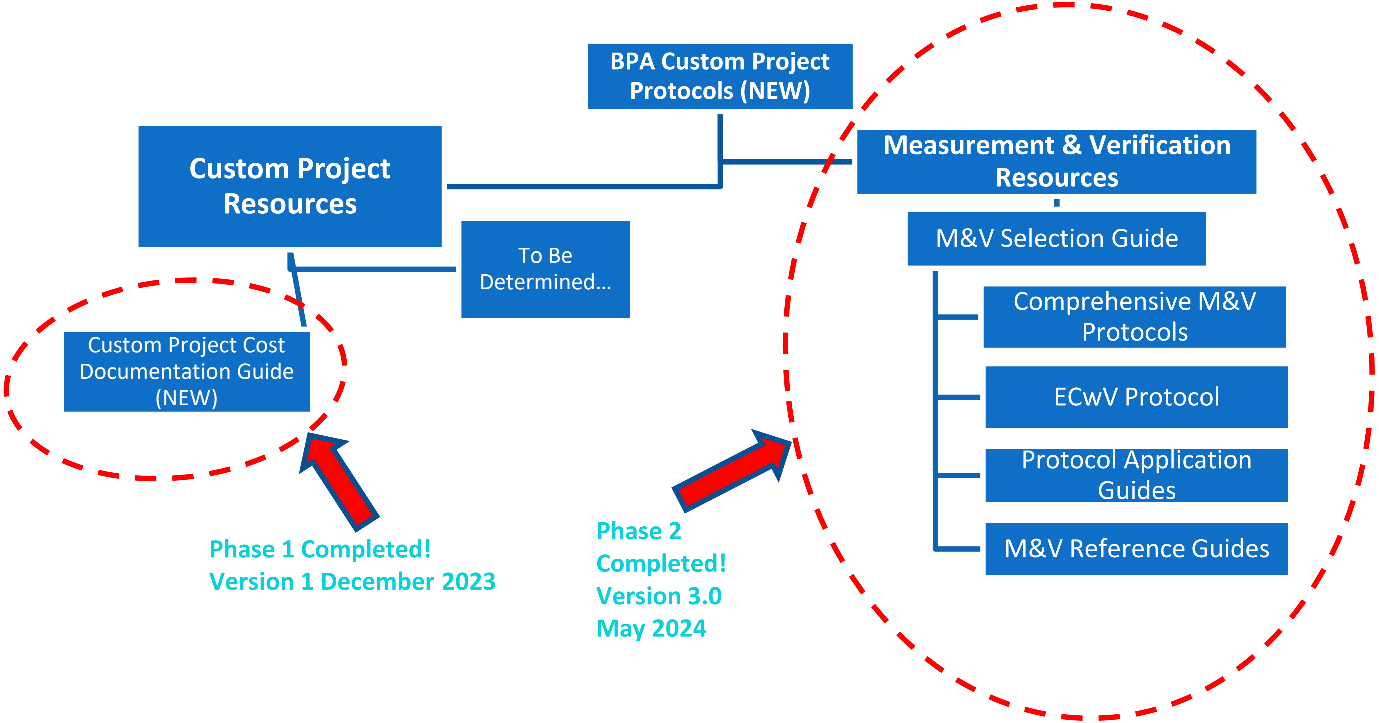
– Examples of selecting an M&V method:

- Meter-Based Energy Modeling
- End Use Metering
- Engineering Calculations with Verification

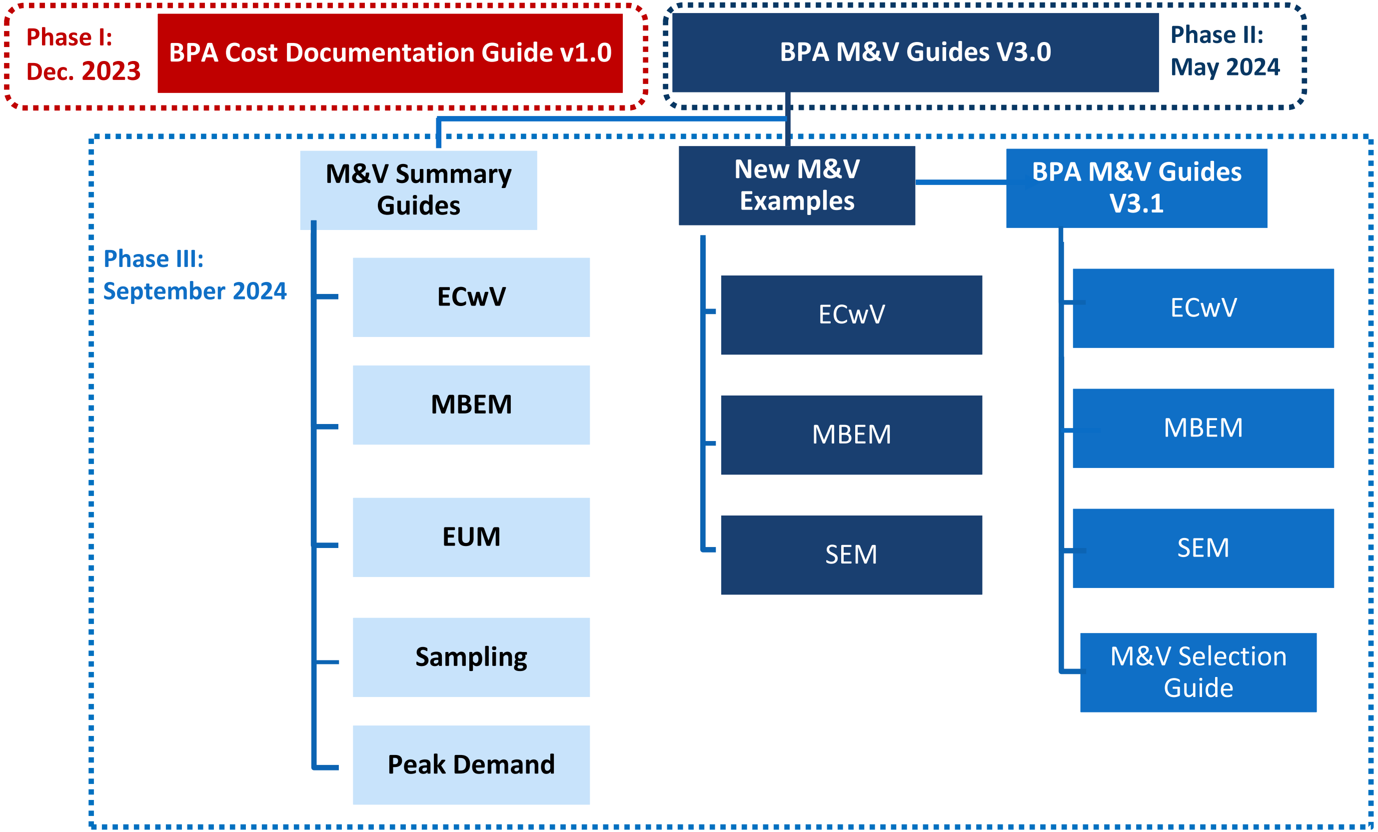
Other M&V examples/general overview as time allows:

- Existing Building Commissioning
- Estimating Peak Demand Impacts
- Electrification

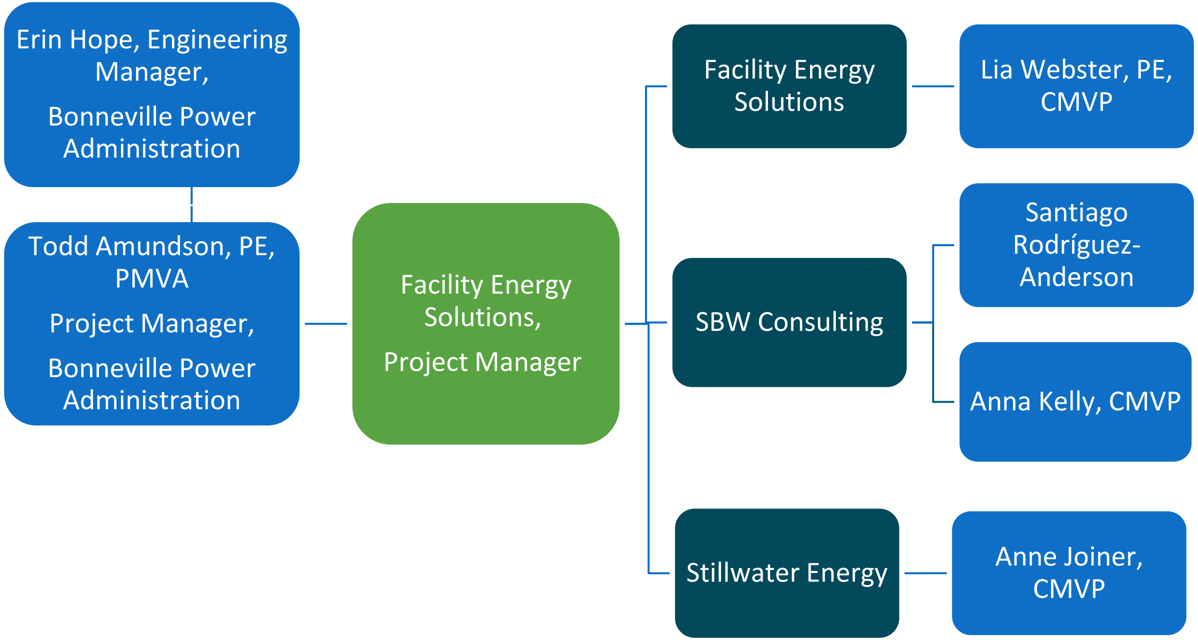
Custom Project Protocols Project Overview



Project Overview



Team

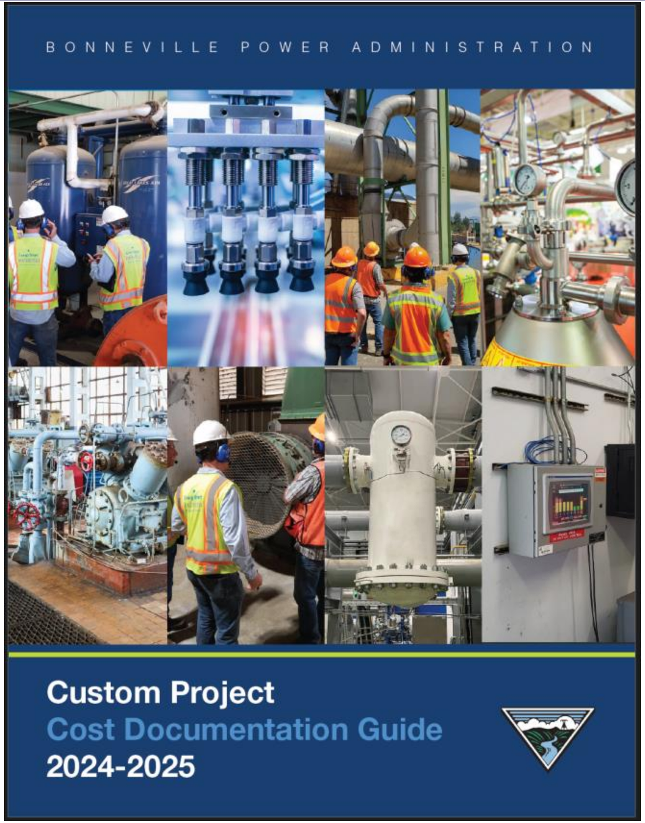

Erin Hope, Engineering Manager,
Bonneville Power Administration
Todd Amundson, PE, PMVA
Project Manager,
Bonneville Power Administration
Facility Energy Solutions,
Project Manager
Facility Energy Solutions
Lia Webster, PE, CMVP
SBW Consulting
Santiago Rodríguez-Anderson
Anna Kelly, CMVP
Stillwater Energy
Anne Joiner, CMVP

BPA's Cost Documentation Guide

Custom Project Cost Documenation Guide:

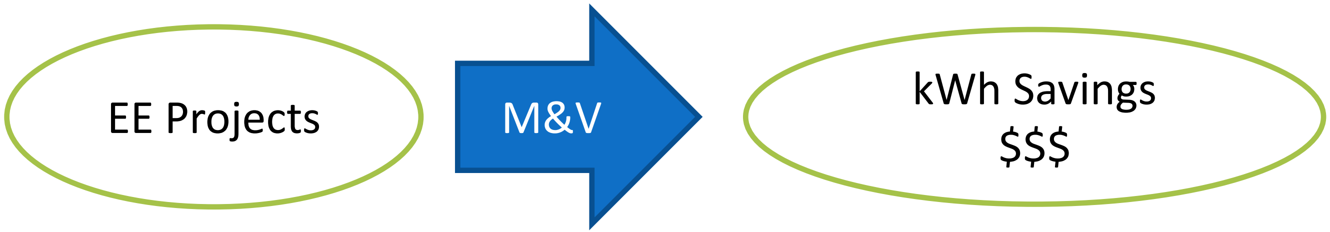
- Completed December 2023
- Defines project costs eligible for incentives
- Details supporting documentation required
- Specifies cost impacts needed for cost effectiveness calcs
- Added to BPA Custom Project Library:

  https://www.bpa.gov/energy-and-services/efficiency/custom-project-protocols



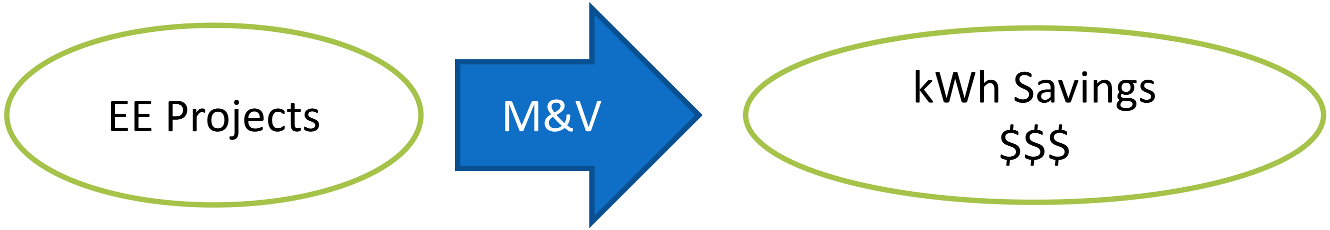
BPA's Custom Project M&V Requirements

Role of Measurement & Verification (M&V)



- M&V determines energy savings (kWh) from EE projects
- Establishes BPA’s payment to a project sponsor
- Ensures programs are cost effective

Role of Measurement & Verification (M&V)



- Regional Technical Forum (RTF) sets M&V methods
- Supported by program evaluations
- Applied as defined in BPA's Implementation Manual

Custom vs. Non-Custom Measures


Regional Technical Forum

Regional Technical Forum Operative Guidelines for the Assessment of Energy Efficiency Measures

Regional Technical Forum
Approved: January 31, 2018
Edited: May 18, 2018

RTF's Operative Guidelines for the Assessment of Energy Efficiency Measures: https://nwcouncil.app.box.com/v/2020RTFGuidelines

Custom vs. Non-Custom Measures

Custom Protocol

Unit Energy Saving (UES)

Standard Protocol

RTF's Operative Guidelines for the Assessment of Energy Efficiency Measures: https://nwcouncil.app.box.com/v/2020RTFGuidelines

Non-Custom Measures

Unit Energy Saving (UES)

Standard Protocol

BPA's Implementation Manual:
hthttps://www.bpa.gov/-/media/Aep/energy-efficiency/document-library/24-25-im-april24-update.pdf

- Details all UES and standard protocol measures

Interim Solutions 2.0:
https://www.bpa.gov/energy-and-services/efficiency/interim-solution-2-0-files

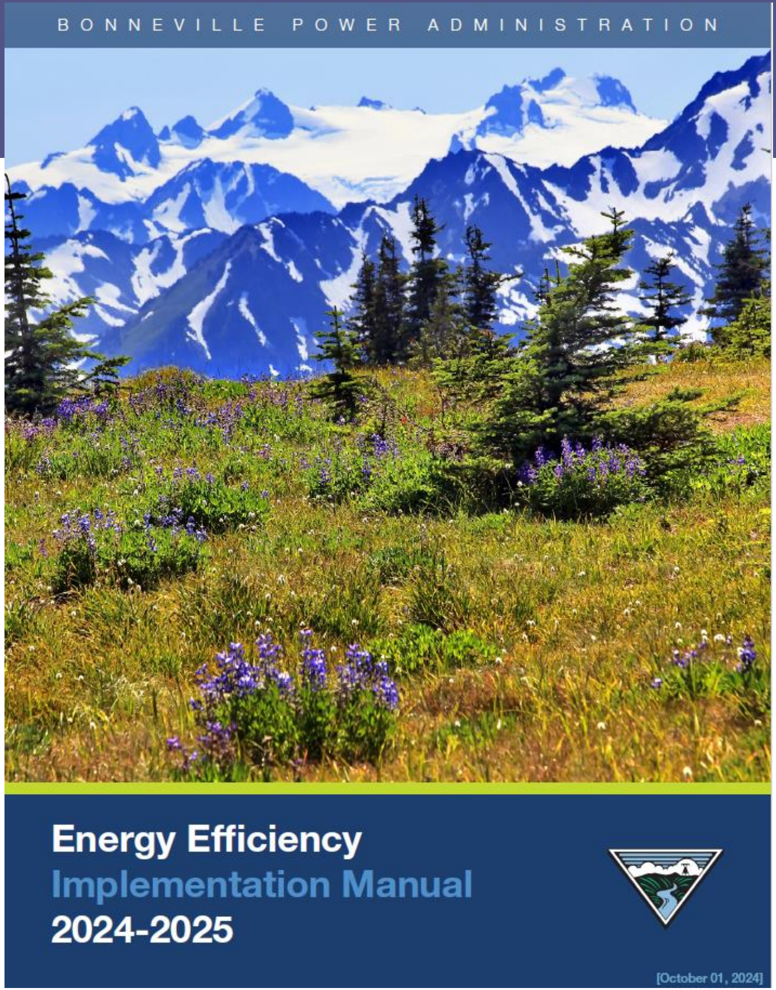
IS2.0 is RETIRED

- UES Measure List (April 2022)
- Savings Calculators
- Reporting Tools

BPA Energy Efficiency Tracking System (BEETS) is up and running!

Non-Custom Measures

- Agricultural sector
  - IM Chapter 7
- Commercial
  - IM Chapter 8
- Industrial
  - IM Chapter 10
- Residential
  - IM Chapter 11



Custom Projects

- Require 'custom' M&V
- Requirements vary
  - by level of savings expected
  - Type of measure or program

BPA's M&V Library
https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification

- Defined in Implementation Manual
  - Select M&V method via *BPA Protocol Selection Guide*
  - (1) engineering calculations with a verification plan, or
  - (2) a comprehensive M&V plan

Custom Projects

- See BPA's M&V Library
  - Recent website revision
- Protocols updated in 2024
- New SEM Guide (MT&R)
  - launched March 2022, updated in 2024
  - *Commercial & Industrial SEM M&V Reference Guide*

BPA's M&V Library
https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification

Quiz!

- How many M&V Guides and Protocol documents does BPA have?
- Is there a need to add more?

