EPA

Guidebook for Energy Efficiency Evaluation, Measurement, and Verification

A Resource for State, Local, and Tribal Air & Energy Officials

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State and Local
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Acronyms and Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AEIC	Association of Edison Illuminating Companies
AMI	advanced metering infrastructure
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAU	business as usual
C&I	commercial and industrial
C&S	building energy code and equipment energy standard
CHP	combined heat and power
CIOU	California investor-owned utilities
CO_2	carbon dioxide
CPUC	California Public Utilities Commission
CVR	conservation voltage reduction
DEQ	Departments of Environmental Quality
DER	distributed energy resources
DOE	(United States) Department of Energy
EE	energy efficiency
EERS	energy efficiency resource standard
EGU	electricity generating unit
EIA	(United States) Energy Information Administration
EM&V	evaluation, measurement, and verification
EPA	(United States) Environmental Protection Agency
ESCO	energy services company
EUL	effective useful life
EVO	efficiency valuation organization
FCM	forward capacity market
FEMP	(U.S. Department of Energy) Federal Energy Management Program
HVAC	heating, ventilating, and air-conditioning
IOU	investor-owned utilities
IPMVP	International Performance Measurement and Verification Protocol
IRP	integrated resource planning
ISO	independent system operator
ISO-NE	ISO New England
kW	kilowatt
kWh	kilowatt-hour
kWh/h	kilowatt-hour per hour
LBNL	Lawrence Berkeley National Laboratory
LEAS	lifetime equivalent annual savings
LED	light-emitting diode
M&V	measurement and verification
MW	megawatt
MWh	megawatt-hour
NAAQS	National Ambient Air Quality Standards
NARUC	National Association of Regulatory Utility Commissioners
NEEP	Northeast Energy Efficiency Partnerships
NGO	non-governmental organization
NREL	National Renewable Energy Laboratory

O&M	operations and maintenance
PUC	public utilities commission
RCT	randomized control trial
RE	renewable energy
RMI	Rocky Mountain Institute
RTF	(Northwest Power and Conservation Council Northwest) Regional Technical Forum
RTO	Regional Transmission Organization
RUL	remaining useful life
SEE Action	State and Local Energy Efficiency Action Network
SIP	State or Tribal Implementation Plan
SPB	stringent practice baseline
T&D	transmission and distribution (system)
TRM	technical reference manual
UMP	(United States Department of Energy) Uniform Methods Project
VSD	variable speed drive

1. Introduction

Investments in energy efficiency (EE) in homes, businesses, and other facilities are a proven and cost-effective strategy for meeting electricity demand and avoiding generation that would otherwise occur at electricity generating units (EGUs).[1] All 50 states currently administer some type of EE program, and most states have mandated EE resource standards (EERS) (ACEEE, 2018a). Some states also have requirements for electricity suppliers to achieve "all cost-effective EE" (Gilleo, 2014). City, town, and other local governments are also advancing EE initiatives such as building energy codes, district energy and combined heat and power (CHP) programs, EE programs targeting low-income and multifamily residents, and EE data sharing and transparency.

To confirm that EE policies and programs are resulting in expected levels of energy savings, jurisdictions typically adopt quantification and verification approaches that are well-documented, rigorous, and consistently applied. These approaches help states, local governments, and tribes carry out key functions and responsibilities, and ensure that EE policies and programs are achieving their goals. This may include helping:

Key Terms for EE Activities

EE measure: A single technology, energy-use practice, or behavior that, once installed or operational, results in a reduction in the electricity use required to provide the same or greater level of service at an end-use facility, premise, or equipment connected to the delivery side of the electricity grid. EE measures may be implemented as part of an EE program or an EE project.

EE project: A combination of measures, technologies, and energy-use practices or behaviors that, once installed or operational, result in a reduction in the electricity use required to provide the same or greater level of service. EE projects may be implemented alone or as part of an EE program.

EE program: Organized activities sponsored and funded by a particular entity to promote the adoption of one or more EE projects or EE measures that, once installed or operational, result in a reduction in the electricity use required to provide the same or greater level of service in multiple end uses, facilities, or premises.

EE activity: An EE measure, EE project, or EE program.

- **Air officials** at Departments of Environmental Quality (DEQ) confirm that EE policies and programs included in air quality implementation plans are achieving real energy savings and emission reductions over the planning or compliance period;
- **Energy officials** at Public Utility Commissions (PUCs) and State Energy Offices (SEOs) establish rigorous, consistent, and transparent approaches for quantifying and verifying EE, while ensuring that EE policy and program goals are achieved and that customer funds are prudently allocated; and
- **All stakeholders** share information, coordinate on quantification and verification procedures, and make EE planning and investment choices that support key jurisdiction-wide goals such as ensuring energy-system reliability, a strong economy, and a healthy environment.