Measurement & Verification Resources

- Background +
- BPA Measurement & Verification Summary Guides +
- BPA Measurement & Verification Protocol Selection Guide V3.1 +
- BPA Fully Adherent International Performance Measurement & Verification Protocols (Comprehensive M&V) V3.1 +
- BPA Protocol for Conducting Engineering Calculations with Verification V3.1 +
- BPA Protocol Application Guides V3.0 +
- BPA Measurement & Verification Reference Guides V3.0 & V3.1 +
- Related Resources +

https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification

BPA M&V Resources

- Background
- BPA M&V Protocol Selection Guide
- BPA Fully Adherent IPMVP Protocols
- Engineering Calculations with Verification
- BPA Protocol Application Guides
- BPA M&V Reference Guides

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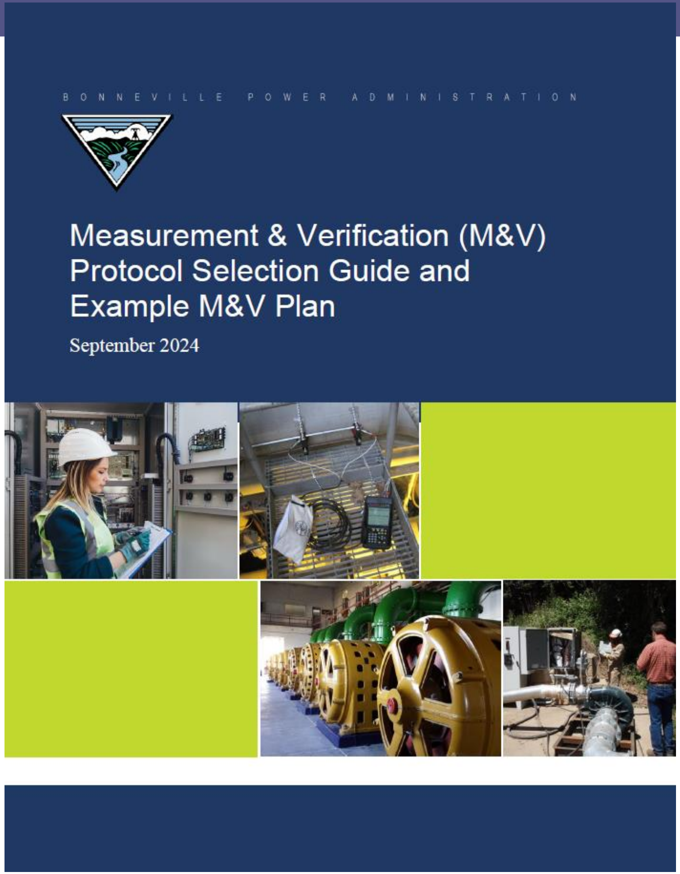
BPA M&V Resources

BPA M&V Protocol Selection Guide

https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification

BPA M&V Protocol Selection Guide and Example M&V Plan

- Overview of M&V Protocols
- General guidance on M&V
- Types of baselines
- M&V Protocol Selection flow-chart
- Examples of protocol selection
- M&V Plan example



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BPA M&V Resources

- BPA M&V Protocol Selection Guide
- BPA Fully Adherent IPMVP Protocols
- Engineering Calculations with Verification

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BPA M&V Resources

- **BPA M&V Protocol Selection Guide**
- **BPA Fully Adherent IPMVP Protocols**
- **Engineering Calculations with Verification**

Measurement & Verification Resources

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- Related Resources +

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BPA M&V Resources

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BPA M&V Resources

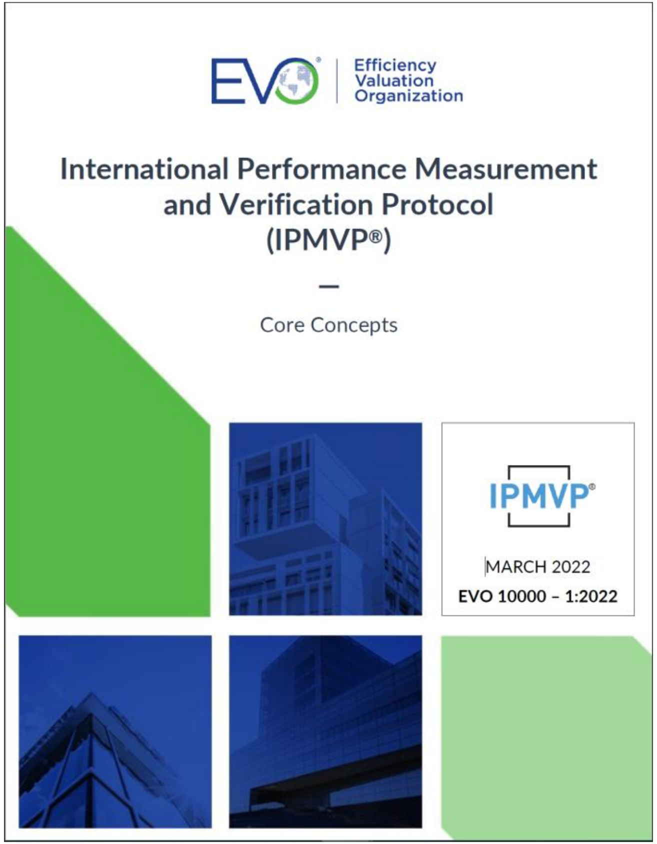
- BPA M&V Protocol Selection Guide
- Verification by Equipment or End-Use Metering
  Verification by Energy Modeling
- Engineering Calculations with Verification

M&V Approaches & Selection Criteria

QUIZ!

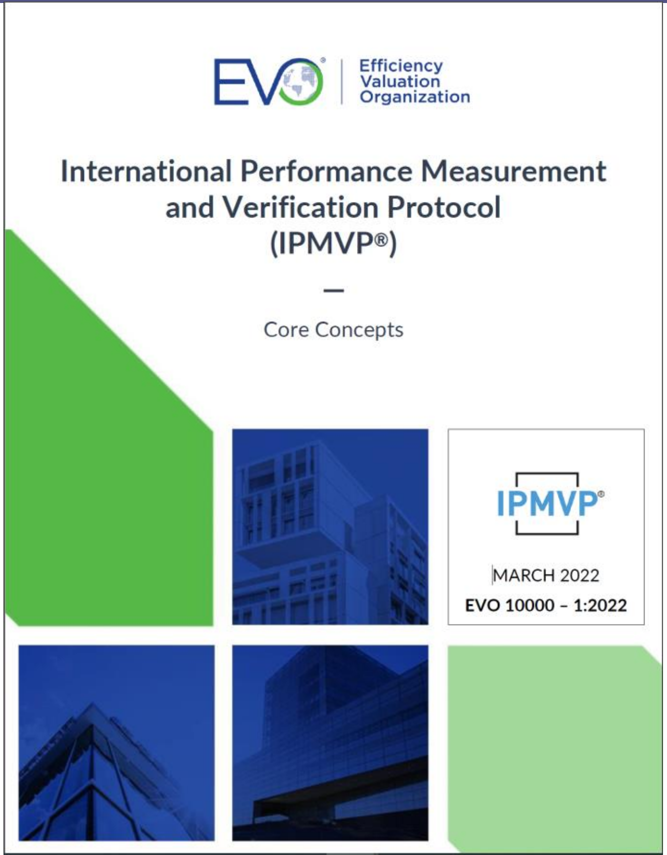
- How long has the IPMVP been used?
- When was most recent IPMVP released?

International Performance Measurement and Verification Protocol (IPMVP)



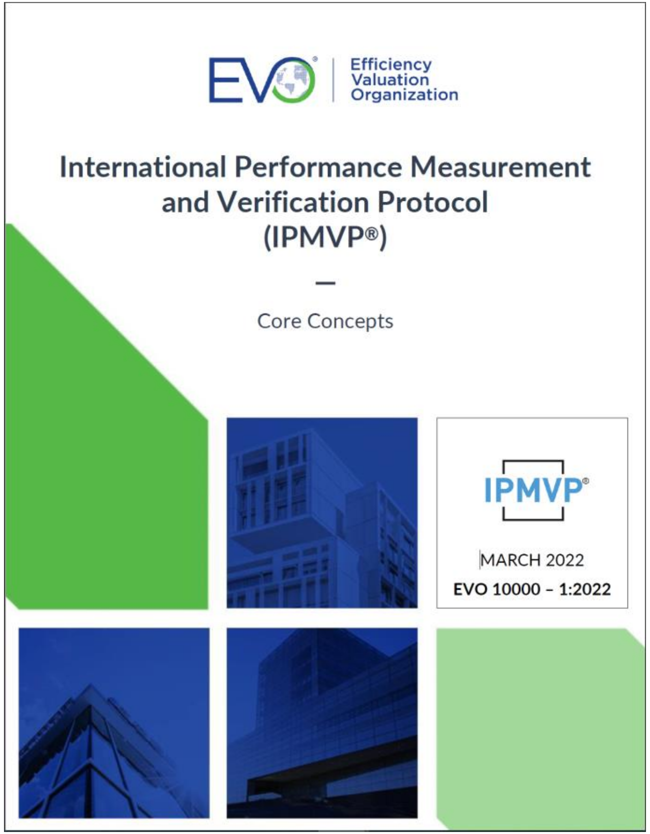
- Used worldwide
- 10 languages, 40 countries
- 25th Anniversary

IPMVP is Foundation for M&V



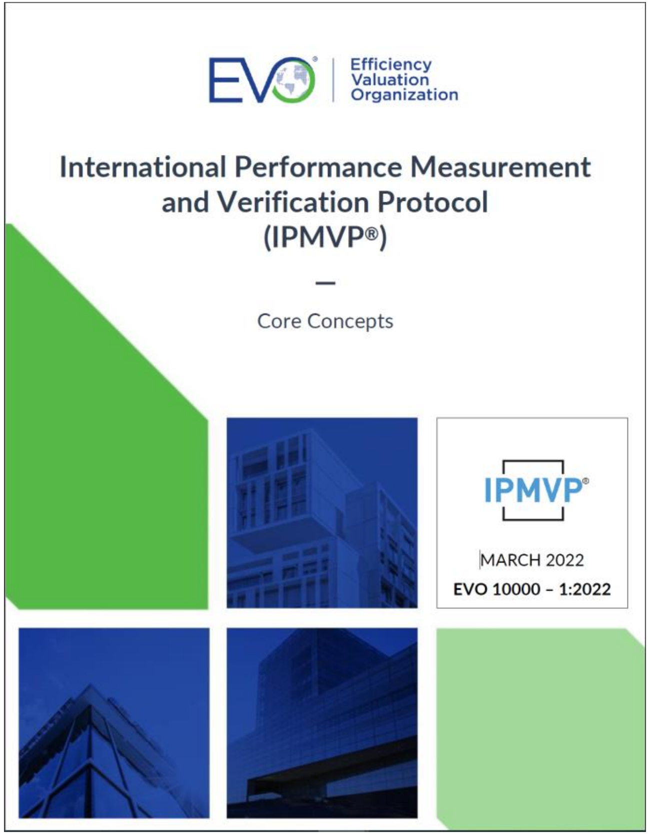
- Terms & Definitions
- Savings Equations
- M&V Plan and Reporting Requirements
- Principles of M&V

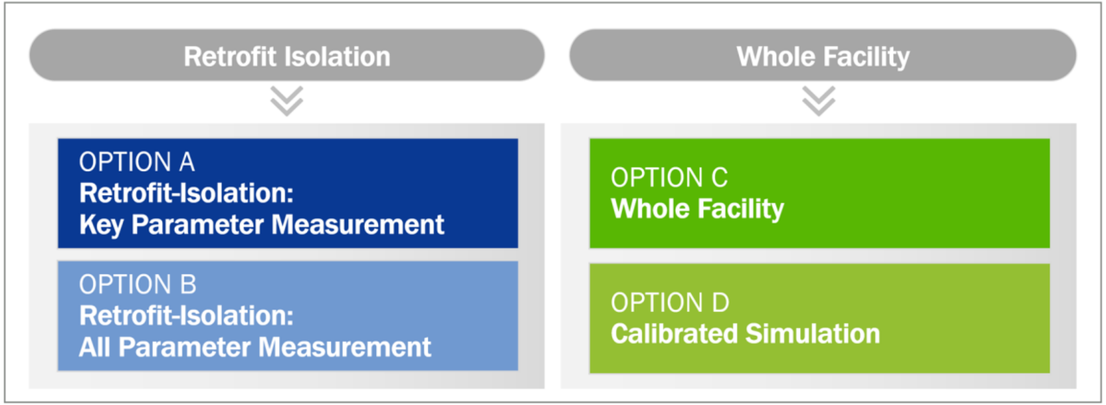
IPMVP is Foundation for M&V



- M&V Options A, B, C, D
- Measurement Boundary
- Routine Adjustments
- Non-Routine Adjustments

IPMVP – Options & Measurement Boundary





- Defines 4 M&V Options
  - Differences in measured data, analyses, and engineering expertise

IPMVP – Options & Measurement Boundary

Retrofit Isolation

OPTION A
Retrofit-Isolation:
Key Parameter Measurement

OPTION B
Retrofit-Isolation:
All Parameter Measurement

Whole Facility

OPTION C
Whole Facility

OPTION D
Calibrated Simulation

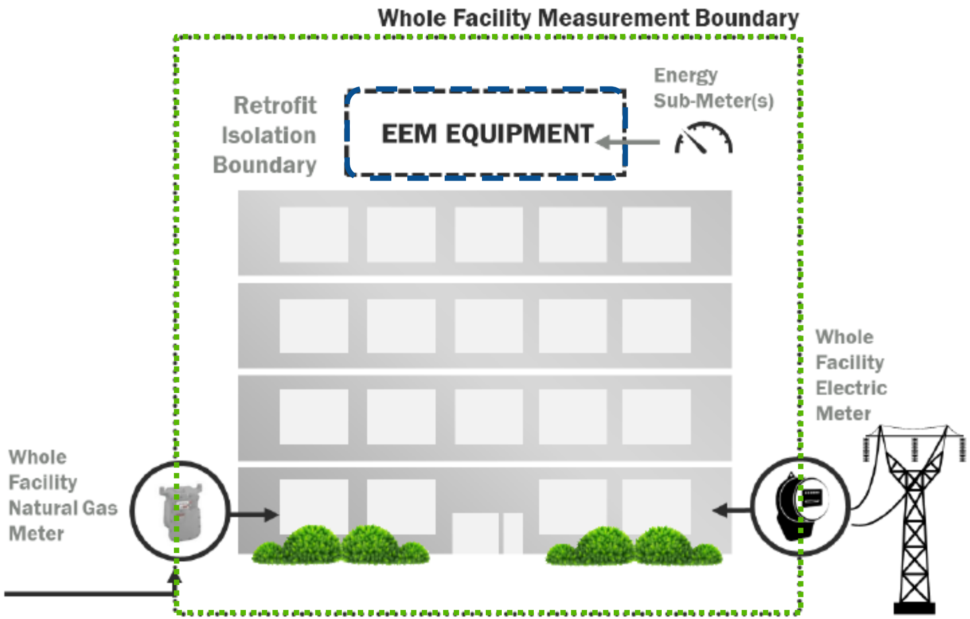
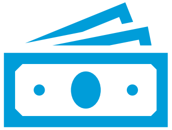


Figure 3: Whole Facility and Retrofit Isolation Measurement Boundaries

IPMVP and BPA – A range of M&V options

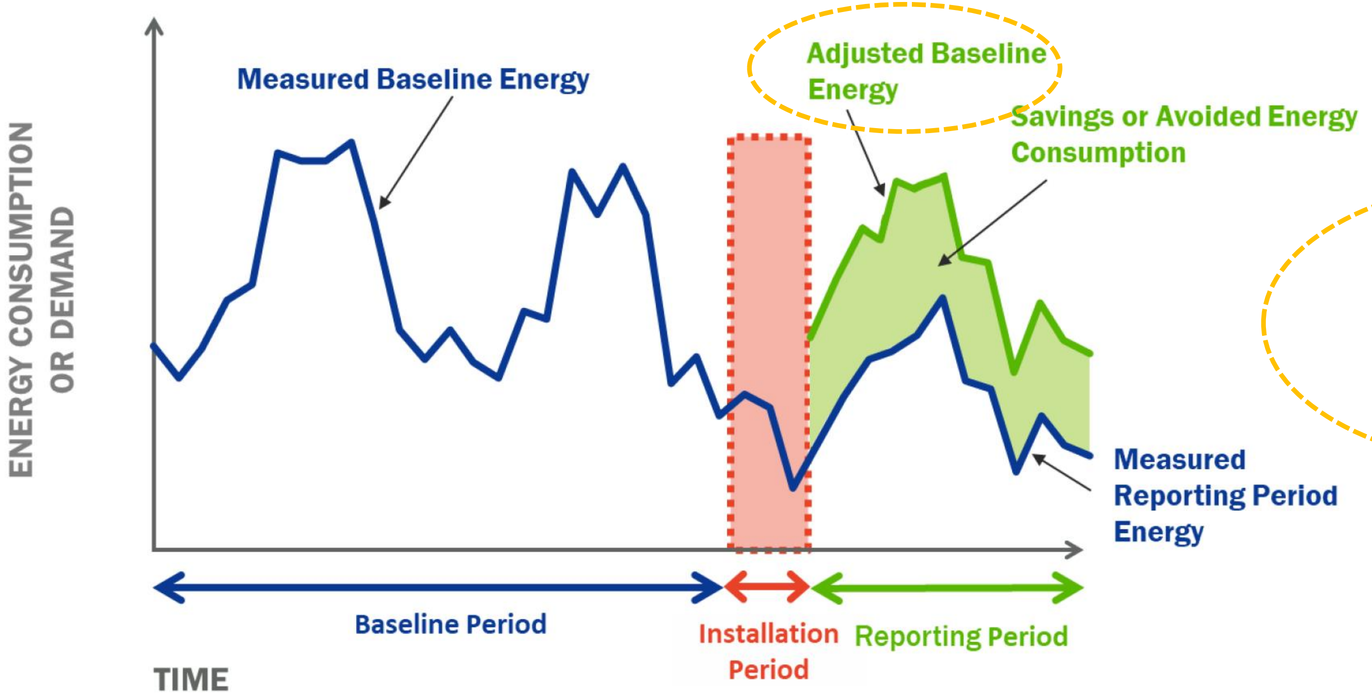
Differences in measured data and analyses

Methods required specific engineering expertise



Variations in the level of uncertainty (accuracy), M&V cost

IPMVP 2022



Adjusted Baseline Energy

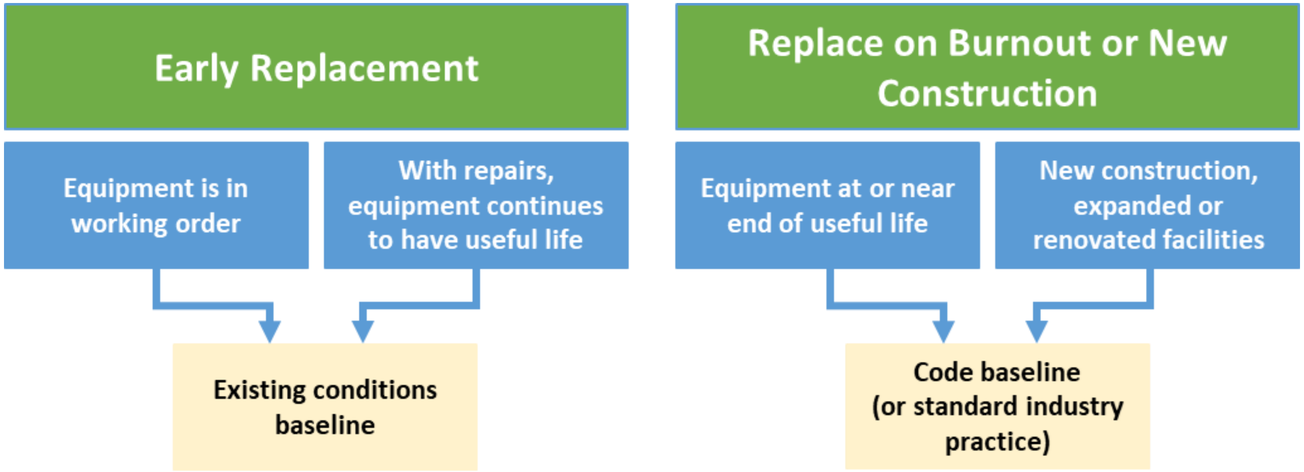
what "would have happened" without the energy project

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

Establish the Baseline

- Energy use:
  - Baseline Energy Use (kWh per year)
  - Energy used within measurement boundary
- Baseline based on:
  - the actual equipment efficiency
  - standard efficiency, or
  - applicable code

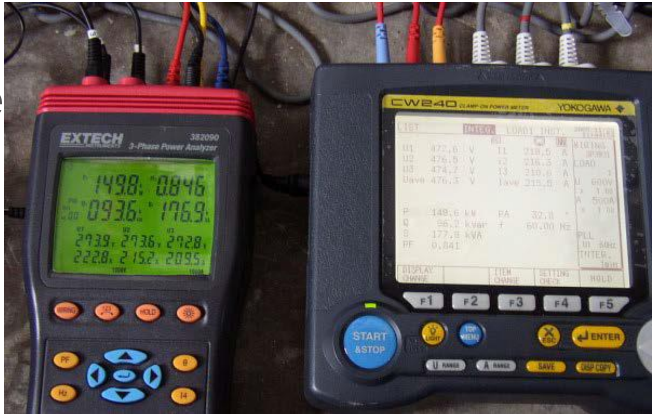
Determine the Baseline



Two things about M&V

- Plan ahead! Timing is critical
  - The baseline no longer exists after the project is installed
  - Make an M&V Plan

- Measurements can difficult &/or expensive but are worth it!
  - Avoid faulty estimates
  - Apples to apples comparison requires an indepe variable
    - Routine adjustments

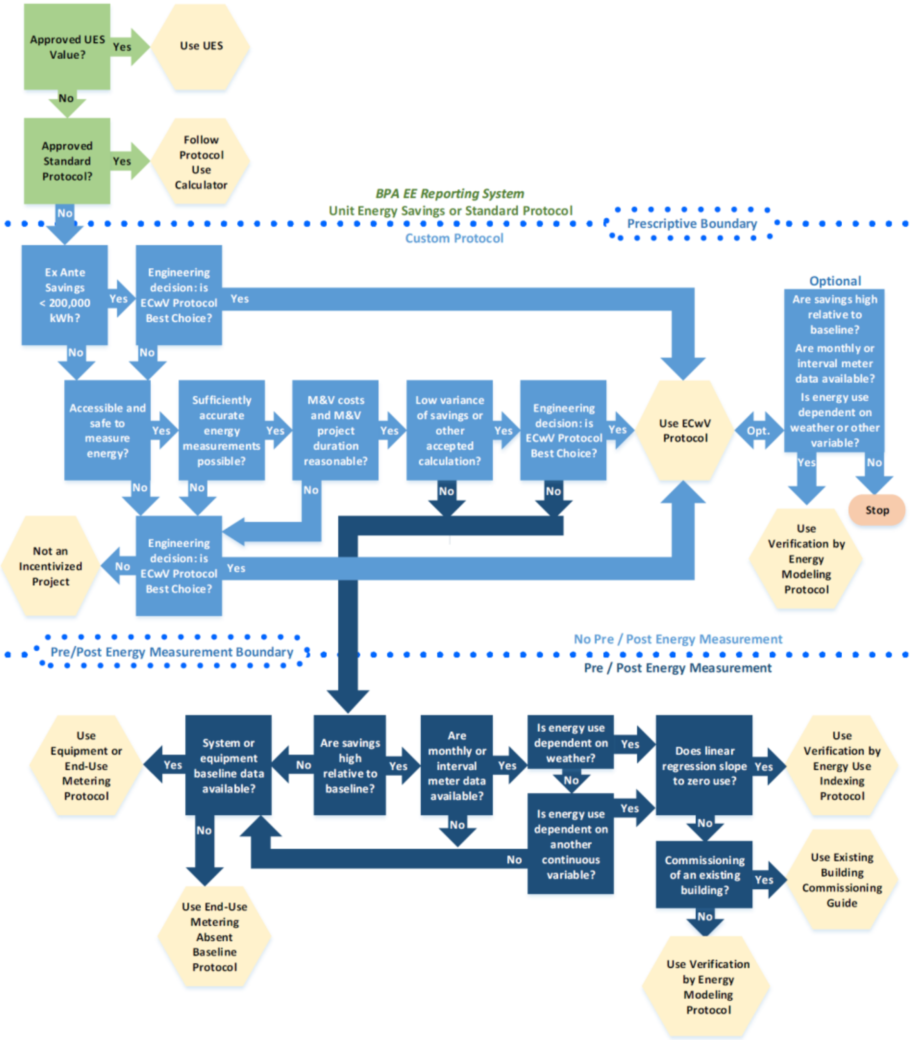


Two ☺ther things about M&V

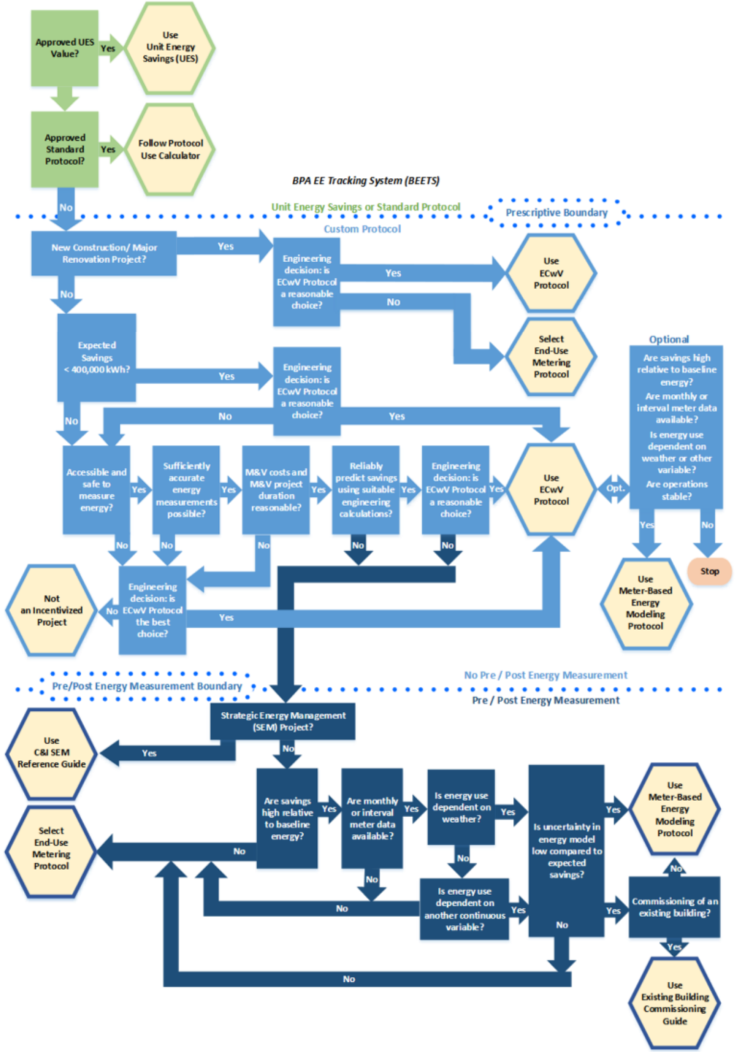
- One size does not fit all!
  - Range of M&V approaches,
    - Levels of accuracy vary
  - Value of savings, context, data availability, staff skills, staff safety, cost

- Always ensure the basic goals of M&V are met:
  - Verify changes were made that have the potential to save energy
    - Include operational verification
  - Measure and document the actual effects of a project

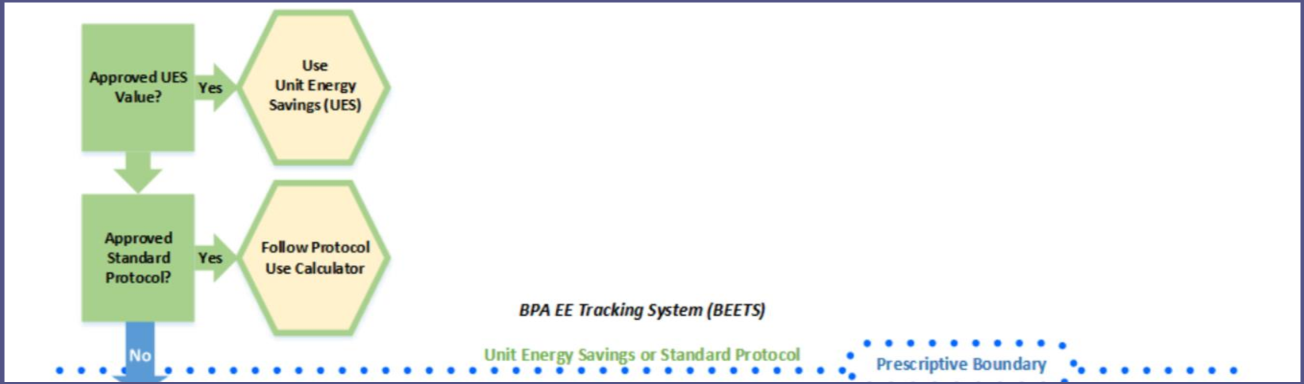
M&V Protocol Selection Guide – from V2.0…



M&V Protocol Selection Guide - to V3.1…

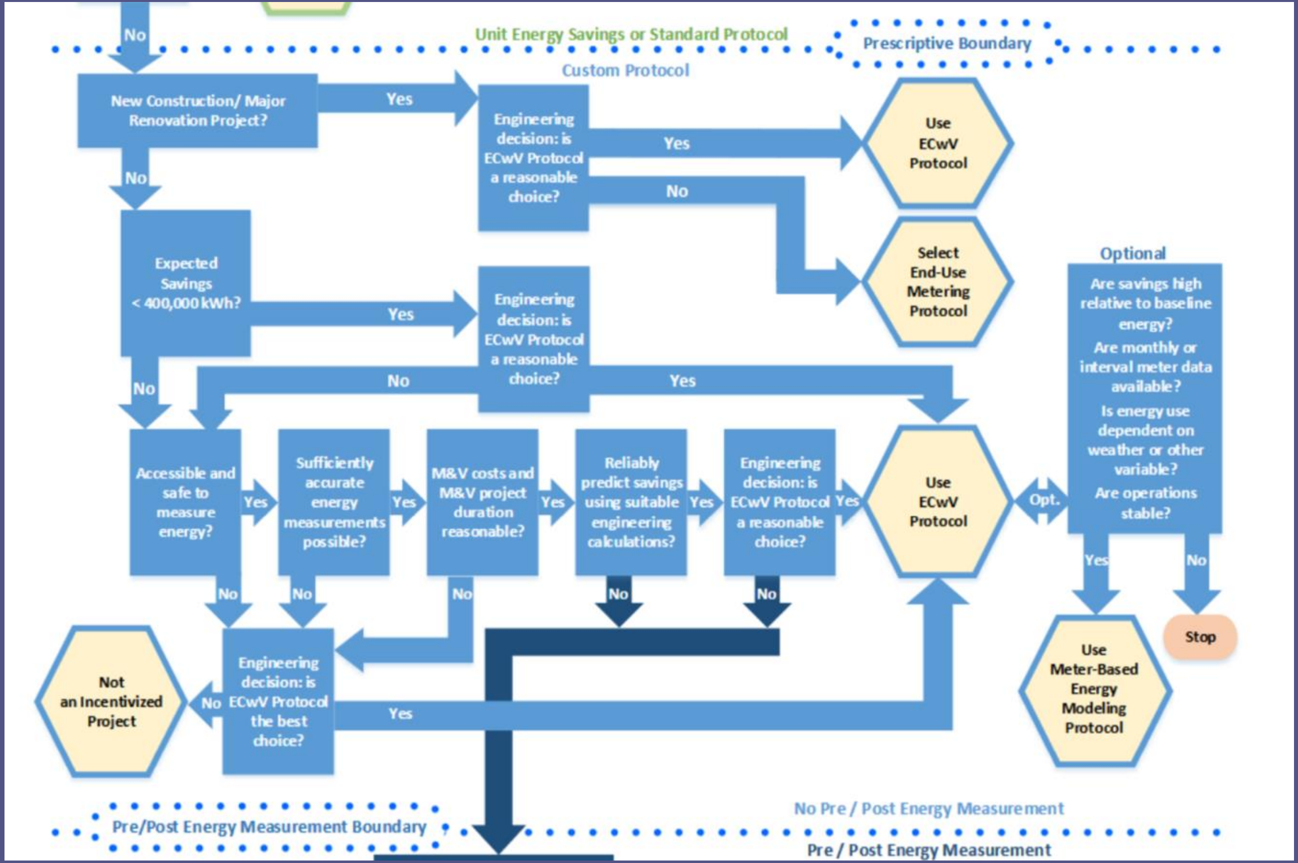


M&V Protocol Selection Flow Chart

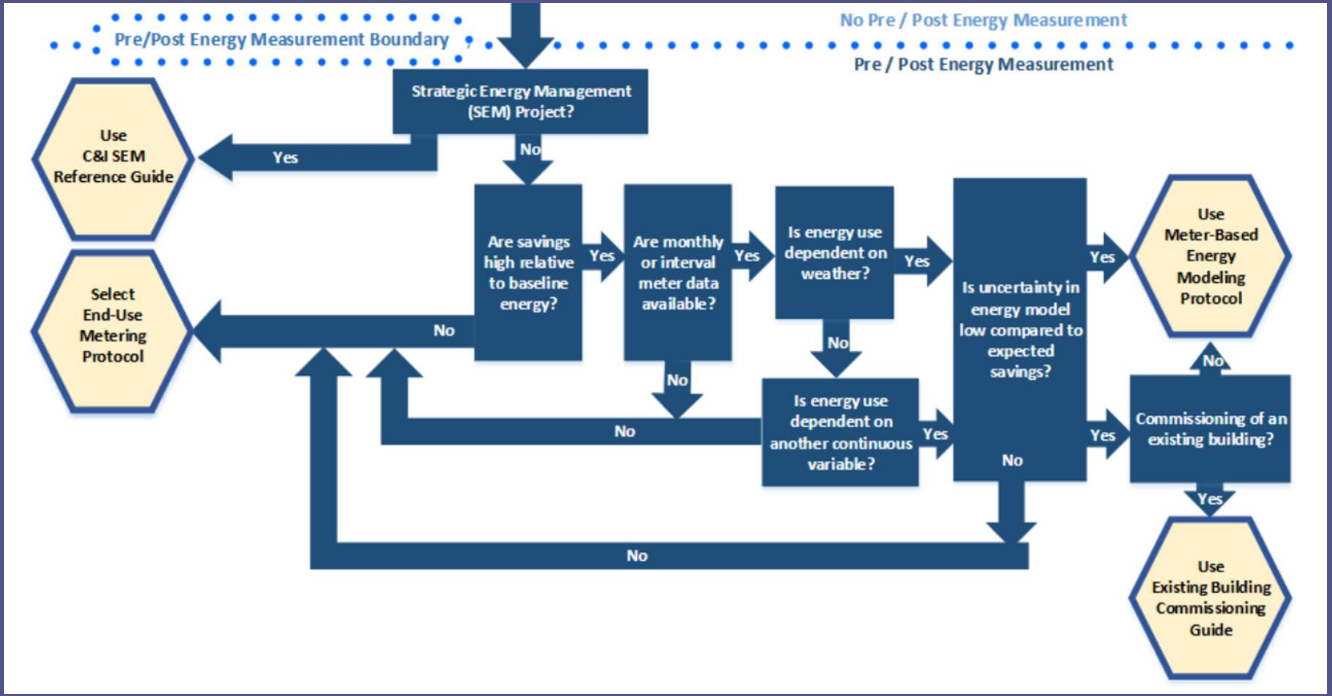


Upper portion remains unchanged from V2.0 to V3.1…

M&V Protocol Selection Flow Chart, V3.1



M&V Protocol Selection Flow Chart, V3.1



BPA M&V Documents

BPA M&V Protocols

BPA M&V Protocol Application Guides

BPA M&V Reference Guides

BPA M&V Protocols

BPA M&V Protocols

Verification by Equipment or End-Use Metering

Verification by Meter-Based Energy Modeling

Engineering Calculations with Verification

BPA M&V Protocols

BPA M&V Protocols	Method
Verification by Equipment or End-Use Metering	Energy measurements / data collection at equipment
Verification by Meter-Based Energy Modeling	Math model(s) of energy & weather* data
Engineering Calculations with Verification	Engineering calculations from system data

BPA M&V Protocols & Guides – Integrated Documents

BPA M&V Protocols	Method
Verification by Equipment or End-Use Metering	Energy measurements / data collection at equipment
End-Use Metering Absent Baseline Measurement Application Guide	
Verification by Meter-Based Energy Modeling	Math model(s) of energy & weather* data
Verification by Energy Use Indexing Protocol	
Engineering Calculations with Verification	Engineering calculations from system data

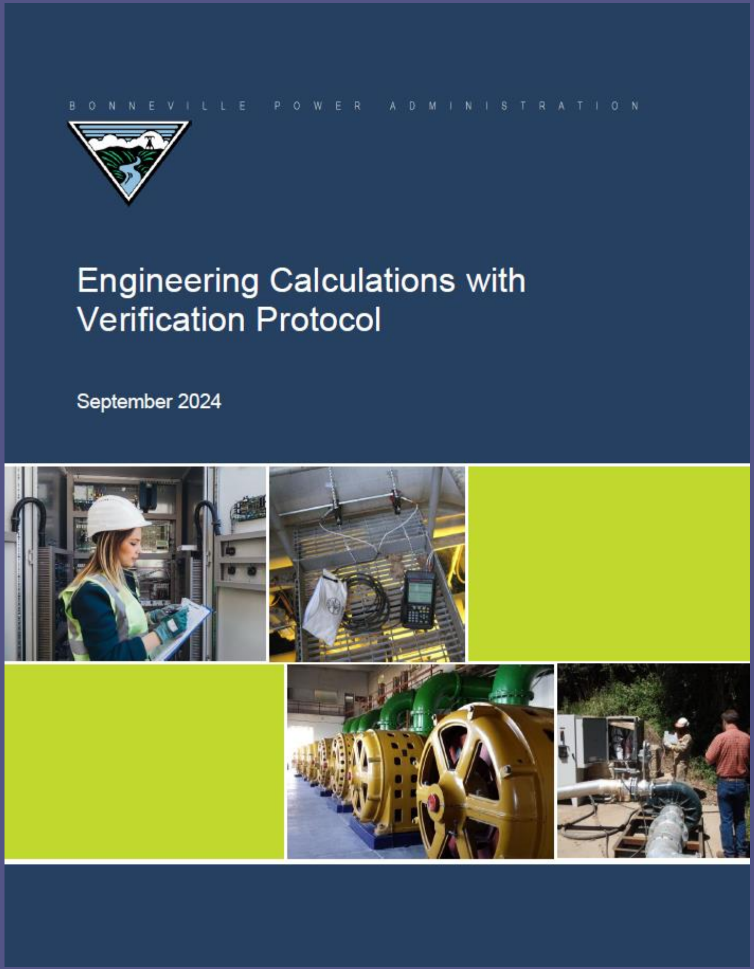
BPA M&V Protocols & Guides

Verification by Equipment or End-Use Metering	Energy measurements / data collection at equipment
Verification by Meter-Based Energy Modeling	Math model(s) of energy & weather* data

- M&V Regression Reference Guide
- Existing Building Commissioning Protocol Application Guide
- C&I Strategic Energy Management M&V Reference Guide

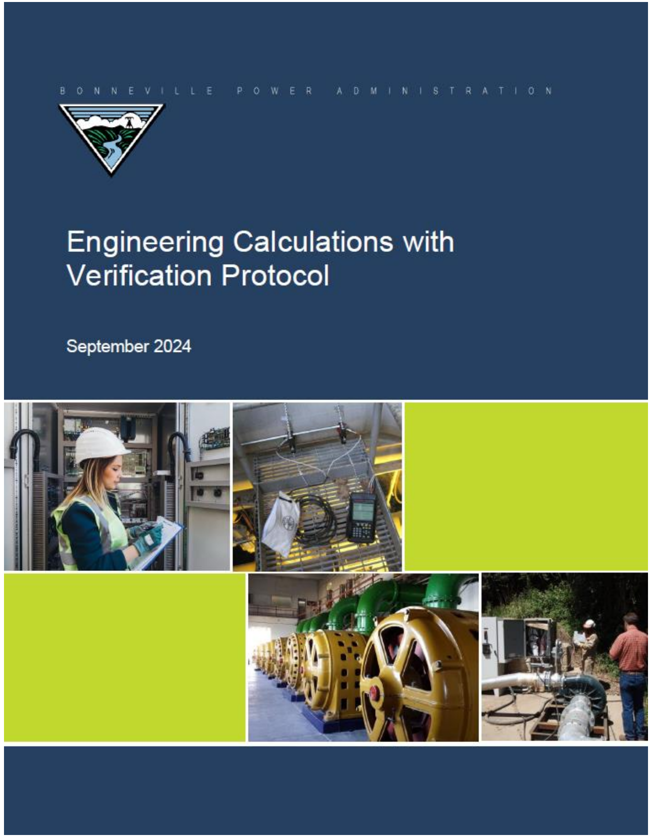
Engineering Calculations with Verification	Engineering calculations from system data