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[1] This *Guidebook* focuses on energy efficiency in the electricity sector as opposed to the energy sector in general, although many of the EM&V approaches described can be applied more broadly.

Considerations for Air Officials

A key audience for this *EM&V Guidebook* is state, local, and tribal air officials interested in including EE policies and programs in their voluntary and regulatory air quality implementation plans. This document does not presume that air officials should achieve EM&V expertise, directly participate in the quantification of EE savings, or manage EM&V oversight activities. Rather, they can use the document to gain a working understanding of EM&V and support discussions with counterparts in energy agencies.

To inform these objectives, the following information is provided throughout this document:

- Key EM&V terms and definitions;
- Text boxes with "considerations for air officials"; and
- Text boxes with "questions for air officials."

Jurisdictions have found that strong partnerships between air and energy officials can help all parties understand the details of EE policies and programs, quantify the resulting energy savings and emissions reductions, and support achievement of key policy and planning objectives.

The set of procedures, methods, and analytic approaches for quantifying and verifying energy savings is known as evaluation, measurement, and verification (EM&V). EM&V compares actual energy use after an EE project or EE measure has been implemented with the best estimate of the likely energy use that would have occurred in the absence of that project or measure.

1.1. Audiences and Uses

EPA is providing this *Guidebook for Energy Efficiency Evaluation, Measurement & Verification (EM&V Guidebook)* to help state, local, and tribal air and energy officials—as well as key stakeholders such as utility EE implementers—take steps to learn about, establish, or refine their EM&V approaches.

1.1.1. Use by Air Officials

EE can avoid generation that would otherwise occur at EGUs, which can reduce air pollution and improve ambient air quality. In some jurisdictions, EE policies and programs are an important component of plans for achieving these environmental objectives. One example is the inclusion of EE activities as an emissions reduction strategy in an air quality implementation plan, such as a State or Tribal Implementation Plan (SIP/TIP) for complying with various sections of the Clean Air Act. Another example is using EE in a plan or "path forward" under U.S. EPA's Advance Program,[2] which promotes voluntary actions in attainment areas to reduce ozone and/or fine particle pollution ($PM_{2.5}$) to help these areas continue to meet National Ambient Air Quality Standards (NAAQS). Using EE in an air quality improvement can, under some circumstances, avoid the need to install traditional emissions-control strategies and lower the overall cost of complying with applicable emissions goals or requirements.

In the context of using EE in a SIP/TIP, jurisdictions typically want to confirm that EE policies and programs will:

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[2] Jurisdictions participating in EPA's Advance Program develop a plan or "path forward" for improving local air quality, implement the measures identified in their path forward, and revisit their path forward periodically to expand and update it. More information is available on EPA's Advance Program website.

- Result in real energy savings and emission reductions over the planning or compliance period; and
- Achieve emission reductions over time in a manner that is quantifiable, permanent, enforceable, and additional.[3]

Applying the practices described in this *EM&V Guidebook* can provide air and energy officials with a credible basis for determining whether EE activities are achieving intended levels of energy savings and emissions reductions. The *EM&V Guidebook* can also help air officials understand the basics of EM&V and engage in discussions with their energy counterparts at SEOs and PUCs. Jurisdictions have found that strong partnerships between air and energy officials can help all parties coordinate on policy goals, understand the details of EE policies and programs, and quantify the resulting energy savings and emissions reductions in a manner that is well-documented, rigorous, and consistently applied.

Questions that Air Officials Can Ask—Getting Started

This *EM&V Guidebook* is intended to help air officials gain a working understanding of EM&V and support discussions with their counterparts in energy agencies. Air officials interested in using EE in a voluntary or regulatory air quality implementation plan can ask the following questions to learn more about EM&V practices in their jurisdiction:

- How can I be confident that savings from EE programs and policies in an air quality implementation plan will result in real emissions reductions?
- What are the main things I need to know about EM&V?
- Where can I find a description of applicable EM&V practices?
- What agencies and other entities are involved with EM&V?
- What are the key technical topics involved in conducting EM&V?
- How can I get involved with EM&V for purposes of representing my agency's perspective?

1.1.2. Use by Energy Officials

Energy officials may use this *EM&V Guidebook* to refine existing EM&V approaches or establish new ones. For example, officials at PUCs and SEOs can use information in the *Guidebook* to update or revise existing EM&V protocols and guidelines that apply to EE implementers operating in their jurisdiction.[4] This helps ensure that EE policies and programs are achieving intended results, and that customer funds —typically collected as a surcharge on energy bills—are prudently allocated. EE implementers such as investor-owned utilities (IOUs), public utilities, and private companies (e.g., energy service companies (ESCOs)) can similarly use this *EM&V Guidebook* as an information resource to support quantification objectives, such as establishing a baseline or selecting EM&V methods. Independent firms hired by

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[3] Additional means that reductions from EE are "surplus" or "incremental" to the baseline identified in a SIP. For example, a state using the "baseline emissions projection pathway" as described in the U.S. EPA's *Energy Efficiency/Renewable Energy Roadmap Manual* must document assumptions about which EE policies are already included—and which are incremental to—the electricity use forecast submitted as part of the SIP. Given that electricity load forecasting may occur at a single- or multi-state level, coordination between agencies, EE implementers, and entities conducting EM&V can help identify which EE savings are included in the baseline forecast and which are not.