- Estimating Peak Demand Impacts Application Guide
- Sampling for M&V Reference Guide
- Glossary for M&V



Engineering Calculations with Verification

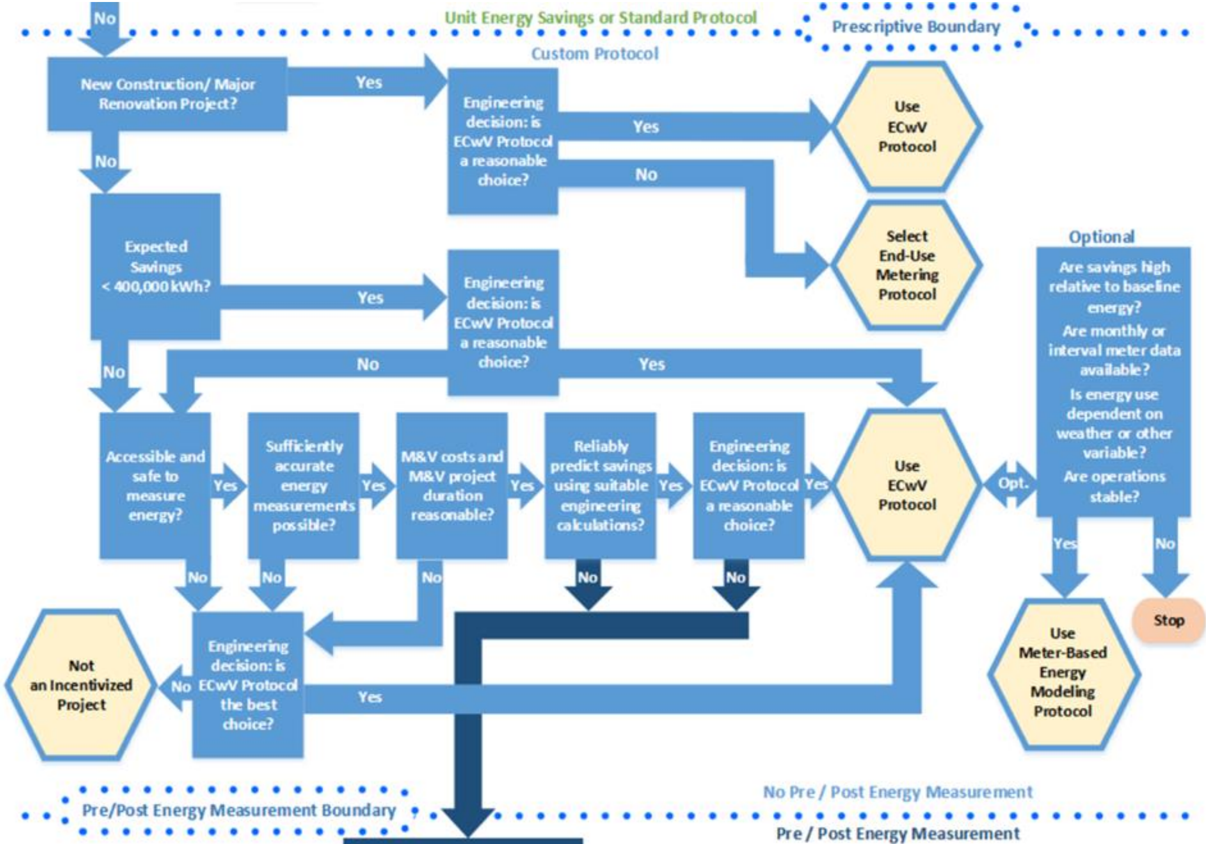
'ECwV Protocol'



Use where:

- Lower saving measures
  - <400,000 kWh per year
- Limited variance in savings
  - Predictable schedules, operations
- Energy measurements not feasible
  - Safety first!
- Cost of M&V with pre- and post-measurements impossible
- Timing of M&V out of sync with project

Engineering Calculations w/ Verification



Engineering Calculations with Verification

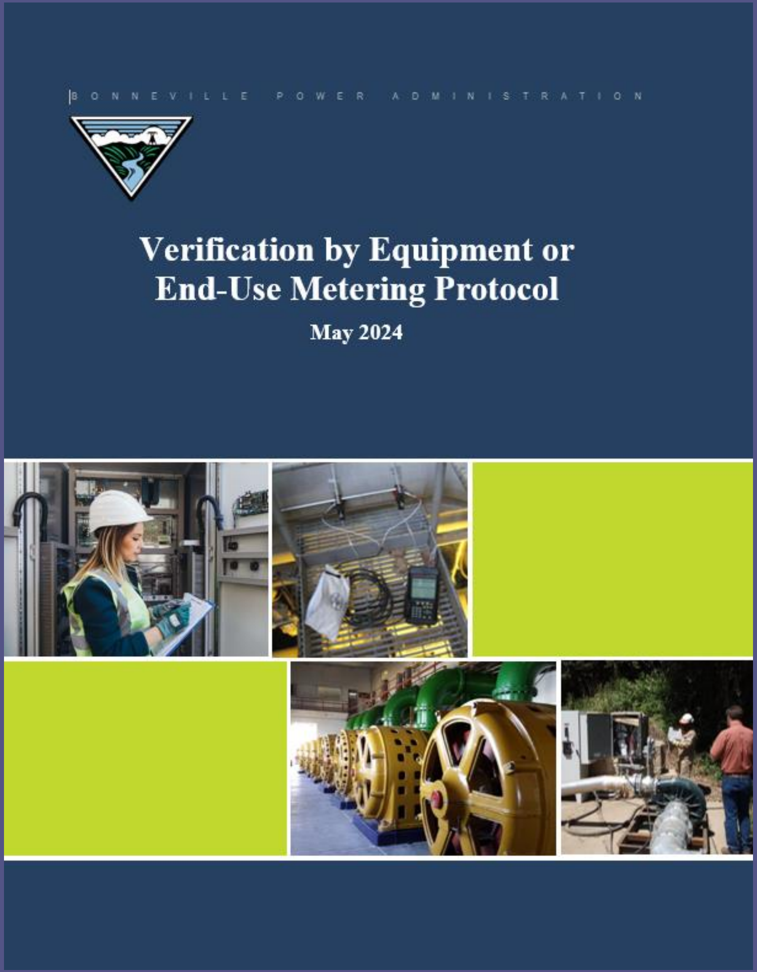
Two main engineering calculation approaches:

1. Custom engineering calculations

   e.g., Spreadsheet calculations

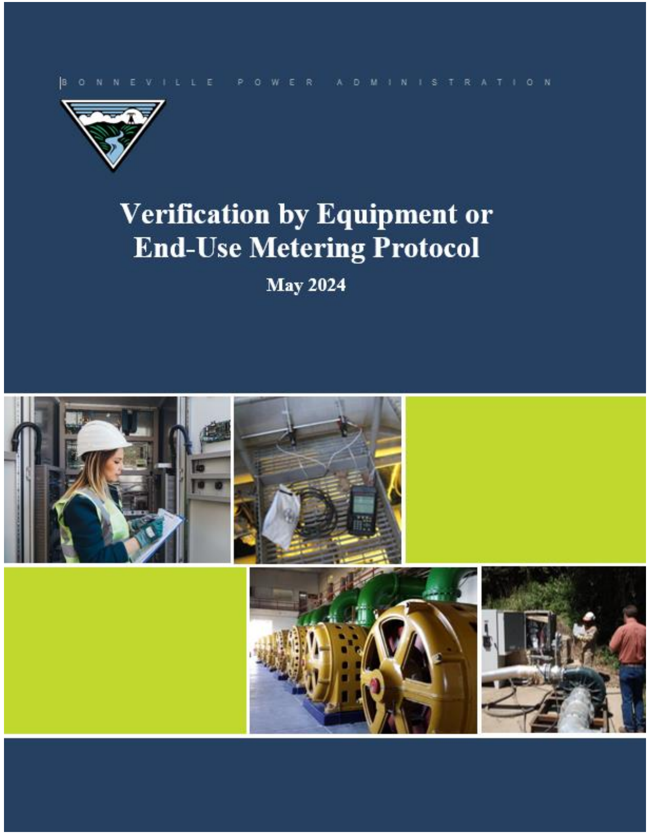
2. Whole Facility Energy Simulation Models

   e.g., EnergyPlus, EQuest



Verification by Equipment or End-Use Metering

‘End-Use Metering’



Use where:

- ECM changes load &/or hours
- Equipment monitoring is feasible
  - Equipment monitoring exists or can be installed
- Limited interactions between ECMs

Equipment or End-Use Metering

- Provides M&V for equipment retrofit using energy measurements before and after

- IPMVP Option A & B: Retrofit isolation
  - Equipment or system level metering

Equipment or End-Use Metering

This protocol is not intended for:

- New Construction*
- ECMs that involve multiple complex interactions or energy flow streams
- Whole building energy modeling or energy simulation

* Updated with additional Absent Baseline content incorporated within does address new construction/major renovation/replacement-on-burnout

Equipment or End-Use Metering - Procedure

M&V Analysis:

- Evaluate the equipment's or end use's energy consumption in baseline and post-ECM

  $$\text{Energy Use} = \Sigma \text{ Load} * \text{Hours}$$

- Categorize the type of load and schedule (hours of use) for baseline and post-ECM case
  - Constant Load or Variable Load
  - Timed-Schedule or Variable Schedule

Equipment or End-Use Metering - Procedure

M&V Analysis (cont.):

- Define ECM’s impact on equipment
  - Change in load &/or change in Hours-of-Use
- Determine metering plan
  - IPMVP Option A or Option B
- Demonstrate the baseline and post-ECM case
  - Loads
  - Hours of use

Equipment or End-Use Metering - Procedure

Protocol includes flexibility for budget and resource constraints.

Option A: Key Parameter Measurement	Option B: All Parameters
Measures most uncertain parameters, estimates reliable parameters	Most rigorous, measures all parameters to understand both load and operating hours
Relies on nameplate data, equipment specifications, manufacturer’s performance curves	Best for measures with variable load and variable schedule

Equipment or End-Use Metering – M&V Reporting

Practical Applications

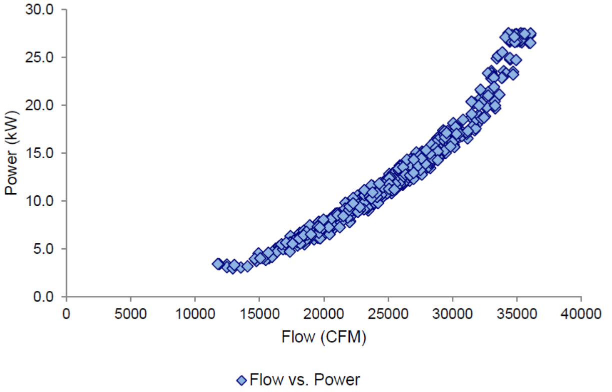
- Measure key parameters when limited
  - use existing & new metering
- It is impractical to measure energy for a year
  - measure over a full-range of operations
  - extrapolate to estimate annual savings

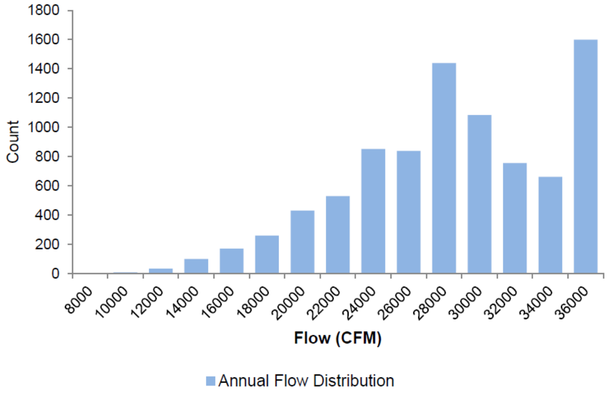
Equipment or End-Use Metering – M&V Reporting

M&V plan & report should define:

- **Loads**
  - Load value and units
  - Detail any proxies
  - Group continuous load data into bins
  - Load profile based on frequency distribution (histogram)

- **Hours of operation**
  - Timed Schedules
  - Variable Schedules





Equipment or End-Use Metering – M&V Reporting

Minimum Reporting Requirements

M&V Plan:

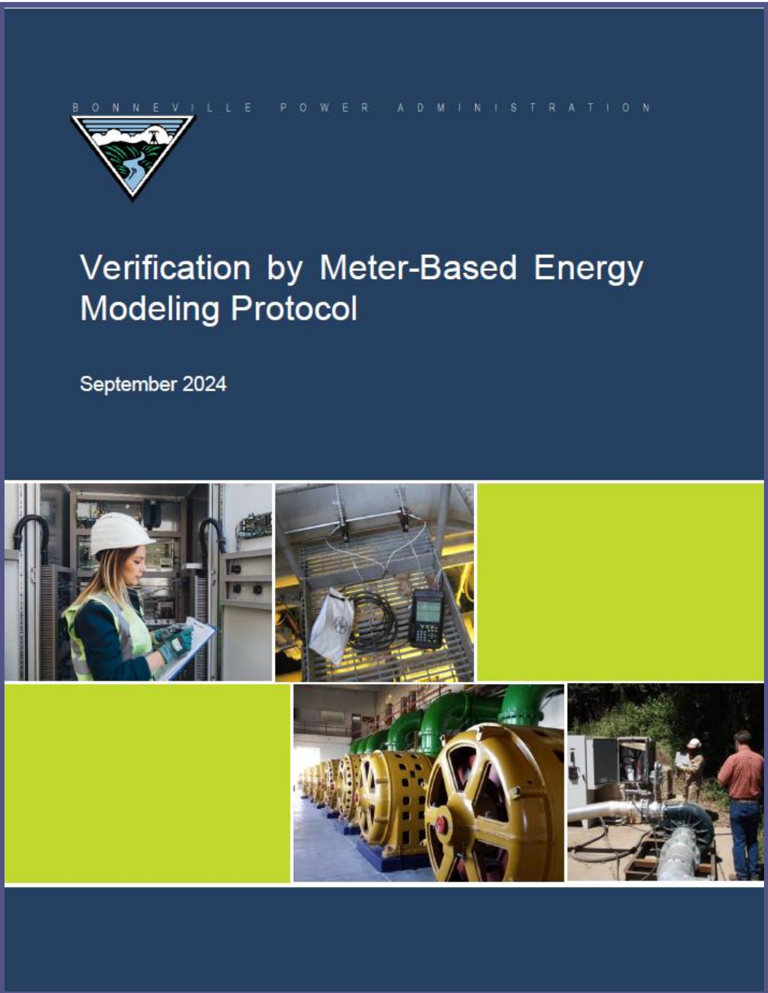
- Define measurement boundary
- Baseline and equipment conditions
- Energy & independent variable data
- Reporting period
- Analysis procedure
- Document any Option A estimated parameters

Savings Verification Report:

- Load and schedule defined
- Impact of ECM
- Summary of data collected
- Baseline period data
- Describe any non-routine events or adjustments
- Report energy prices or rates used
- Report both energy & cost savings
- Provide verification of potential to save

Equipment or End-Use Metering

- *End-Use Metering Absent Baseline*
    - An application of *Equipment or End-Use Metering Protocol*
- Used when in-situ baseline is not viable
    - Newly constructed facilities
    - Major additions to an existing facility
    - Replacement of failed equipment
- Baseline set to code or industry standard practice


BONNEVILLE POWER ADMINISTRATION

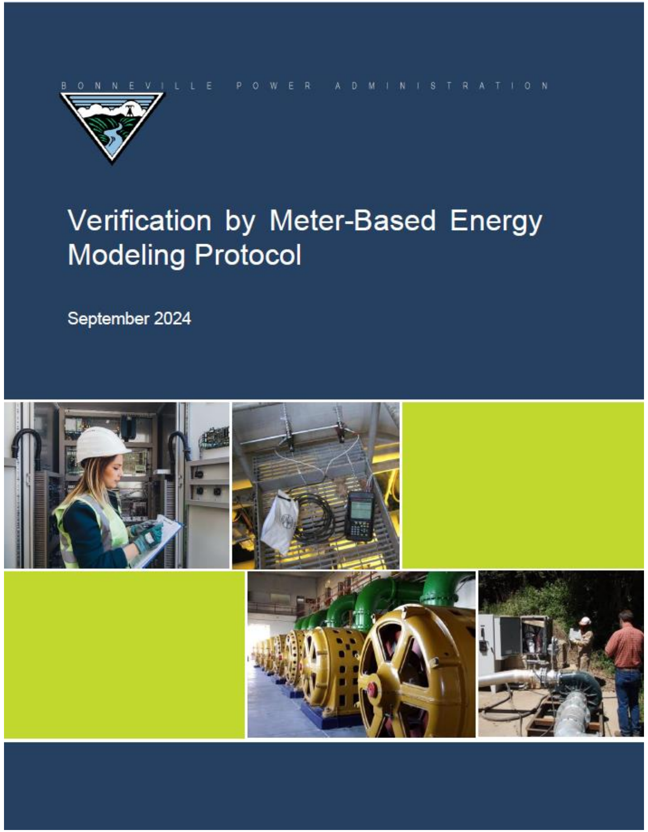
Verification by Meter-Based Energy Modeling Protocol

September 2024

Verification by Meter-Based Energy Modeling Protocol

‘Whole-Facility Energy Modeling’

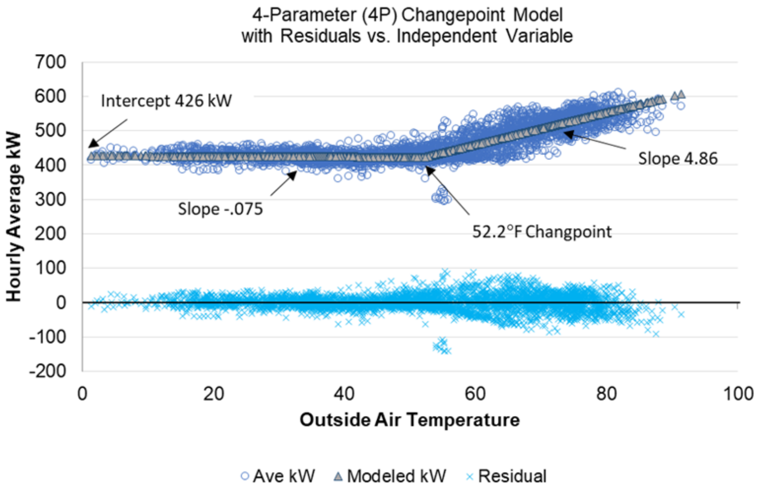
Verification by Meter-Based Energy Modeling



Use where:

- High level of savings
- Multiple, interactive ECMs
- Whole-building energy data
  - Hourly, Daily
- Energy use is predictable
  - e.g., schedule and weather
  - Low model uncertainty

Meter-Based Energy Modeling - Procedure



- IPMVP Option C
- Mathematical model
  - Whole-facility energy use
  - Independent variable(s)
    - e.g., outdoor temperature, production variable
- Models are statistically valid
  - Daily time interval is typical
    - e.g., Hourly, Daily, Weekly
- Method sensitive to Non-Routine Events