[4] See Section 3 for a list of EE EM&V protocols and guidelines.

energy officials and EE implementers can also use this *EM&V Guidebook* as a resource for interpreting local protocols and guidelines. Finally, representatives of EE-related nongovernment organizations (NGOs) and advocacy organizations can employ approaches described in this *EM&V Guidebook* when examining whether a jurisdiction's EE policy and program regulatory goals are being achieved in a cost-effective and equitable manner.

1.2. Experience with EM&V

Jurisdictions began to scale up EE as an energy strategy in the 1970s. Since then EM&V has been critical to EE's success, credibility, and expansion. EM&V methods have been refined and improved over time as EE program strategies evolved. The practices in wide use today—and upon which the EM&V approaches in this *EM&V Guidebook* are based—are codified in protocols established by the National Renewable Energy, U.S. DOE's Federal Energy Management Program (FEMP), and several other collaboration-driven organizations. Today, jurisdictions around the country use EM&V as the metric for determining whether EE activities are achieving critical electricity reliability, planning, and other policy goals.

The oversight and quantification of EE in each of these contexts may differ slightly depending on objectives, but always rely on EM&V protocols and guidelines that are robust, transparent, and well-documented. These oversight mechanisms have generated a set of quantification procedures that are widely applied to ensure compliance with a broad range of local, state, and regional policy goals and regulatory requirements.[5] The specifics of how EM&V is applied—including the appropriate level of oversight and review—necessarily vary by policy context and the specific objectives for which EE is deployed.[6]

1.3. Scope, Contents, and Use with Other EM&V Resources

1.3.1. Scope of EE Activities Addressed

This *EM&V Guidebook* is intended to support the range of EE activities that can be included in a SIP/TIP for purposes of achieving NAAQS compliance, including:

- Building-level EE projects and measures, including those implemented as part of an EE program (which are currently in place in all 50 states) or to achieve a jurisdiction's energy policy goals;
- EE installed or operating across all customer sectors, including low-income segments of the population;[7] and
- EE implemented by IOUs, public utilities, private companies such as an ESCO, and the owners and operators of large commercial or industrial (C&I) facilities.

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[5] For example, the New England Independent System Operator (ISO-NE) established an EM&V protocol for quantifying capacity savings (expressed in MW) during a limited number of hours, supporting EE as a reliability resource, and calculating payments to EE providers. See the ISO New England Manual for Measurement and Verification of Demand Reduction Value from Demand Resources (2014).

[6] For more information, see U.S. EPA's *EM&V for Energy Efficiency Policies and Initiatives* (2017).

[7] This includes EE activities targeting low-income customers. While low-income EE activities can generate important energy savings, they are generally implemented to lower the burden of energy costs for a disadvantaged population. EE programs in this segment are typically designed to deliver co-benefits including but not limited to improved health, safety, and comfort, beyond just electricity savings.

This *EM&V Guidebook* is not a regulatory or guidance document and therefore does not establish requirements. The *Guidebook* also does not apply to or address:

- Market transformation approaches (e.g., the ENERGY STAR Retail Products Platform);[8]
- EE in the mobile-source sector or implemented onsite at an EGU;
- Estimates of the potential for EE savings that may exist in various sectors of a state or community's economy;
- Options for implementing, funding, or encouraging EE in a jurisdiction, such as EE policies, regulations, programs, or projects; or
- Renewable energy (RE), CHP, or other zero- and low-emitting distributed energy resources (DERs) that generate electricity.

1.3.2. Summary of Contents

This *EM&V Guidebook* draws from and builds on decades of state, local, and private-sector experience quantifying and verifying savings from EE projects and measures.[9] It defines terms, provides brief descriptions and context for key EM&V topics, and identifies "applicable practices" for conducting EM&V. Definitions are compiled into a glossary at the end of this document. For select sections, this *EM&V Guidebook* also identifies "considerations for air officials" and presents questions intended to support dialogue between air officials and their energy counterparts. In addition, the *Guidebook* includes a list of existing and complementary EM&V protocols and guidelines.

In providing this *EM&V Guidebook*, EPA recognizes that the best-practice approaches, protocols, and procedures that are now used by states, EE implementers, and others will evolve and improve over time as new technologies and methods emerge, and as the EE marketplace changes. To ensure that it continues to reflect current practice—and that air officials can continue to have confidence in emission reductions from EE policies and programs—EPA may periodically provide new versions of the *Guidebook* with updated and additional information.

1.3.3. Use with Other EM&V Protocols and Guidelines

Other EM&V guidelines and technical resources are available to support state, local, and tribal officials, EE implementers, and EM&V practitioners working to quantify EE programs. Several states and ISOs have their own EM&V protocols for evaluating EE programs funded by energy customers. At the national level, two widely used EM&V resources are SEE Action's *Energy Efficiency Program Impact Evaluation Guide* ("SEE Action Guide," SEE Action, 2012a) and the National Renewable Energy Laboratory's *Uniform Methods Project: Determining Energy Efficiency Savings for Specific Measures* ("UMP," NREL, 2018).

The SEE Action Guide establishes basic EM&V definitions and provides high-level descriptions of foundational concepts, approaches, and methods for quantifying EE savings, avoided emissions, and other impacts. This *EM&V Guidebook* maintains consistency with the SEE Action Guide, but also

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[8] For more information on EM&V for the ENERGY STAR Retail Products Platform, see: https://www.energystar.gov/esrpp/emv.

[9] EE projects and measures are typically implemented by IOUs, public utilities, private companies such as ESCOs, or the owners and operators of large commercial or industrial facilities. EE can occur within all sectors of the economy, including low-income segments of the population and disadvantaged communities.

establishes actionable EM&V approaches and “applicable practices” (see Sections 2.1 – 2.7). These approaches and practices can serve as an information resource for air and energy officials that can readily be tailored to address a jurisdiction’s specific policy objectives and EM&V priorities.

In contrast to this *EM&V* Guidebook, the UMP provides a detailed set of prescriptive options, methods, and procedures for quantifying EE savings for specific measure types. It also includes protocols for key cross-cutting topics such as survey design, sample design, and metering. The UMP therefore provides EM&V practitioners with a recipe for interpreting and implementing a jurisdiction’s overarching EM&V protocols and guidelines (which can potentially be established or refined using this *EM&V Guidebook*).

This document is not meant to replace these and other EM&V protocols and guidelines. Rather, it builds on and compiles existing practices into a single actionable resource supplemented with key questions and considerations for air officials.

2. EM&V Practices for Quantifying Energy Savings

Quantifying energy savings from an EE activity is a multi-step process, described in Sections 2.1–2.7 of this *Guidebook*. The following EM&V topics are addressed:

1. Establishing a Baseline
2. Selecting a Method
3. Determining the Time and Location of Energy Efficiency Savings
4. Determining the Duration of Savings (i.e., effective useful life)
5. Verifying Savings
6. Accounting for Additional Aspects of Savings Quantification
7. Characterizing Accuracy

Each of the sections below defines **Key Terms** and includes **Discussion** and **Applicable Practices** sections. Where applicable, text boxes highlighting **Considerations for Air Officials** and **Questions that Air Officials Can Ask** are provided.

2.1. Establishing a Baseline

2.1.1. Discussion

Energy savings are the difference between energy consumption with an EE activity in place and the consumption that otherwise would have occurred during the same period. The consumption that otherwise would have occurred is called the baseline. Establishing baselines for savings is a key challenge of EM&V because determining the baseline requires identifying what would have happened absent the EE activity.

For example, if an EE project involves installing new high-efficiency equipment, the alternatives that could have occurred absent the EE activity include:

- No change (existing equipment remains in place and unchanged indefinitely);
- Installation of new equipment that is *less* energy efficient; or

- Installation of the same high-efficiency equipment, but at a later point in time.

Each of these situations requires a different baseline. Three common ways to establish the baseline are the **existing conditions**, the applicable **code/standards**, or the typical **market practice**. See definitions in the text box, *Key Terms for Establishing Baselines*. In addition, some baselines are specified on a "custom" basis (i.e., specified by an explicit, project-specific condition that would have been implemented in the absence of the project).

Key Terms for Establishing Baselines

Baseline: what would be in place without the EE activity or initiative. The term "baseline" can refer to the baseline characteristics (the efficiency level and operating conditions) that would have occurred without the EE activity, or to the baseline consumption (the electricity consumption that would have occurred at the baseline characteristics).[10]

Operating conditions: the conditions in which the EE project, measure, or facility is operated, including but not limited to weather, occupancy, and hours of operation.

Existing conditions baseline: a baseline corresponding to the efficiency level of equipment, systems, or construction in place prior to the EE activity.

Code/standards baseline: a baseline corresponding to an efficiency level based on applicable federal, state, or local equipment standards or building codes.