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

Verification by Meter-Based Energy Modeling

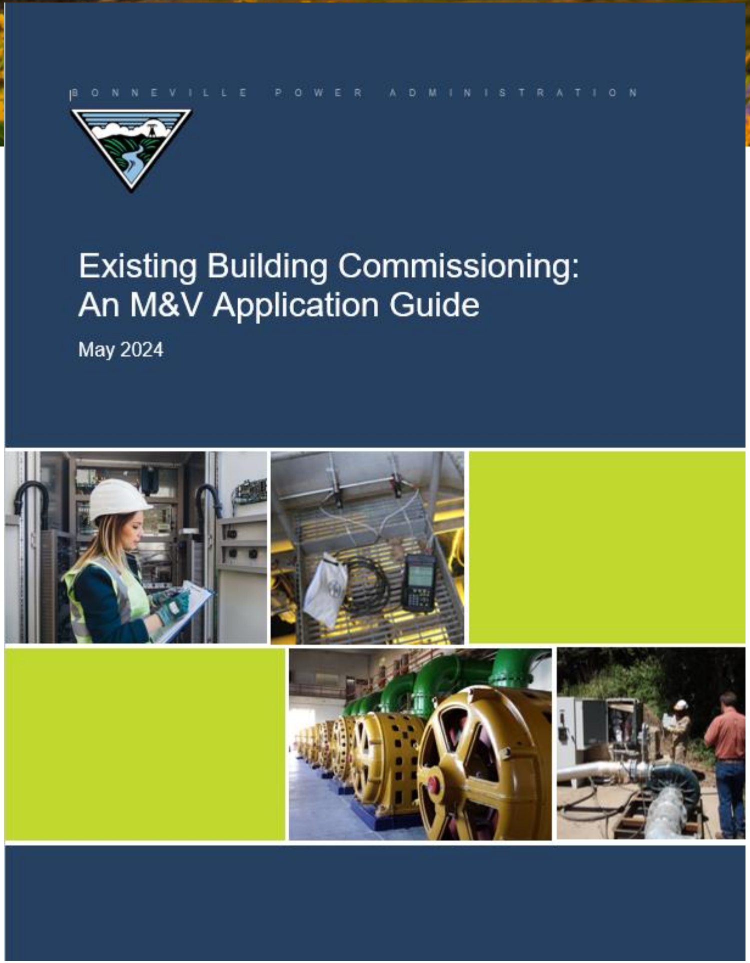
- *Energy Use Indexing*
  - an application of *Verification by Energy Modeling Protocol*
  - Option C
- Used when savings are normalized or ‘indexed’
  - e.g., per square ft

Meter-Based Energy Modeling - Reporting

Multi-Year Savings Reporting	• Incremental year-over-year savings used for payments
Backsliding or Negative Savings	• Actual savings to be reported to BPA
Re-Baselining	• Only required when major operations change

Meter-Based Energy Modeling

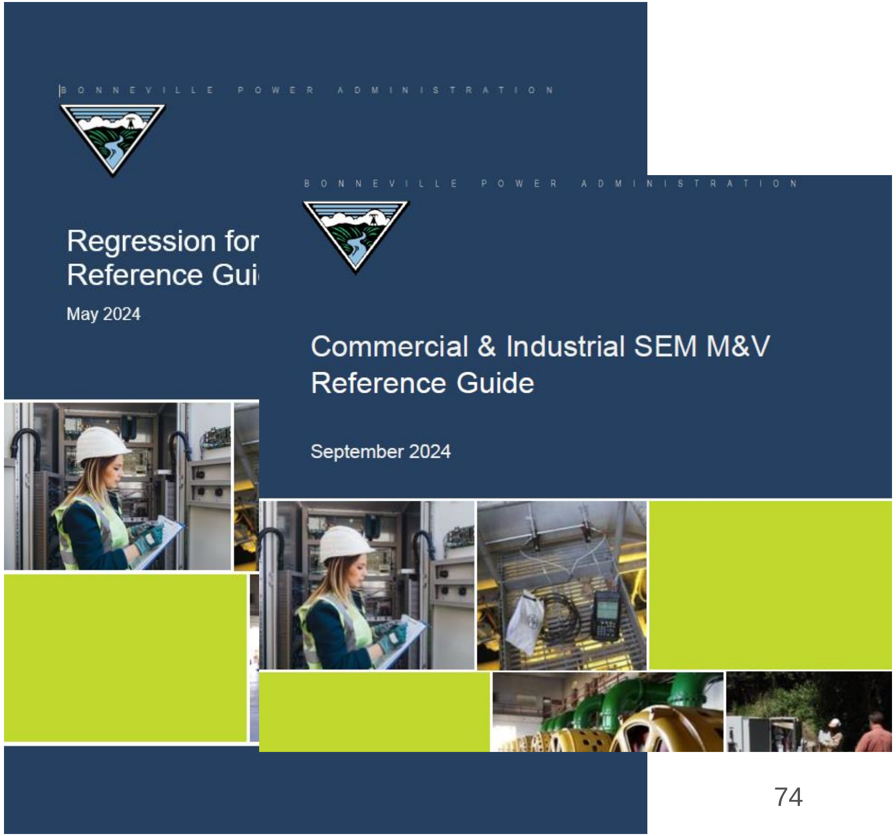
- *Existing Building Commissioning*
  - an application of *Verification of Meter-Based Energy Modeling Protocol*
- Used when EBCx projects
  - Option B & C
  - Building or System level analyses
- Highlights integrating M&V and EBCx processes



Meter-Based Energy Modeling

- *Regression Modeling Reference Guide*
  - Detailed background for *Verification by Meter-Based Energy Modeling Protocol*

- *Commercial Industrial Strategic Energy Management M&V Reference Guide*
  - An application of *Verification by Meter-Based Energy Modeling Protocol*



Examples

Reference Handout

Example – New Chiller Installed Exceeding Code Requirements

- An air-cooled chiller serves the air handling units at an emergency care center that operates 24/hours every day. The existing chiller had unexpectedly failed and a temporary chiller was used until the new one was installed. Since the existing chiller is no longer functional, the new unit must meet local code requirements. ASHRAE 90.1 – 2022 was the code version in place at the time of the project which requires full load efficiency of about 1.2 kW/ton. The owner plans to install a unit that is more energy efficient than is required by code, and the new chiller selected has a full load efficiency of about 0.9 kW/ton, a 25% improvement in full load efficiency.
- The baseline efficiency could be accurately estimated, but the system loads were unknown and could not be measured during the baseline period due to the short time line for the equipment to be installed.

Question: What protocol seems most appropriate?

Example - New Chiller Installed Exceeding Code Requirements (continued)…

- Engineering Calculations with Verification (ECwV)?
  – Although the amount of savings expected was far less than 400,000 kWh, ECwV was not selected because baseline chiller loads and hours of operation could not be reliably estimated.
- Verification by Meter-Based Energy Modeling (MBEM) Protocol?
  – MBEM could not be used because the expected level of savings were small (<2%) compared to building consumption.

Example - New Chiller Installed Exceeding Code Requirements (continued)…

- Verification by Equipment or End-Use Metering Protocol's 'Absent Baseline Measurement' Approach?
  - Yes. This approach was chosen for the project since the energy savings need to be determined relative to an 'absent baseline' scenario (i.e., the post-installation operating conditions using code-minimum chiller efficiencies). Note this method requires spreadsheet calculations to determine baseline energy, similar to an ECwV method.
  - This equipment operates under a variable load and a variable schedule that are not impacted by the retrofit. Only the efficiency of the chiller is changed. The measure results in a change in efficiency, so that savings equation was selected from the EUM protocol:

kWh Savings = (Effbase - Effpost)*Loadpost*Hourspost

Example - New Chiller Installed Exceeding Code Requirements (continued)…

- Outdoor air temperatures and the chiller's cooling loads were quantified through control system trends (the supply and return chilled water temperatures, status (on/off) of the constant volume chilled water pumps) and the chilled water flow rate from the test and balance report. Data was collected for six weeks after the new chiller was installed and covered a wide range of operating conditions. Spot measurements of the new chiller's power consumption (kW) were made at the motor control center using a true RMS power meter. Measurements were taken under different conditions over several days.
- Measured load data from the new chiller was correlated with outdoor air temperatures through regression analysis and a typical annual load profile (in ton-hours) was estimated using average annual weather for the project site. The measured kW was used to verify performance met manufacturer's specifications. The equipment manufacturer's performance data was used with this load profile to estimate the code-baseline chiller energy consumption. Energy use of the baseline and installed chillers were estimated using the measured load and the part load performance efficiencies of the units, and energy savings were the difference in the estimated energy use between the code-baseline and post-installation scenarios calculated using the selected savings equation, shown above. Final energy savings were **20,800 kWh / year**.

Example – Gymnasium Heating System Upgrade

- School district staff were considering upgrading a high school gymnasium’s existing heating system which includes a diesel-powered steam boiler serving steam heating coils in the air-handling units and unit heaters as well as a heat exchanger which served a 50-gallon domestic hot water system.

- The choices for new heating systems were installing either electrical-powered code-compliant resistance heating systems or installing high-efficiency heat pumps (two split system heat pump units and a packaged heat pump unit).

- The proposed heat pumps and packaged unit had back-up heat consisting of electrical resistance heat strips, and the packaged unit included demand-controlled ventilation controls. A 120-gallon electric heat pump water heater was proposed to replace the 50-gallon unit to assure hot water capacity met requirements for the gym’s occupancy.

Example – Gymnasium Heating System Upgrade (continued)…

- Records of diesel purchases and monthly consumption amounts were available for the previous two years. Since the existing equipment was antiquated and required replacement this project is considered an end-of-life equipment replacement that should use a code-compliant baseline.

- An initial electric energy savings estimate of 104,000 kWh per year was generated: the energy use of a hypothetical code baseline using electric resistance heat was estimated from the diesel fuel use (consumption was converted to electric energy use, then adjusted by an estimated boiler efficiency). The electric energy use of the heat pumps was estimated by dividing the code baseline consumption by the average efficiency improvement provided by the heat pumps based on improvement in heating seasonal performance factor (HSPF). The initial electrical energy savings was estimated as the difference between the baseline use and use of the new heat pumps and packaged units.

- Although this project changed the fuel used for the heating system, savings were not impacted by the fuel change and are eligible for BPA incentives. Energy savings from this project are based on replacing a code-compliant hypothetical baseline using resistance heat with higher efficiency heat pump units.

Question: What protocol seems most appropriate?

Example – Gymnasium Heating System Upgrade (continued)…

- Engineering Calculations with Verification?
  - Perhaps? For projects saving less than 400,000 kWh, the M&V Selection Guide offers either the *Engineering Calculation with Verification Protocol* or the optional *Verification by Meter-Based Energy Modeling Protocol* as viable methods to verify savings for this project.
  - Because the measured energy use from a new dedicated electric meter would be available in the post-installation period and could be compared to the estimated code baseline energy use (described above) once adjusted to post-installation weather conditions, ***Verification by Meter-Based Energy Modeling Protocol*** was selected.

Example – Gymnasium Heating System Upgrade (continued)…

- After completion, monthly energy use data on the new systems and weather data from the site were collected. After 3 months, a preliminary check on the results was made to ensure savings were apparent, Annual savings calculations were made after 12 months of data was collected. The *Verification by Meter-Based Energy Modeling Protocol* was implemented using the software tool ECAM, which is a whole building-based analysis that compares baseline energy use and post-installation actual utility energy data with respective actual local weather data using regression analysis. Verified savings reported were **145,400 kWh/year.**

- No other projects were planned, and it was understood that no deemed measures (i.e., lighting, computer network management, etc.) would be implemented until the post-installation data collection was complete. If any deemed measures were installed in that time period, then all or a portion of the deemed energy savings would be subtracted from the whole building “gross” energy savings to determine the “net” savings from the projects’ implemented measures.

BPA M&V Resources

- Overview of M&V Resources
  - Protocols, Guides
  - Other helpful M&V items

- Potential Updates to BPA M&V
  - Evaluation results
  - Your comments

Measurement & Verification Resources

- Background +
- BPA Measurement & Verification Summary Guides +
- BPA Measurement & Verification Protocol Selection Guide V3.1 +
- BPA Fully Adherent International Performance Measurement & Verification Protocols (Comprehensive M&V) V3.1 +
- BPA Protocol for Conducting Engineering Calculations with Verification V3.1 +
- BPA Protocol Application Guides V3.0 +
- BPA Measurement & Verification Reference Guides V3.0 & V3.1 +
- Related Resources +

BPA M&V Summary Guides

BPA M&V Summary Guides

- Purpose
  - Provide an overview of selected BPA M&V Protocol or Guide
  - Help users understand BPA's M&V methods
- Approach
  - Summarizes M&V protocol or guide
  - 2 to 4 pages
  - Provides an overview of the M&V procedure
  - Includes 'When to Use', 'When Not to Use'
  - Provides links to related BPA documents and other resources
  - Highlights examples included
- Result
  - 5 Summary Guides:
    - ECwV, EUM, MBEM, Sampling for M&V, Peak Demand Impacts

BPA M&V Protocols & Guides V3.0 / V3.1

M&V Protocol Selection Guide and Example M&V Plan

Verification by Equipment or End-Use Metering Protocol

Verification by Meter-Based Energy Modeling Protocol

- M&V Regression Reference Guide
- Existing Building Commissioning Protocol Application Guide
- C&I Strategic Energy Management M&V Reference Guide

Engineering Calculations with Verification Protocol

- Estimating Peak Demand Impacts Application Guide
- Sampling for M&V Reference Guide
- Glossary for M&V

BPA M&V Summary Guides

- Verification by Equipment or End-Use Metering Protocol
- Verification by Meter-Based Energy Modeling Protocol
- Engineering Calculations with Verification Protocol
- Estimating Peak Demand Impacts Application Guide
- Sampling for M&V Reference Guide

SUMMARY GUIDE: Sampling for M&V: Reference Guide

SUMMARY GUIDE: Estimating Peak Demand Impacts

SUMMARY GUIDE: Equipment or End-Use Metering Protocol

SUMMARY GUIDE: Meter-Based Energy Modeling Protocol

SUMMARY GUIDE: Engineering Calculations with Verification Protocol

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Administration's (BPA) *Engineering Calculations with Verification Protocol* (ECwV) uses engineering algorithms to estimate baseline and post-installation energy use of equipment, systems, or buildings. Savings are the difference in estimated electricity consumption between the baseline and post-installation scenarios.

Engineering calculations:

- Are either developed in spreadsheets (e.g., Excel) or in energy simulation modeling software (e.g., eQUEST)
- Are based on the physics of systems
- Do not require measured energy use
- Require field verification and true up of calculations
- Accuracy of savings estimates can vary and depend on data and assumptions used
- Are intended for use on smaller projects

WHEN TO USE

SUMMARY GUIDE:

Engineering Calculations with Verification Protocol

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Administration's (BPA) *Engineering Calculations with Verification Protocol* (ECwV) uses engineering algorithms to estimate baseline and post-installation energy use of equipment, systems, or buildings. Savings are the difference in estimated electricity consumption between the baseline and post-installation scenarios.

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- Require field verification and true up of calculations
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- Are intended for use on smaller projects

WHEN TO USE

- Measures saving less than 400,000 kwh/yr
- New construction / major renovations
- Retrofit or replacement of existing equipment
- Equipment and system operations are well understood
  - Values of key operating parameters
  - The relationship of important variables to other driving variables
- The measure's impacts on the system are well understood
- Knowledge of the system to which the measure applies
- Knowledge of the physics underpinning how the measure saves energy
- Equipment-level energy measurements are not feasible

WHEN NOT TO USE

- Physics of system performance are not clearly defined
- Operational details of system or equipment are not documented

PROCEDURE

Collect Data

Step 1: Describe the process and energy efficiency measure:

- Baseline conditions
- Post-installation conditions

Gather project related data:

- Existing and new system design and specifications
- Operational data

Pre-Installation

Step 2: Establish baseline annual energy use (kWh / year)

- Use existing or code conditions

Step 3: Estimate post-installation annual energy use (kWh/year)

Step 4: Calculate energy savings (kWh/year)

Post-Installation

Step 5: Measure verification

- Inspections, measurements, functional testing, trend logs

Step 6: Adjust estimated energy savings

- True up assumptions

REPORTING REQUIREMENTS

- Detailed descriptions of the project and efficiency measures. The description(s) should contain:
  - Sufficient detail to clearly understand the processes involved
  - The proposed savings measure details
  - How the measure will achieve the stated savings
- Detailed energy savings calculations should include:
  - Step by step descriptions
  - Details of the data used
  - Input and output details from software simulations
- Documentation may include pictures, field notes, equipment specifications, vendor quotes, calculation files, and written reports

TIPS

- Use accepted algorithms or well known software
- Annotate assumptions and equations used
- Conduct spot measurements or use available trend data
- Use equipment specifications (e.g., pump & fan curves, manufacturer specifications)
- Double check work!

TOOLS & RESOURCES

- **Weather Data:** NREL's TMY3 Weather Data
- **Software Tools:** Energy Plus, EQuest, ECAM, DOE software tools
- **Guidelines:** IPMVP, state building energy codes (OR, WA), ASHRAE, AHRI

APPLICATION SPECIFIC CONSIDERATIONS

Within the ECwV Protocol there are two calculation approaches considered:spreadsheet based engineering calculations and simulation models. Each approach has some specific requirements and considerations summarized below.

	SPREADSHEET CALCULATIONS	SIMULATION MODELS
Overview	Engineering estimates of system or equipment energy use are developed for the baseline and post-installation scenarios.	Software models of a system or whole building are developed to estimate energy use for the baseline and post-installation scenarios.
Analysis	Calculations made in spreadsheets (e.g., Excel) based on hourly analyses or annual temperature bins (8,760 hours).	Software simulating a whole-building (e.g., EnergyPlus, DOE-2 / eQUEST) or of system-level (e.g., pump tool) is used.
Use Cases	• Use for equipment or system-level retrofit or replacement projects in existing facilities • Correlations in site-specific operations and independent variables can be developed • Savings originate from a single piece of equipment or system • Savings are largely from controls changes • Method and data to calculate savings is available	• Use for new construction or major renovation projects • Correlations to real data cannot be developed • Measures affecting envelope loads or with other complex interactions • A simulation model already exists • Zone loads need to be estimated
Approach	Equipment level estimates of energy use based on known engineering relationships (e.g., air flow vs. fan speed, efficiency vs load) and site specific system data.	Building or system-level estimates of loads and energy use based on engineering relationships (e.g., air flow vs. fan speed, efficiency vs load) are used with site specific system data.
Savings	Savings are the difference in estimated electricity consumption between baseline and post-installation scenarios.	One simulation model is developed (e.g., baseline) and then modified to represent the change in conditions (e.g., post-installation).

EXAMPLES OF ENGINEERING CALCULATIONS

The ECwV Protocol includes four examples of how the protocol is applied to different types of energy savings projects.

Example 1

Scope:
New air compressor and dryer with increased capacity

M&V Approach:
Engineering Calculations using a publicly available software tool

Reference:
ECwV pg. 53

Example 2

Scope:
New windows and HVAC system at an elementary school.

M&V Approach:
Simulation Approach for an Existing Building using eQuest

Reference:
ECwV pg. 58

Example 3

Scope:
Installation of high speed rollup doors.

M&V Approach:
Engineering Calculations using a vendor supplied software tool

Reference:
ECwV pg. 61

Example 4

Scope:
More efficient configuration of conveyor systems

M&V Approach:
Engineering Calculations using a custom spreadsheet

Reference:
ECwV pg. 70

BPA RESOURCES

BONNEVILLE POWER ADMINISTRATION

BPA Measurement and Verification Resource Library

Engineering Calculations with Verification Protocol

M&V Protocol Selection Guide and Example M&V Plan

SUMMARY GUIDE:

Equipment or End-Use Metering Protocol

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Adminstration's (BPA) *Verification by Equipment or End-Use Metering Protocol* (EUM) is used for measures that impact isolated equipment or systems and uses monitored energy use and/or other parameters in the baseline and post-installation scenarios. Savings are determined from defined equations based on loads and hours of use in the baseline and post-installation scenarios.