Market baseline: a baseline corresponding to an efficiency level based on the common practice for new equipment or installations in the market.

Dual baseline: a baseline used for programs targeting early replacement; corresponds to existing efficiency up to the remaining useful life (RUL) of the existing equipment, systems, or construction; and to either code/standards or market baselines for new installations for the remainder of the effective useful life (EUL) of the EE activity. (See Section 2.4 for details on establishing EULs.)

Stringent practice baseline (SPB): a baseline corresponding to the more stringent[11] of any applicable codes or standards, and the common market practice for the situation.

Policy baseline: a baseline corresponding to business-as-usual projected conditions (e.g., energy consumption, emissions) used to assess the effect of a potential new policy or policy change.

For example, as illustrated in Figure 1, when the EE activity involves installing high-efficiency equipment at the time of normal or natural replacement, the baseline can be defined in terms of less-efficient new equipment that otherwise would have been installed. This equipment might be specified in terms of applicable codes or standards—i.e., using a code/standards baseline—or might be based on typical practice for the market, using a market baseline. With either of these baseline specifications, the annual EE savings is the difference in annual consumption between the high-efficiency and less-efficient new equipment options. These savings are assumed to accrue for the lifetime of the new high-efficiency equipment (see Section 2.4).

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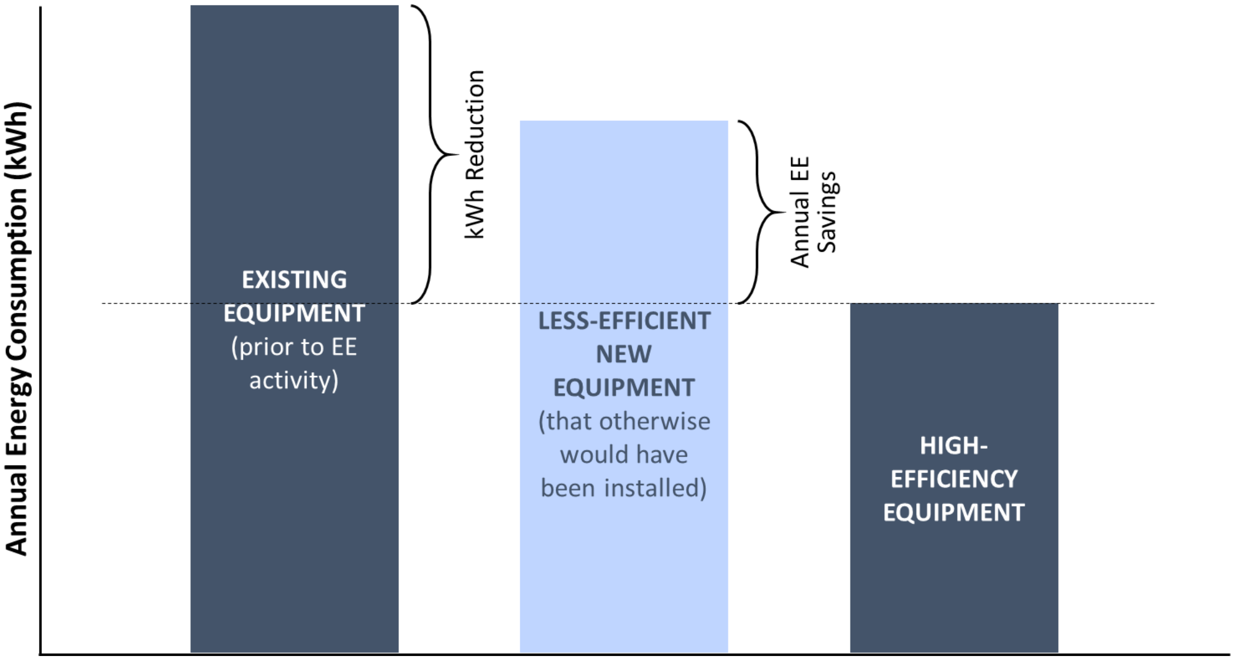
[10] Some practitioners use "baseline" strictly to mean gross savings baseline. In this document the term is used more broadly as the comparison point for calculating savings for various objectives. It is important to understand the definitions of baseline used when consulting other documents.

[11] Most stringent means requiring the lowest energy use.

Figure 1. Comparison of Total kWh Reduction vs. EE Savings for the Installation of New EE Equipment



Another scenario is when an EE program or an ESCO targets customers with aging equipment and seeks to replace it earlier than the customers would have done on their own. In such an “early replacement” case, the EE activity includes not just installing high-efficiency equipment but also accelerating the timing for replacement of the existing equipment. The savings in this case are quantified relative to existing conditions for each year up to the time of natural replacement. Up to that time, the existing equipment would still have been in place. After the time of natural replacement, savings are quantified relative to the typical replacement equipment. That is, a dual baseline is appropriate for this situation.

Questions that Air Officials Can Ask—Baselines

This *EM&V Guidebook* is intended to help air officials gain a working understanding of EM&V and support discussions with their counterparts in energy agencies. Air officials interested in using EE in a voluntary or regulatory air quality implementation plan can ask the following questions to learn more about EM&V practices in their jurisdiction:

- Will EE savings result in emissions reductions beyond business as usual (BAU)?
- What forecast of energy consumption is used in air quality planning?
- How can I confirm that EE savings in an air quality implementation plan are additional (i.e., surplus) to levels of EE in the BAU forecast?
- How are baselines for EE projects and measures relevant to air quality planning?

Typical practice in the market often varies by market segment. For example, typical practice among low-income, hard-to-reach, or small business customers is frequently closer to the code/standards baseline, even if the practice in the broader market is at a higher efficiency level. For this reason, publicly funded EE programs commonly adopt segment-specific strategies for reaching these customers and specify corresponding baselines.

Jurisdictions that use market baselines or SPBs regularly update the baseline by conducting periodic reviews and market studies to ensure that these baselines reflect current conditions. Since technology and practice in the market is constantly evolving and improving (typically at faster rates than codes or standards), market baselines and SPBs may need to be updated more frequently than code/standards baselines.

Savings from EE Programs and Other EE Initiatives

EE policies and publicly funded EE programs implemented by utilities are designed to increase the adoption of EE projects and measures beyond what otherwise would occur. For such policies and programs, it may be of interest to quantify the direct effects of the program-supported EE projects or measures themselves (i.e., savings compared to not implementing those projects or measures), the effects of the programs (i.e., savings compared to not implementing the program), or the effects of broader EE policies such as changes to codes and standards (i.e., savings compared to not implementing the policy). Each of these cases represents a different type of savings, as defined in the box, *Key Terms for Savings*. The type or types of savings that are quantified depends on the objectives for the policy or program and the associated quantification. In each case, savings are defined according to what effects are being measured. Figure 2 illustrates the different savings calculations.

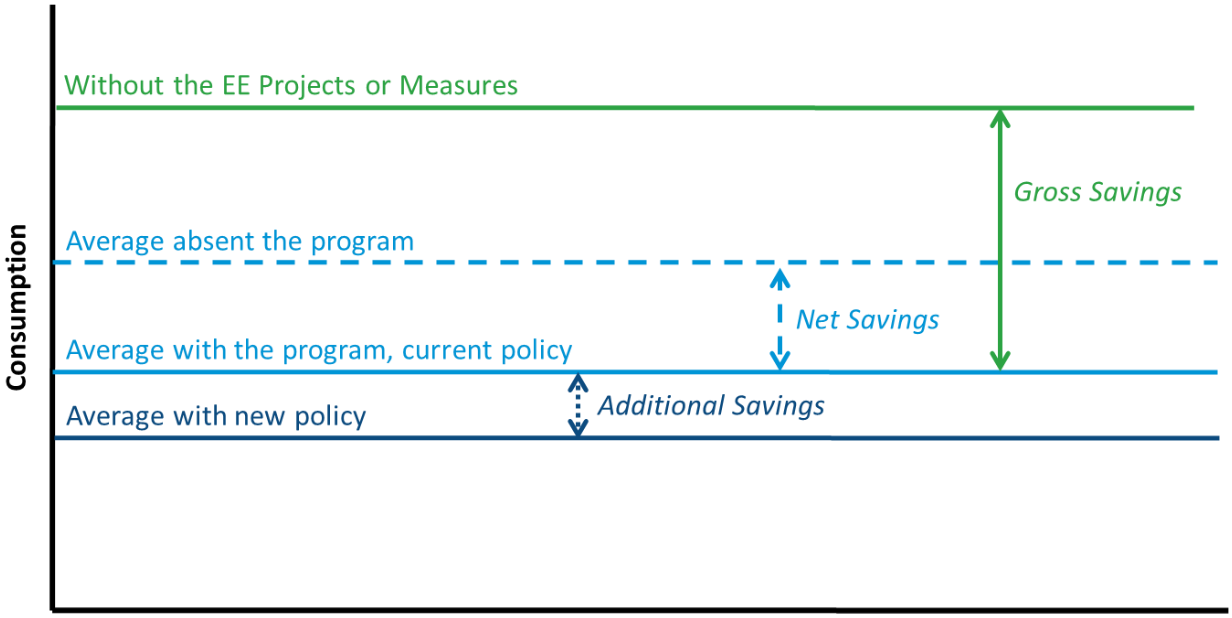
Key Terms for Savings

Gross savings: the difference in energy consumption with an EE project or EE measure in place versus the baseline consumption without the project or measure in place.