End-Use Metering:

- Energy use characteristics of load and hours of use are defined for baseline and post-installation scenarios
- System or equipment-level parameters are monitored
- Measured energy and operational data are used
- Can use code defined or existing baseline conditions
- Requires field verification and true up of baseline conditions
- Allows for a range of accuracy depending on data used

WHEN TO USE

- Measures that impact stand alone equipment or systems (e.g., fans, pumps, motors, lighting, chillers, and boilers)
- Equipment and system operations can be monitored
- Retrofit or replacement of existing equipment
- Can apply to end of life or early replacement projects
- Where equipment or system loads and schedules can be monitored or determined from other data

WHEN NOT TO USE

- Measures involving multiple pieces of equipment with complex interactions
- Projects with significant interactive effects
- Where equipment or system level measurements are not feasible
- Metering period(s) are too short to reflect full range of operations
- Projects with random loads or schedules

PROCEDURE

1 **ASSESS BASELINE** — Identify category for baseline's load (constant or variable) & schedule (timed or variable)

2 **CONSIDER IMPACTS** — Determine impact on baseline's load & schedule

3 **ASSIGN POST-INSTALL CONDITIONS** — Identify category for post-install's load (constant or variable) & schedule (timed or variable)

4 **SELECT EQUATION** — Select equation to use to determine savings

5 **IDENTIFY REGESSIONS** — Determine relationships between load and schedule and other parameters

6 **COLLECT DATA** — Identify & collect required data during baseline and post-installation periods

7 **CALCULATE SAVINGS** — Calculate energy savings using selected equation

REPORTING REQUIREMENTS

- Data for the baseline and reporting periods
- Load and schedule for baseline and reporting periods
    - include sources of data along with necessary data correlations and proxies applied
- The savings equation used
- Operational verification results

TIPS

- Use measured energy and operational data to establish loads and hours of use
- Use the 'Absent Baseline' approach when a code compliant or standard practice baseline is required
- Level of rigor can vary based on the measurements included
- Measure power (kW) when possible and can be done safely
- Develop equations from measurements to characterize variable loads
- Equipment specifications may be used with operating data to determine loads
- Use 'bins' to group data (e.g., hours at a range of temperatures)
- Loads and hours of use from post-installation period can apply to the baseline if unchanged

TOOLS & RESOURCES

- ASHRAE Guideline 14-2014 Annex E for Retrofit Isolation Approach Techniques
- State building energy codes (OR, WA)

APPLICATION SPECIFIC CONSIDERATIONS

Within the EUM Protocol there are two calculation approaches considered: end-use metering and end-use metering absent baseline. Each approach has some specific requirements and considerations summarized below.

	END-USE METERING APPROACH	END-USE METERING ABSENT BASELINE APPROACH
Overview	Savings are determined from monitored data (energy use and operational parameters) in baseline and post-installation periods on isolated equipment or end-use.	Savings are determined from monitored post-installation data (energy use and operational parameters) from isolated equipment or end-use. Post-installation data and code-specified parameters are used to determine baseline energy use.
Approach	Energy use characteristics of the equipment are broken down into load and hours of use components, and whether these components are constant or variable in baseline and in post-installation periods.	
Analysis	Measured load and operating data from the baseline and post-installation are analyzed. Regression analysis can be used to extrapolate measured data to a full year.	Measured load and operating data from the post-installation are used with code requirements to determine baseline loads and hours of use. Regression analysis can be used to extrapolate measured data to a full year.
Use Cases	• Early replacement of equipment in existing buildings • Monitoring equipment exists or temporary loggers can be added	• End of life equipment replacements in existing buildings • Targeted efficiency improvements of equipment or systems in new buildings or major renovations to existing building
Savings	Measured load (kW) and hours of use data are used in defined equations to determine energy savings.	Measured load (kW) and hours of use from the post-installation period and estimated baseline kW and hours of use based on code are used in defined savings equations.

EXAMPLES OF END-USE METERING

The EUM Protocol includes seven examples of how the protocol is applied to different types of energy savings projects. Six of these examples are highlighted below.

Example 8.1
Scope: Motor upgrade in existing building
Approach: EUM - measured kW
Reference: EUM pg. 39

Example 9.1
Scope: New construction lighting improvements
Approach: EUM Absent baseline
Reference: EUM pg. 57

Example 8.2
Scope: New on/off controls for fans
Approach: EUM - measured kW, hours
Reference: EUM pg. 42

Example 9.2
Scope: Replacement of failed chiller
Approach: EUM Absent baseline
Reference: EUM pg. 58

Example 8.4
Scope: Constant flow to variable volume
Approach: EUM - measured kW, flow rate
Reference: EUM pg. 51

Example 9.3
Scope: New construction high efficiency motor
Approach: EUM Absent baseline
Reference: EUM pg. 60

BPA RESOURCES

BONNEVILLE POWER ADMINISTRATION

BPA Measurement and Verification Resource Library

Equipment or End-Use Metering Protocol

M&V Protocol Selection Guide and Example M&V Plan

SUMMARY GUIDE:

Meter-Based Energy Modeling Protocol

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Administration's (BPA) *Verification by Meter-Based Energy Modeling Protocol* uses regression analysis of meter-based energy data and key independent variables to create mathematical models of the baseline energy consumption. Savings are then determined by subtracting the post-installation energy consumption from model adjusted baseline energy consumption. Savings for typical conditions can be determined if a post-installation period energy model is developed and adjusted to typical conditions and the baseline energy is also adjusted to typical conditions.

Meter-Based Energy Models:

- Require continuous energy and independent variable data
- Are developed using regression analysis, often using specialized software tools
- Are based on the empirical analysis of data
- Use of method requires sufficient accuracy of the baseline model
- Are best for existing buildings or systems whose operations are predictable and expected to remain consistent

WHEN TO USE

- Projects in existing systems and facilities with significant energy impacts (>3-5%)
- Energy and independent variable data are available for at least one year
- Building or system operations are consistent
- Energy interactions between measures are significant
- Expected savings are large compared to the uncertainty in the model
- Savings from measures are otherwise hard to quantify

WHEN NOT TO USE

- A code or standard practice baseline is required
- Post-installation monitoring period is limited
- Accuracy of baseline model is insufficient relative to savings
- Other changes occurred in baseline period or are expected post-installation
- Individual savings for one of several measures is needed
- Operations are inconsistent or expected to change

PROCEDURE

Collect Data

Step 1: Collect Baseline Data

- Energy use data for full range of operating conditions (e.g., 1 yr)
- Identify independent variables driving energy use (e.g., outdoor temperature) and collect data

Create Model

Step 2: Develop Baseline Energy Model

- Collect, clean, and graph data
- Select and develop a model
- Validate the model
  - Compare model statistics to expected level of savings

Post-Installation

Step 3: Adjust Baseline Model
Use post-installation conditions (e.g., outdoor temperatures) to adjust baseline energy

Step 4: Calculate Energy Savings
Measured energy from post-installation period is subtracted from adjusted baseline energy

REPORTING REQUIREMENTS

- Define the measurement boundary to encompass the building or system
- Document baseline system and impacts from measures
- Include energy and independent variable data
- Provide model development procedure and details on model:
  - Software used
  - Type(s) of models (e.g., change point, time of use and temperature)
  - Independent variables
  - Error or uncertainty in model

TIPS

- Use a common time interval (hourly, daily, weekly, or monthly) for all data
- Short-time interval data (e.g., daily, hourly) provides additional granularity
- Uncertainty in model should generally be no more than 50% at a confidence level of 68%
- Level of uncertainty in an energy model will vary with the data's' time interval
- Track and adjust for non-routine events (e.g., maintenance shutdown)

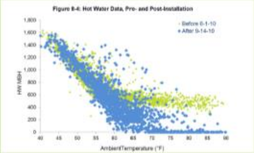
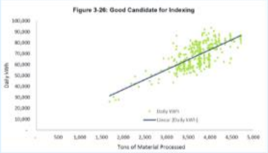
TOOLS & RESOURCES

Data analysis tools are available but require familiarity to use (i.e., a learning curve)

- **M&V Tools:** NMECR, ECAM, CalTRACK, UT
- **Statistical analysis:** R, SAS, Python
- **Weather Data:** NREL's TMY3 weather data, NOAA's historic weather data
- **Guidelines:** ASHRAE Guideline-14

APPLICATION SPECIFIC CONSIDERATIONS

Within the Meter-Based Energy Modeling Protocol there are two methods presented: energy modeling and modeling with energy indexing. Each method has some specific requirements and considerations summarized below.

	ENERGY MODEL	ENERGY INDEX
Overview	Develop a data-driven regression-based model(s) of the baseline energy use to an independent variable (e.g., weather). Savings are the difference between monitored energy use in the post-install period and the baseline energy use adjusted to monitored post-install conditions. Calculating normalized savings requires creating a post-installation energy model, and adjusting it and the baseline model to "normal" conditions. Savings are the difference between the two adjusted models.	Develop a data-driven regression-based model of the baseline energy use to an independent variable (e.g., production rate) and adjust it to "normal" conditions. Create a model of the post-installation energy use and adjusting it to "normal" conditions. Savings are the difference between the two adjusted models.
Use Cases	Use when the relationship between energy use and weather (and/or other independent variable) requires multiple regressions (e.g., change-point models) or the model is non-linear.	Use when the energy use is proportional to one or more independent variables (e.g., energy use per widget produced) where the regression model is linear.
Insights	Change point models can provide insights into system performance.	Method is not recommended with more than one independent variable.
Example Model		

EXAMPLES OF METER-BASED MODELS

The *Verification by Meter-Based Energy Modeling Protocol* includes three examples of how the protocol may be applied to different types of energy savings projects. The first example models measured heating and cooling energy, and the other two model the energy use of industrial equipment.

EXAMPLE 1
Replacement of leaking heating & cooling valves

Method:
Meter-Based Energy Models - End-use analysis

Reference: MBEM pg. 81

EXAMPLE 2
Modification to industrial pumping systems

Method:
Meter-Based Energy Models - Energy Use Indexing (kWh per kGal)

Reference: MBEM pg. 89

EXAMPLE 3
Replacement of compressed air equipment

Method
Meter-Based Energy Models - System level analysis

Reference:
MBEM pg. 93

BPA RESOURCES

Meter-Based Energy Modeling Protocol

Regression for M&V: Reference Guide

Commercial & Industrial SEM M&V Reference Guide

BONNEVILLE POWER ADMINISTRATION

SUMMARY GUIDE:

Estimating Peak Demand Impacts

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Administration's (BPA) *Estimating Peak Demand Impacts Application Guide* discusses impacts from capacity savings on utilities, defines BPA's peak demand period, and provides several methods to estimate demand savings from energy savings projects.

Peak demand impacts:

- Affect generation, transmission, and distribution capacities
- Can impact cost effectiveness of projects for customers
- Are based on reductions during specific times of day/months which see maximum system loads
- May be determined using the BPA M&V Protocol selected for the project
  - Engineering Calculations with Verification
  - End-Use Metering
  - Meter-Based Energy Modeling
- Approach used to quantify depends on the data available
- Accuracy of demand savings estimates can vary and depend on data and assumptions used
- Are not used in BPA's incentive calculations
- Are not included in BPA's project reporting requirements

WHEN TO USE

- Utilities quantifying demand impacts from energy efficiency projects and programs
- Energy efficiency projects with substantial peak demand reductions that will:
  - impact utility planning, or
  - significantly change customer costs through peak kW charges or time of use rates

WHEN NOT TO USE

- Projects with no or low expected peak demand savings
- Projects with energy only (kWh) rates

PROCEDURES

1. Use direct estimation

- Requires hourly or sub-hourly data from baseline and post-installation period

- OR-

2. Use secondary resources

- Required when hourly data is not available
- Use with with inputs and outputs of energy savings calculations

End-Use Metering

- Use measured data from baseline and post-installation period
- Weather dependent measures should be adjusted to TMY3 weather using regression analysis

Meter-Based Energy Modeling

- Hourly models of the baseline and post-installation periods are adjusted to Typical Meteorological Year (TMY3) data
- Estimate saving during each hour in the peak period and average results
- Daily models should use load shapes to estimate the distribution of energy and savings across hours (for efficiency only projects)

Engineering Calculations

- Hourly (8760) calculations can be used with coincident factor, if needed
- For bin hour analyses, identify weather conditions during peak period

DEFINITIONS

Capacity or peak demand savings

- Difference in the average baseline and post-installation demand during the peak period time and/or weather conditions
- Uses the average reduction during the peak demand window

Load shapes show the average consumption or savings across a period of time (daily, weekly, yearly)

Coincident factor is the percentage of full power draw of the targeted equipment during peak period

Energy to demand factor for a specific measure or end-use is ratio of peak demand savings to energy savings

BPA Peak Period BPA defines the peak period as cold winter weekday mornings from 6:00 AM to 10:00 AM (hours ending 7, 8, 9, and 10 local prevailing time)

TOOLS & RESOURCES

Weather Data: NREL's TMY3 Weather Data
Load shapes: RTF, EPRI
Guidelines: *Uniform Methods Project Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocol*

SUMMARY GUIDE:

Sampling for M&V: Reference Guide

BONNEVILLE POWER ADMINISTRATION

OVERVIEW

Bonneville Power Administration's (BPA) *Sampling for M&V: Reference Guide* can be used with retrofit isolation M&V protocols when the number of affected systems is too large to meter and analyze. Sampling allows use of a valid sample of the systems.

Sampling for M&V:

- Is used along with M&V protocols:
  - Equipment or End-Use Metering Protocol (EUM)
  - Engineering Calculations with Verification Protocol (ECwV)
- Details how to select valid samples
- Uses a sample of equipment measurements
- Requires groups of similar retrofits (e.g., lighting fixtures)
- Is used to reduce M&V expenses
- Reduces accuracy of reported energy savings
- Includes the use of limited statistics
- Emphasizes validating results of sampled measurements

WHEN TO USE

- Projects that include a 'population' of many similar retrofits
  - lighting upgrades, controls upgrades, rooftop unit replacements, motor replacements, industrial equipment
- Projects using either the EUM or ECwV M&V Protocol
- Sufficient samples to represent the entire population are required
- When additional uncertainty in savings estimates is not important

WHEN NOT TO USE

- Projects that include unique equipment
- Equipment with different operating conditions
- Where Meter-Based Energy Modeling M&V Protocol is used
- When project savings need to be very accurate
- Where metering is sufficient to cover all systems retrofit
- There is significant variability in the 'population' of retrofits

PROCEDURE

Collect Data

Step 1: Group data on planned retrofits

- Inventory all retrofits
- Grouped by their load and operating hours (pre and post)

Define Approach

Step 2: Select a sampling strategy

- Simple random samples
  - homogeneous population
- Stratified random samples
  - multiple groups within a population

Step 3: Assign level of variability

- 0 to 1 for each group

Step 4: Define desired accuracy

- Confidence and precision
- 90% confidence at ±10% precision is recommended

Step 5: Randomly select samples

- Include alternates

Use Samples

Step 6: Measure selected samples

- Include alternate samples

Step 7: Validate Results

- Overall precision of results

REPORTING REQUIREMENTS

- Define sampling procedure used
- Details on population and groups:
  - Population sizes
  - Characteristics of each group (e.g., load, performance, hours)
    - Assumed Cv for each group
    - Sample size selected and used
  - Confidence and precision targeted
  - Actual precision achieved
  - Calculation and adjustments made
- Other M&V details required by M&V protocol used

TIPS

- Use stratified sampling with multiple groups
- Group members of the population with identical characteristics together
  - Ensure groups are homogeneous
  - Exclude unique items and measure separately
  - Characteristics measured using samples must be uniform
- Characteristics include performance and usage metrics (e.g., power, operating hours)
- A large range of values results in a high Cv
- Assume a Cv or 0.5 for most groups
- Samples usually comprise <10% population
- Meter extra samples
- Define a method to field identify alternate samples

TOOLS

Generated random samples (0 to 1) in Excel:

- RAND()

EXAMPLES OF RANDOM SAMPLING

BPA's *Sampling for M&V: Reference Guide* includes three examples of how to apply each type of sampling strategy: simple random sampling, stratified random sampling, and the less common sampling for binomial applications.

APPLICATION 1
Replace multiple similar motors

Method:
Simple Random Sample

Reference:
Sampling pg. 17

APPLICATION 2
Replace multiple HVAC units

Method:
Stratified Random Sample

Reference:
Sampling pg. 18

APPLICATION 3
Identify level of failed lighting fixtures

Method
Bionomial Distribution

Reference:
Sampling pg. 20

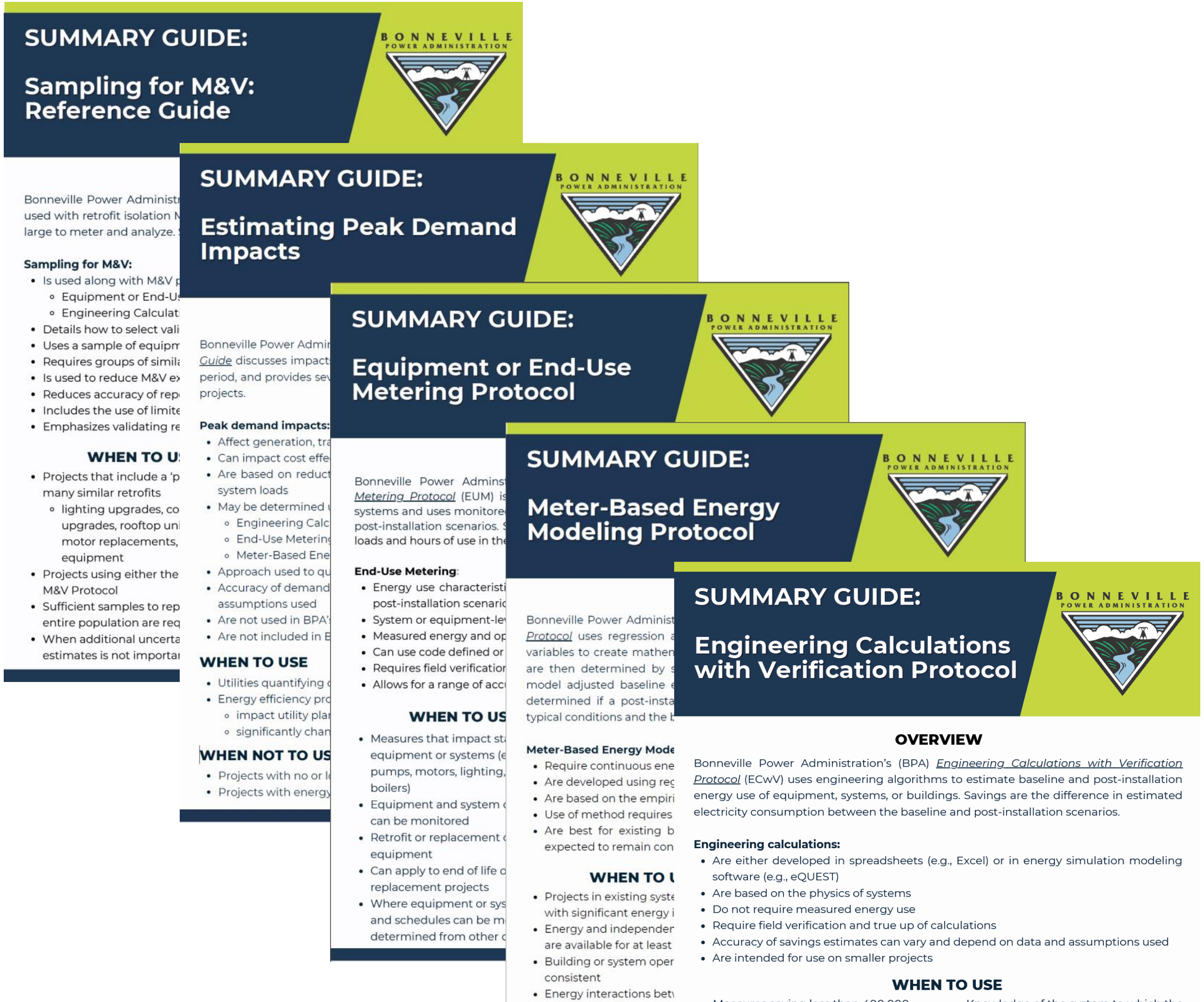
BPA RESOURCES

BPA Measurement and Verification Resource Library

Verification by Equipment or End-Use Metering Protocol

Engineering Calculations with Verification Protocol

BONNEVILLE POWER ADMINISTRATION



SUMMARY GUIDE: Sampling for M&V: Reference Guide

SUMMARY GUIDE: Estimating Peak Demand Impacts

SUMMARY GUIDE: Equipment or End-Use Metering Protocol

SUMMARY GUIDE: Meter-Based Energy Modeling Protocol

SUMMARY GUIDE: Engineering Calculations with Verification Protocol

OVERVIEW

Bonneville Power Administration's (BPA) _Engineering Calculations with Verification Protocol_ (ECwV) uses engineering algorithms to estimate baseline and post-installation energy use of equipment, systems, or buildings. Savings are the difference in estimated electricity consumption between the baseline and post-installation scenarios.

Engineering calculations:

- Are either developed in spreadsheets (e.g., Excel) or in energy simulation modeling software (e.g., eQUEST)
- Are based on the physics of systems
- Do not require measured energy use
- Require field verification and true up of calculations
- Accuracy of savings estimates can vary and depend on data and assumptions used
- Are intended for use on smaller projects

WHEN TO USE

BPA Custom Project Protocols

THANK YOU!

– Further discussion

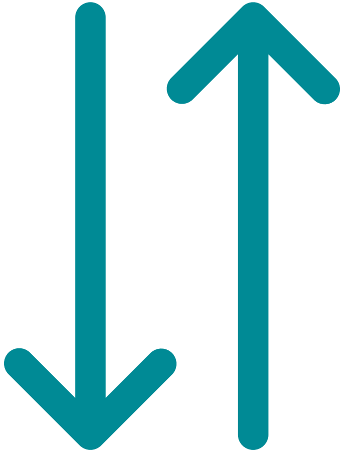
– Questions or Comments?

Thank you!

Additional Content

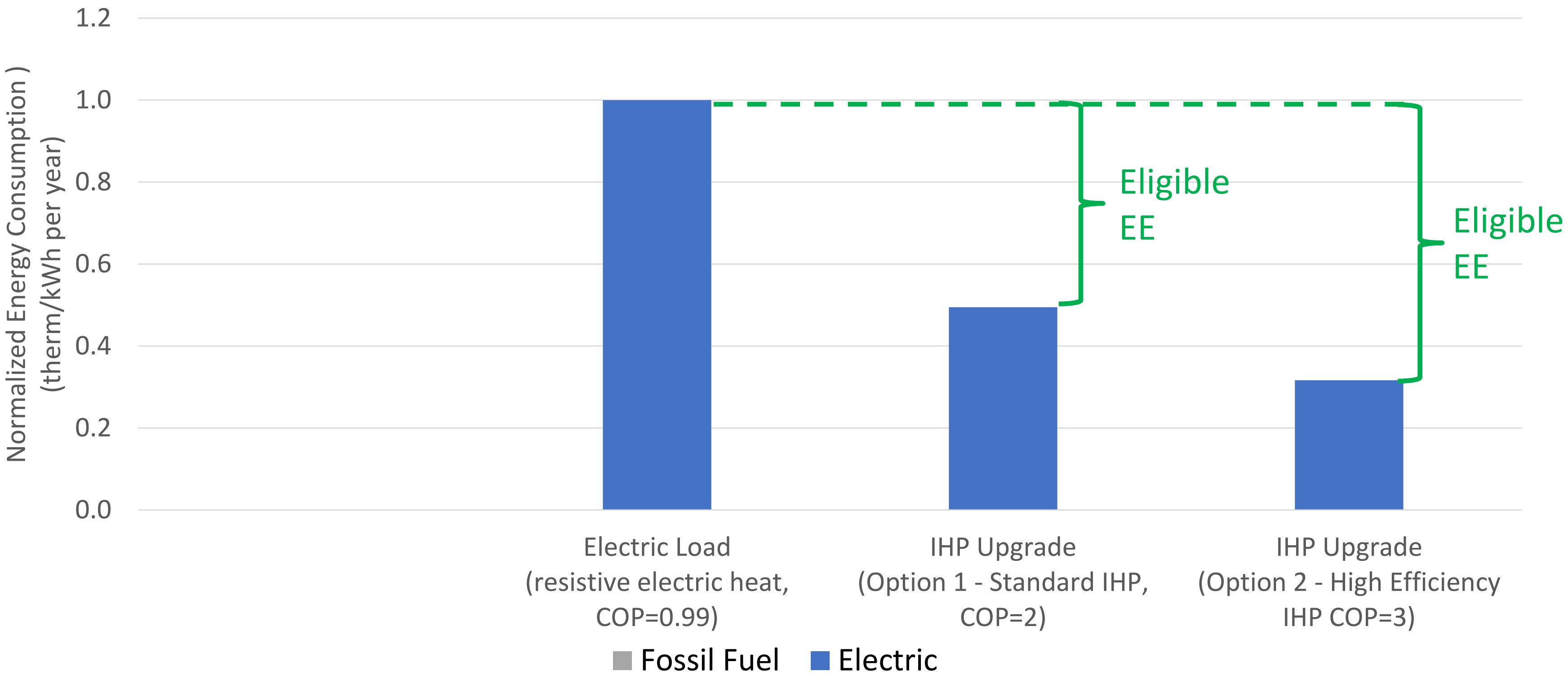
"Fuel Switching Implications"
And
ECwV

Fuel switching implications

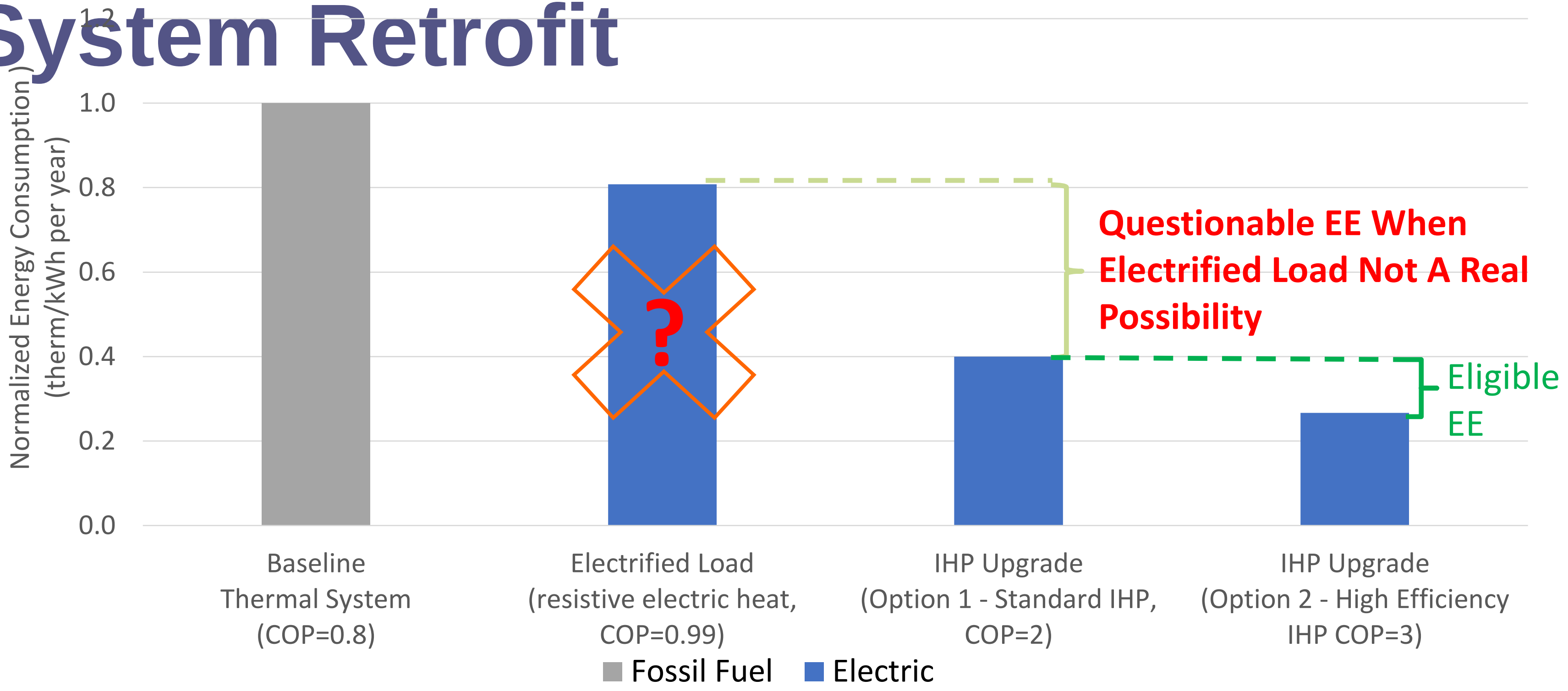


- Retrofit projects that change primary energy source require careful review of the technology options available
- New construction projects require consideration of standard practice
- Our objective is to help sites select the <u>most energy efficient</u> IHP option

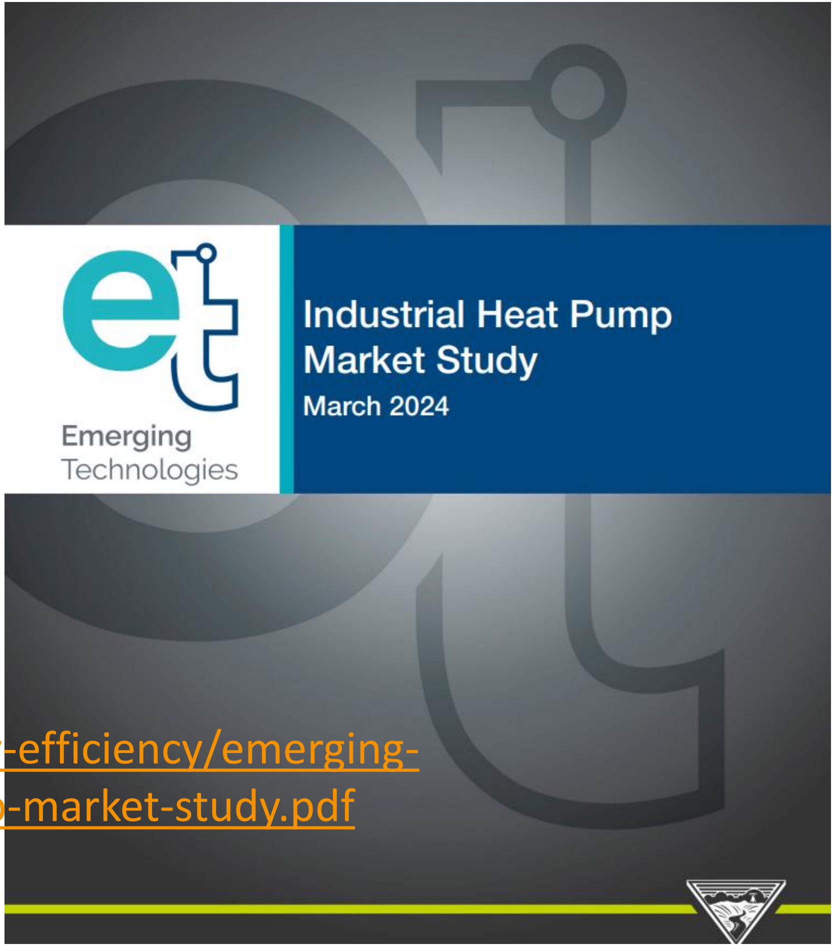
Baseline scenario 1: Retrofit of existing electrified load



Baseline Scenario 2: Thermal System Retrofit



BPA EE Emerging Technology Industrial Heat Pump Market Study



Completed by Cascade Energy in March 2024

Available for download at:

https://www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/202403-industrial-heat-pump-market-study.pdf

Engineering Calculations with Verification Procedure

ECwV Protocol is an approach based on models of equipment, systems, or buildings, rather than pre- and post-project measurements of energy use.

Two Main Engineering Calculation Approaches:

1) Engineering calculations, typically spreadsheet-based

2) Whole-building simulation (eQuest, EnergyPlus, etc)

Common Requirements, Regardless of Approach:

1) A well-substantiated baseline
2) Reasonable characterization of post-implementation behavior

Step 1: Process/Measure Description

- Describe the existing (pre-retrofit or *base case*) system.
- Describe the proposed (post-retrofit or *efficient-case*) system.
- Describe the measure; include sufficient information so it is clear how the proposed measure will be implemented and how it will achieve the stated savings.

Step 2: Establish Baseline Annual Energy Use

- Baseline Energy Use:
  - *Baseline Energy Use (kWh per year) = ∑(Op Hours * Equipment Load (kW per hr))*

- The baseline is:
  - the actual equipment efficiency,
  - standard efficiency, or
  - applicable code

Step 2: Establish Baseline, continued

- Use accepted engineering algorithms and procedures from recognized technical organizations.
  - ASHRAE, SMACNA, ANSI, etc.
- Annotate all assumptions or constants used in engineering calculations.
- Use rated performance factors tested under accepted procedures specified by recognized rating agencies.
  - ARI, AGA, ANSI, ASTM, etc.
- Provide an explanation when equipment performance rating conditions vary from standard conditions.

Step 3: Establish Post-installation Annual Energy Use

- Post-Installation Energy Use
  Post-Install Energy Use (kWh per year) =
  $\sum[\text{Op Hours} * \text{Equip Load (kW per hr)}]_{post}$
- Post-installation calculation is based on the projected performance.
- Inputs and associated assumptions must be clearly stated and verifiable.
- Use of a manufacturer-specific simulation product can be acceptable, but may require additional information.
- Description must provide sufficient detail to provide the basis for your projection.

Common Pitfalls

- Research suggests a nearly universal tendency to underestimate off-shift equipment operation.
- Much more interior lighting is used after hours than is typically modeled.
- Equipment that is understood to be "always on" is still rarely on for 8,760 hours per year. Conversely, almost no equipment is always off, including equipment that is only intended for redundancy.
- Savings for night setback is often overstated.

Common Pitfalls, continued

- Motor load factors may often be lower than assumed.
- While variable frequency drives (VFDs) provide significant savings, calculations should include a limit on how low the power can go.
- The fan affinity laws are “widely misapplied and misused.”

Common Specific Issues

- The detail required in a calculation is often dependent on the level in the building hierarchy for which the calculations are intended.
- Fan and pump curves can be very valuable in creating good calculations.
- Use redundant measurements when possible and appropriate.
- Do not use fixed power or efficiency.

Common Specific Issues, continued…

- A common controls or existing building commissioning measure is to add or change reset strategies for chilled water and condenser water.
- Note that motor efficiency can drop off significantly at low load. Similarly, VFD efficiency drops off significantly at low speeds.
- For most variable flow systems, power is not proportional to the cube of flow.

General Spreadsheet Calculations Guidance

- **Don't bury constants inside formulas; explain any uncommon constants.**
- **List equations, including explanations of variables.**
- **Use names for variables instead of cell references as much as practical.**
- **Consider breaking long calculations into multiple steps where helpful for clarity.**

General Spreadsheet Calculations Guidance, continued

- **A good organizational approach uses the following sections for each savings calculation:**
  - Summary of Results
  - General Fixed Inputs – baseline and post
  - Curve Fits – baseline and expected post
  - Equations – list and explanation
  - Calculations – by category (occupancy, equipment status, day type, etc.)

Simulation Modeling

- Aka Physics Models
- Option D

Sources of Simulation Support

- U.S. DOE
  - EnergyPlus, BeOpt
  - FEMP resources
- ASHRAE
  - 1050-RP, Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models
  - Guideline 14, Measurement of Energy and Demand Savings.
- IBPSA

Good Candidates for Simulation Analysis

- Building enclosure upgrades
  - Insulation
  - Windows
- Installation of skylights and automatic daylighting control in conditioned spaces

Possible Candidates for Simulation Analysis

- Chiller retrofit
- Packaged HVAC system retrofit
- Supply air pressure reset controls
- Refrigeration retrofits
- Air-side economizers
- Demand controlled ventilation
- Supply air temperature reset controls

Poor Simulation Analysis Candidates

- Lighting retrofit
- Motor efficiency
- HVAC retrofits for specific system types not accurately represented by the simulation tool
- Process efficiency measures where building envelope loads have little or no impact on energy use
- Retrocommissioning

ECwV with New Construction and Renovation

- Does not require model calibration
- Most applicable for smaller projects
- Most appropriate with interactive efficiency features
- Most convenient when a simulation model has been developed for other purposes, e.g., energy code compliance or green building rating system points

Simulation - ECwV Applicability

- New building – no historic energy use
- A major addition – no historic energy use
- Major renovation, refurbishment, or change of use – historic energy use information irrelevant

Savings Verification Report should define loads

➡ For a constant load

- Load value and units
- How load value was obtained
- Any proxies justified and their development described

➡ For variable load

- Load frequency distribution
- How distribution was obtained
- Consider grouping continuous load data into 5 to 10 bins

Savings Verification Report should define schedules

➡ **For a timed schedule**

- Source for the schedule
- Total annual hours

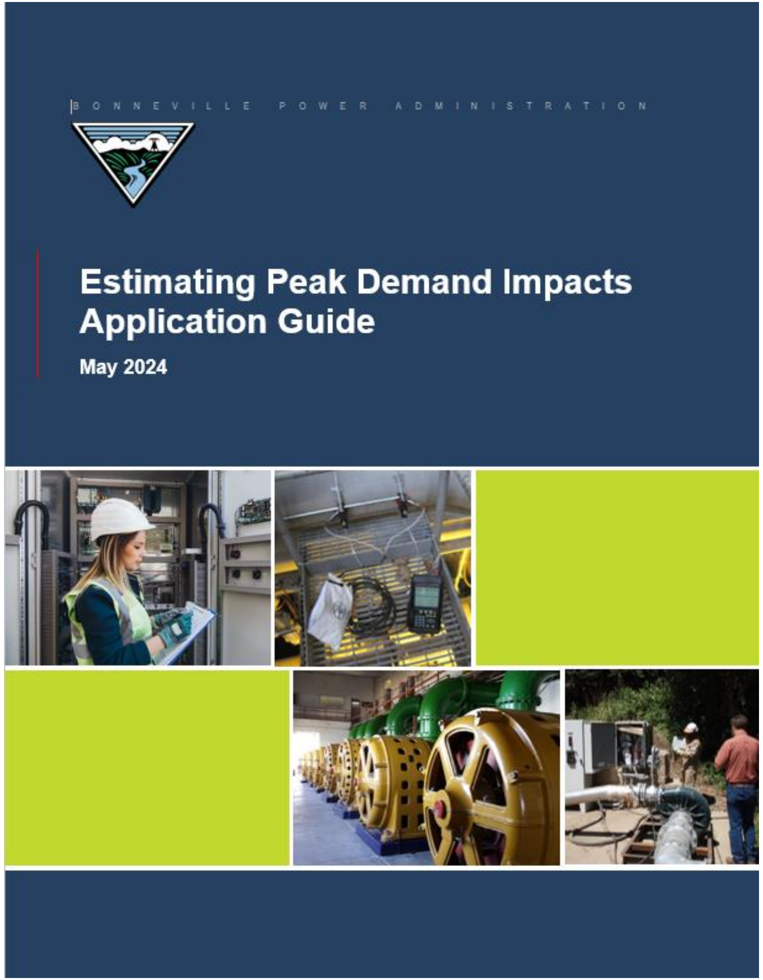
➡ **For a variable schedule**

- Source for estimate of hours during the measurement period
- Total annual hours

Operational Verification☼

- Demonstrates that in the post-installation period, system is operating (or not operating) as modeled

- If post-installation data indicates less than predicted performance, either:
  - ➡ Take action to help customer fully install measure properly and then re-verify; or
  - ➡ Use the same calculation methodology to get revised measure savings estimate



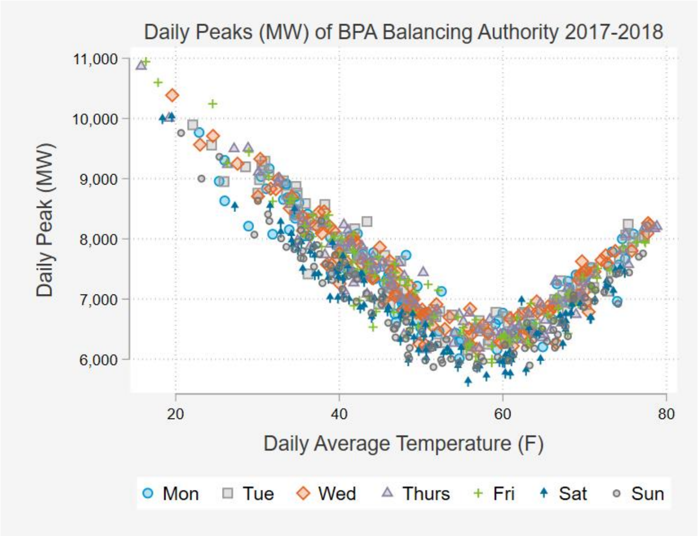
- Overview of capacity impacts and peaking conditions of the BPA system
- Core concepts and data management considerations
- Applied examples
  - Constant Load, Timed Schedule
  - Energy modeling with hourly data
  - Energy modeling with daily data
  - Engineering bin calculations

Introduction

- The existing BPA M&V protocols focus on estimating the energy savings (kWh) resulting from incented upgrades
- Some of the savings delivered by these upgrades will be coincident with times when the electric system is most constrained
  - These are peak demand (kW) or capacity savings
- Instead of quantifying how much energy is saved annually, peak demand savings analysis looks at savings during a narrow portion of the year
  - Requires us to ask “When is energy saved?”