Net savings (for an EE program): the difference in energy consumption with an EE program in place versus the consumption without the program in place.

Additional savings (for energy or air quality planning): energy savings additional to the savings explicitly or implicitly assumed in an energy or air quality policy baseline.

Figure 2. Illustration of Gross, Net, and Additional EE Savings



Net & Gross Savings, in Practice

To illustrate the concepts of gross and net savings, consider an EE program that provides incentives for purchasing high-efficiency heat pumps. Using a code/standards baseline, gross savings are quantified as the difference in consumption between the high-efficiency heat pump and one that meets the current appliance standard. The EE program's gross savings are the sum of the savings for all the efficient heat pumps in the program. The EE program's net savings are more narrowly defined as savings *caused by the program*. In simple terms, net savings are equal to the gross savings of the projects and measures supported by the EE program, minus the gross savings from the subset of these measures that *would have occurred without the program*.[12]

Gross savings measure the effect of the EE projects or measures themselves, or the difference in consumption with the EE projects or measures in place compared to consumption without them. The baselines defined in the box, *Key Terms for Establishing Baselines*, are each used to quantify gross savings for different situations.

For publicly funded EE programs, a key consideration is the quantity of energy savings due specifically to the EE program itself. These **net savings** represent the reduction in consumption compared to what it would have been without the program. The quantification of net savings serves an important role in energy resource planning and informs decisions about whether to continue or modify an EE activity in future planning cycles. Net savings is often quantified by first estimating gross savings and then multiplying by a separately determined net-to-gross ratio.

Net savings can be more complex to quantify than gross savings. This is because quantifying net savings requires determining not just what EE activity was implemented and the corresponding gross savings, but also why it was implemented and to what extent the EE program motivated customer decisions. Chapter 21 of the Uniform Methods Project describes methods for determining net savings and net-to-gross ratios (NREL, 2014a).

For regional energy or air quality planning, the quantification approach typically estimates the effects of a new or expanded EE policy or program (or other EE initiative) compared to what would occur without the policy or program in place. For such purposes, **additional savings** are of interest. That is, the additional savings with the new or expanded EE policy or program, over and above what would have occurred under BAU conditions (i.e., under regional BAU policy or planning assumptions). See the *Considerations for Air Officials* box below.

Table 1 summarizes the savings of interest for different quantification objectives.

Table 1. Savings of Interest for Different Quantification Objectives

Quantification Objectives	Savings are Quantified by Comparison To...	Savings of Interest
Quantify the effect of implementing EE projects or measures	What would have occurred without the EE project or measure in place	Gross Savings
Quantify the impact of an EE program	What would have occurred without the program in place	Net Savings
Quantify the additional effect of a regional policy or planning scenario	Policy baseline	Additional Savings

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[12] Net savings may also be defined to include any savings from EE activities that occurred because of the program but outside of it (e.g., savings from high-efficiency heat pumps purchased because of program marketing, by customers who do not fill out rebate forms and are therefore not tracked by the program).

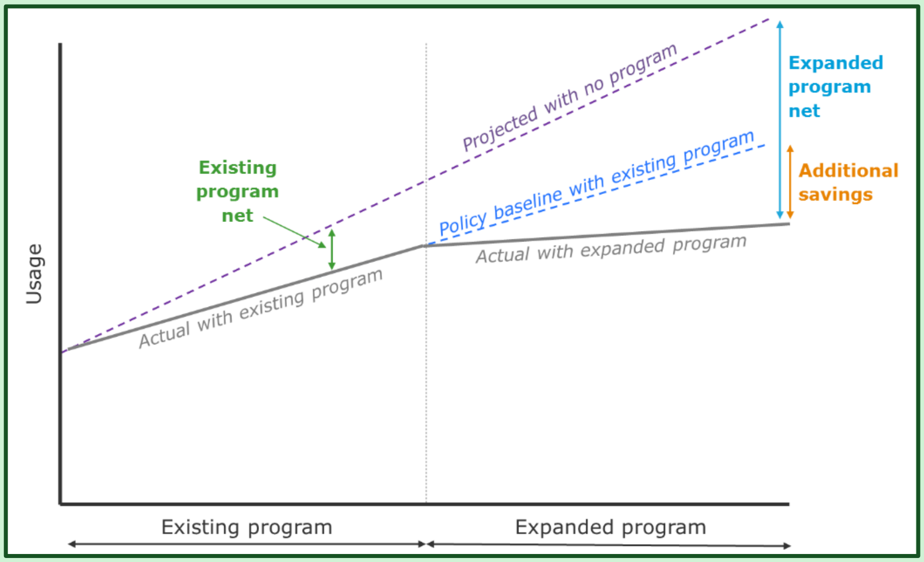
Considerations for Air Officials

State, local, and tribal officials designing a plan for reducing emissions and/or improving air quality may wish to account for the reductions in energy consumption from EE policies and programs in their jurisdiction.[13] In these situations, the level of EE savings that is appropriately counted toward applicable policy or planning goals is “additional” to EE that is already expected to occur (e.g., EE savings already “embedded” in energy consumption forecasts associated with the plan to reduce emissions or improve air quality). In jurisdictions where no previous EE policies or programs have been implemented, all savings attributable to the new EE would be considered additional (sometimes referred to as “surplus” or “incremental”).