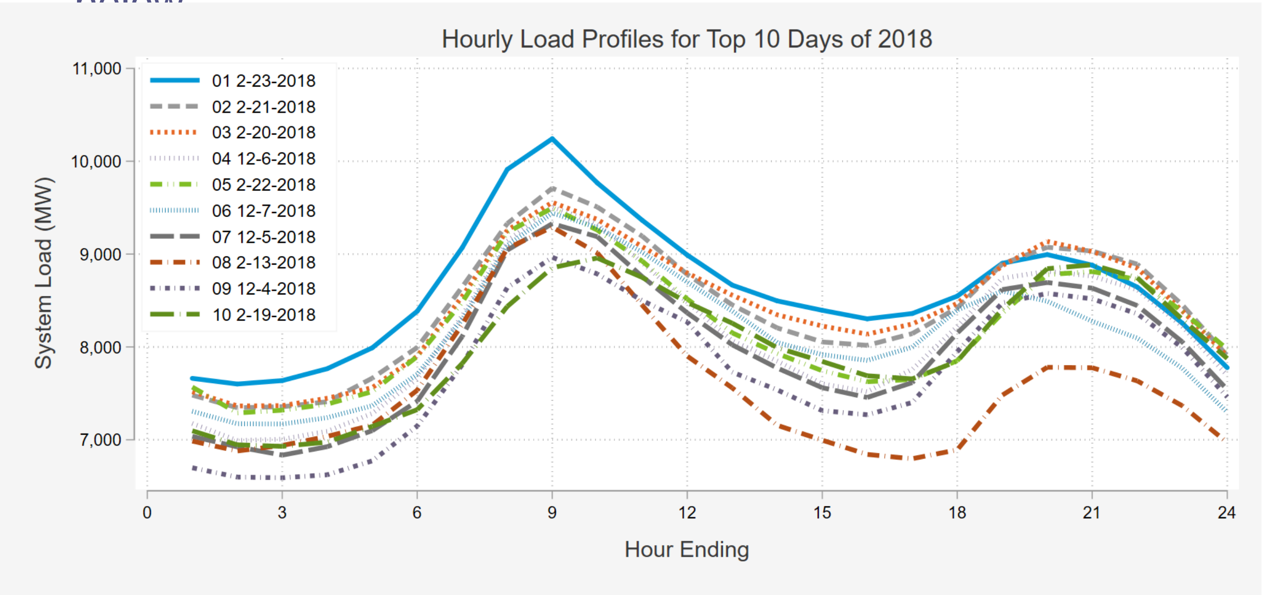
Peak Demand Definition for BPA

- M&V practitioners should seek to understand the local definitions and requirements of the program or utility they support
- Local variations aside, the BPA system as a whole is winter-peaking and those peaks are driven by cold weather



Peak Demand Definition for BPA

- Hourly load profiles for the top 10 days of 2018 are shown below



Peak Demand Definition for BPA

- All ten of the highest peak load days in 2018 occurred during winter months
- The daily peak is generally set in the morning hours
- In this application guide, the peak demand period is defined as 6:00 AM to 10:00 AM on cold winter weekdays
  - For weather-dependent savings, practitioners may want to factor in expectations of the typical weather conditions during system peaks

Core Concepts

- The appropriate approach for estimating peak demand savings is driven by what data is available
- **Direct estimation with primary data** requires the availability of hourly or sub-hourly measurements of the parameter(s) of interest
  - The modeling approach is similar to the normalized savings procedure described in the *Verification by Energy Modeling Protocol*
- **Estimation using secondary sources** uses secondary information along with inputs or outputs of energy savings calculations

Core Concepts

- When using secondary sources to estimate average savings during the peak demand window, concepts/tools practitioners may leverage include:
  - **Load shapes** – tables/charts showing average distribution of consumption or savings across some period
  - **Coincidence factor** – the ratio of the equipment’s average load during the peak demand period to the full power draw of the equipment when operating
  - **Energy to demand factor** – the ratio of peak demand savings to annual energy savings for a measure type or end-use

Data Management

- Working with hourly or sub-hourly data requires careful attention to certain data management procedures to ensure accurate inferences:
  - What convention is used in the time stamps from the facility revenue meter or end-use logging equipment?
  - Do the time stamps represents the beginning of an interval or the end of an interval?

15-minute Interval Data Example

Date	Timestamp	Hour Ending	Peak Period?
2/12/2019	05:45:00 AM	6	No
2/12/2019	06:00:00 AM	6	No
2/12/2019	06:15:00 AM	7	Yes
2/12/2019	06:30:00 AM	7	Yes
2/12/2019	06:45:00 AM	7	Yes
2/12/2019	07:00:00 AM	7	Yes
2/12/2019	07:15:00 AM	8	Yes

Data Management

- For sub-hourly data, do the measurements represent average demand or energy consumed?
- Practitioners should also handle missing data before beginning analysis
  - Gaps, spikes, and missing/zero/negative reads happen with high-frequency data
- Charting the raw data is a useful tool for identifying potential data issues
  - Observations that are clearly bad should be removed

Basic Procedure

- The basic formulation of the peak demand savings algorithm is shown in Equation 1. Two mathematically identical forms are shown

Equation 1: Generalized Form of the Peak Demand Savings Algorithm

$$\Delta kW_{peak} = \frac{\sum_i^n (kW\ baseline_i - kW\ efficient_i)}{n}$$

-OR-

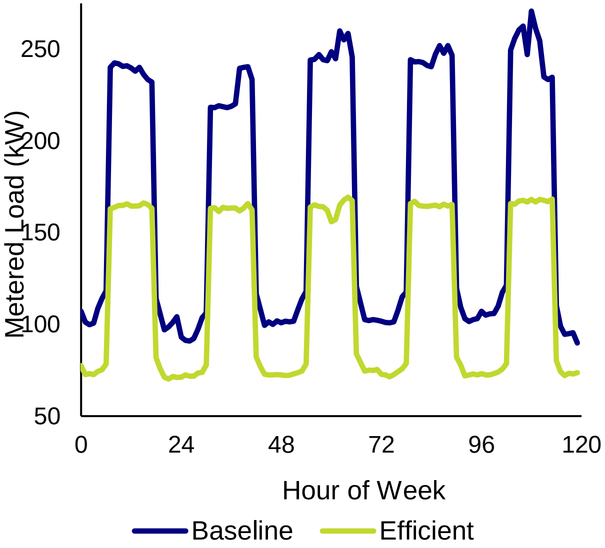
$$\Delta kW_{peak} = \frac{\sum_i^h (kWh\ baseline_i - kWh\ efficient_i)}{h}$$

Example 1

SIMPLE DIFFERENCE IN AVERAGES

Simple Example

- The figure to the right shows average hourly loads for a large compressed-air load before/after the addition of a VFD
- The site contact indicated that the load pattern is uncorrelated with weather conditions



Simple Example

- In this case, the estimated peak demand savings is equal to the average difference in power draw from 6:00 AM to 10:00 AM on weekdays between the baseline and efficient metering periods

Peak Demand Savings Calculation

Hour Ending	Mean kW Baseline	Mean kW Efficient	kW Savings
7	116.3	78.4	37.9
8	239.3	164.4	74.9
9	240.8	165.0	75.8
10	242.4	164.6	77.8
Average kW Reduction During Peak Demand Window			**66.6**

Example 2

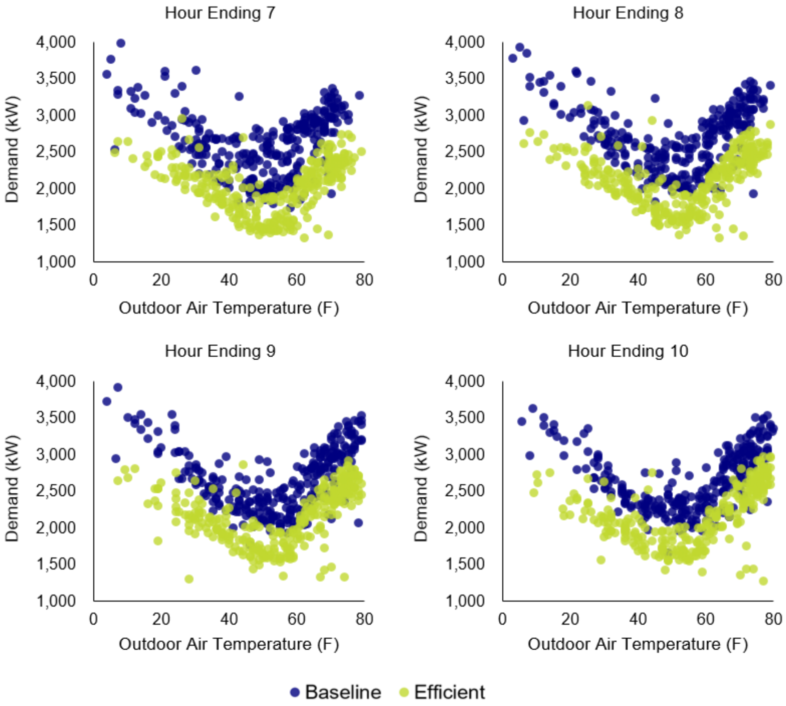
PEAK DEMAND IMPACTS WITH HOURLY DATA

Modeling with Hourly Data

- In the previous example, load was not weather-dependent. This allowed for a relatively simple approach (difference in averages)
- What happens when load is weather-dependent?
  - Regression modeling should be used to determine the relationship between load and weather during the peak period. This should be done separately for the baseline and efficient periods
  - The regression models will then be cast over typical meteorological year (TMY) weather. TMY weather should be filtered to hours ending 7, 8, 9, and 10 during December, January, and February

Modeling with Hourly Data

- Consider a facility that implemented multiple conservation measures over a six-week period
- The figure to the right compares load and outdoor air temperature during the relevant hours
- The analysis dataset can be limited to the heating slope side of the spectrum



Modeling with Hourly Data

- The table below shows the results of eight distinct regression models – one for each hour per period. TMY weather is also shown in the table

Period	Hour Ending	Model Intercept	OAT Coefficient (Slope)	Average TMY3 Temperature (F)
Baseline	7	3,502.8	-25.71	22.1
Baseline	8	3,691.6	-28.96	22.8
Baseline	9	3,660.5	-28.38	24.1
Baseline	10	3,515.7	-25.50	25.3
Efficient	7	2,843.0	-23.98	22.1
Efficient	8	2,930.8	-24.14	22.8
Efficient	9	2,853.6	-22.40	24.1
Efficient	10	2,734.4	-19.63	25.3

Modeling with Hourly Data

- In the table below, the regression coefficients (shown on previous slide) with the TMY weather values predict demand for each hour using the baseline and efficient period models. The estimate of capacity impacts for the hour is calculated as the baseline demand minus the efficient period demand.

Hour Ending	Predicted Baseline (kW)	Predicted Efficient (kW)	Demand Savings (kW)
7	2,934.7	2,313.0	621.7
8	3,031.2	2,380.3	651.0
9	2,976.4	2,313.8	662.6
10	2,870.4	2,237.7	632.7
Peak Demand Period	**2,953.2**	**2,311.2**	**642.0**

Modeling with Hourly Data

- Because the relationship between load and temperature was relatively stable across the peak period, this analysis could have been done with fewer regression models
  - Practitioners could model the four hours together in two regression models (one each for baseline/efficient periods) and predict demand using the average OAT of the four-hour period
  - The analysis could even be done with a single regression by including an indicator variable for the post implementation period and an interaction between the temperature variable and the post indicator
- In some jurisdictions, the definition of peak demand incorporates some assumption about extreme weather. In this case, the TMY weather conditions can be replaced with the extreme weather values

Example 3

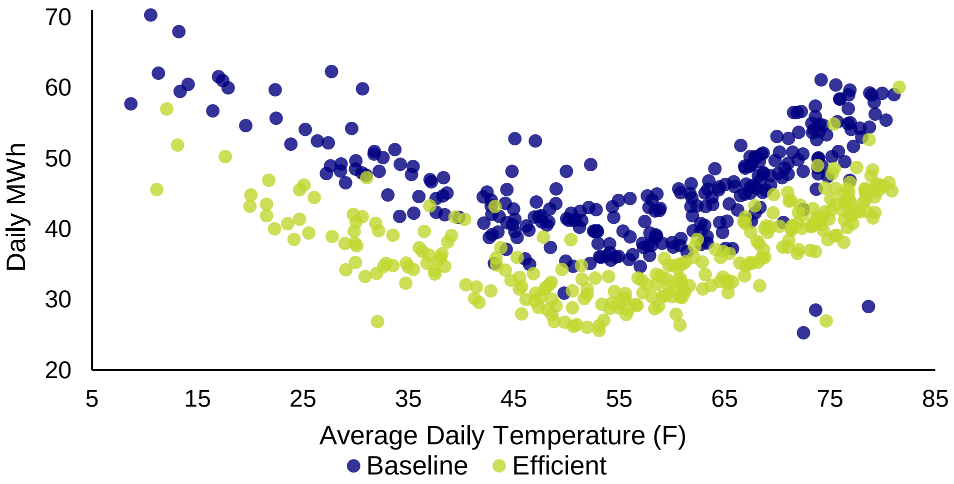
PEAK DEMAND IMPACTS WITH DAILY BILLING DATA

Modeling with Daily Data

- When the *Verification by Energy Modeling* or *Verification by Energy Use Indexing* protocols are used with daily or monthly meter readings, it is not possible to directly estimate the peak demand impact from the data used in the energy savings analysis
- A secondary load shape is needed to estimate how the energy savings are distributed across the hours of the day or across the hours of a year

Modeling with Daily Data

- Consider the facility from the previous example. The figure below shows daily energy consumption (MWh) against average daily temperatures
- Suppose daily kWh savings are estimated to be 11,258 kWh



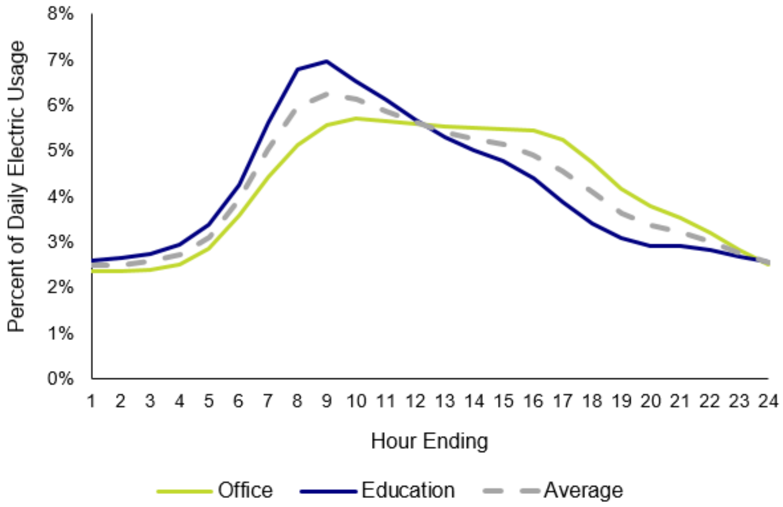
Modeling with Daily Data

- In order to distribute the 11,258 kWh of daily energy savings across the day, a secondary load shape is needed
- The facility in this example is a university and the project involved multiple EEMs that affected multiple end-uses
  - Based on this information, a whole premise load shape is a reasonable choice
  - The implicit assumption in applying a premise load shape to energy efficiency savings is that the savings are distributed proportionately to load
    - Equivalently, savings are proportionate to consumption
    - This assumption is not valid for all ECMs

Modeling with Daily Data

- The EPRI Load Shape Library does not include a “University” building type. The closest types available are “Education, K12” and “Office, Large.” The figure below shows the daily load shapes for these building types and an average of the two for an Oregon location

Hour	Share	Hour	Share
1	2.48%	13	5.41%
2	2.50%	14	5.25%
3	2.57%	15	5.12%
4	2.72%	16	4.92%
5	3.11%	17	4.56%
6	3.91%	18	4.08%
7	5.02%	19	3.62%
8	5.95%	20	3.35%
9	6.26%	21	3.21%
10	6.12%	22	3.02%
11	5.88%	23	2.76%
12	5.63%	24	2.53%



Modeling with Daily Data

- From the table on the previous slide, the average load share during the peak hours is 5.84%
  - It's important to average these values rather than sum them
- This value can be applied to the daily energy savings estimate:

$$\Delta kW = Estimated\ Daily\ kWh\ Savings * Average\ Share\ During\ Peak\ Hours$$

$$\Delta kW = 11{,}258 * 0.0584 = 657.5\ kW$$

- This method produced a peak demand savings estimate similar to the peak demand impact produced in the previous example (via hourly data)
  - This suggests that the EPRI load shape was a reasonable proxy
  - Performing such a check is generally not possible

Load Shape Resources

- Class load shapes used for cost allocation and rate design
- EPRI Load Shape Library
- Regional Technical Forum
  - 2006 California Commercial End Use Survey (CEUC) and End Use Load and Customer Assessment Program (ELCAP) conducted by BPA in the 1980s are primary sources
- There are advantages and disadvantages to each

Example 4

ENGINEERING CALCULATIONS WITH VERIFICATION

Engineering Calculations

- The *Engineering Calculations with Verification Protocol* uses project-specific equipment characteristics and sound engineering principles to estimate energy savings from custom energy efficiency projects
- Bin calculations are a common method for weather dependent projects
  - A bin calculation separates the hours of the year into different temperature bins, and the practitioner estimates the expected loading conditions for the baseline and efficient cases estimated for each bin

Engineering Calculations

- Consider a project in a Spokane hospital where VFDs are added to supply-air fan motors
  - The baseline controls for the motors were backward inclined airfoil
- Bin calculations for this project are shown on the next slide
- For peak demand impacts, practitioners should focus on the temperature bin that corresponds to the peak period – likely the “20-29 degrees” bin for the peak period definition used here

Engineering Calculations

Supply Air Fan Bin Calculation

Temperature Bin	Hours	Part Load Ratio	Flow Fraction Baseline (Backward Inclined Airfoil)	Flow Fraction Efficient (VFD)
Below 10 degrees	10	0.92	1.02	0.81
10-19 degrees	91	0.85	1.02	0.81
20-29 degrees	569	0.71	0.89	0.49
30-39 degrees	1,593	0.63	0.8	0.39
40-49 degrees	2,029	0.55	0.8	0.39
50-59 degrees	1,523	0.48	0.72	0.31
60-69 degrees	1,477	0.60	0.8	0.39
70-79 degrees	781	0.72	0.89	0.49
80-89 degrees	533	0.79	0.96	0.63
90-99 degrees	146	0.84	0.96	0.63
Above 100 degrees	8	0.91	1.02	0.81

Engineering Calculations

- For a 50-horsepower fan of 90% efficiency and assumed load factor of 0.8, the peak demand impact calculation would be as follows:

$$\Delta kW = kW_{Baseline} - kW_{Efficient}$$

$$\Delta kW = 0.746 * HP * \frac{Load\ Factor}{Efficiency} * (Flow_{Base} - Flow_{EE})$$

$$\Delta kW = 0.746 * 50 * \frac{0.8}{0.9} * (0.89 - 0.49) = 13.26\ kW$$

- This example illustrates the simplest capacity savings calculation that would accompany use of the *Engineering Calculations and Verification Protocol*
- Practitioners will encounter EEMs where the peak demand savings analysis requires incorporation of additional secondary information

Questions?

Resources

- BPA Measurement & Verification Resources. Available at: https://www.bpa.gov/energy-and-services/efficiency/measurement-and-verification
- Electric Power Research Institute Load Shape Library. Available at: http://loadshape.epri.com
- National Renewable Energy Laboratory. 2017. Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures – Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocol. Available at: https://www.nrel.gov/docs/fy17osti/68566.pdf
- *Pennsylvania Public Utility Commission. 2019. Technical Reference Manual, Volume 3: Commercial and Industrial Measures.* Available at: *http://www.puc.pa.gov/pcdocs/1614951.docx*