In cases where EE policies and programs have been in place and reducing energy consumption for an extended period, the jurisdiction should take care to account only for EE savings beyond BAU energy savings levels to avoid double counting. (See Figure 3.) A plan for reducing emissions and improving air quality that includes a new EE initiative may be more likely to result in savings beyond BAU levels.

In all cases, a key analytical question for air and energy officials is, “what levels of historical and ongoing EE savings are already embedded in the energy-use baseline, and what level of EE savings is new and additional?” Once the additional EE savings are quantified, they can be translated into emissions reductions and/or improvements in air quality. That is, progress toward an air quality goal is measured in terms of emissions reductions and/or air quality improvement beyond levels assumed under the energy use baseline, and not in terms of EE savings.

Figure 3. Illustration of Additional EE Savings from Expanding an Existing EE Program



Combining Public Program and Private EE Savings on a Common Basis

Some jurisdictions have established market mechanisms where EE can be offered for bid or for trade. For example, the Forward Capacity Markets of the ISO-NE and PJM Interconnection that take bids for capacity allow EE to participate in the market, subject to measurement and verification rules. EE trading platforms may emerge in the future, based on considerations by certain states and regions.[14]

In cases where market rules allow for EE from both public programs and private implementation to be offered for bid or trade, it is desirable to apply a single approach for quantifying savings. This ensures

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[13] Examples of such plans are provided in Section 1.1.1.

[14] For example, see: https://www.nrel.gov/docs/fy09osti/45970.pdf

that the market applies the same valuation to the EE, regardless of whether it was implemented via a public program, a private-sector ESCO, or by an end-use customer without public funding.

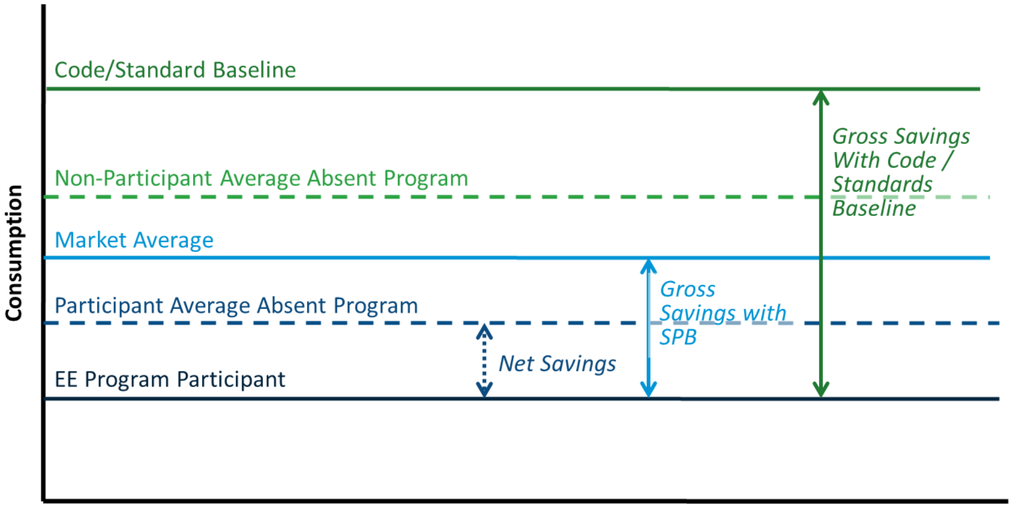
Given that the purpose of these markets is to stimulate additional EE, it is also desirable to count savings beyond the level that would occur due to natural equipment turnover. This avoids a situation in which the market provides payments for EE projects or measures that were going to occur anyway (i.e., it avoids imposing costs on the market without generating new value).

These combined objectives—(1) establishing common quantification approaches and (2) counting savings beyond natural stock acquisition and turnover—pose a challenge from a policy perspective. In the case of publicly funded EE programs, the net-savings metric counts only savings caused by those programs (savings beyond the level that would have occurred without the EE program), consistent with the second objective. However, the concept of "net savings" is not applicable to privately implemented EE investments. Therefore, when it is desirable to count public and private EE on a common basis, it is typically necessary to use gross rather than net savings for both, along with a common set of rules for establishing baselines.

Gross savings calculated using an SPB (described in the definitions box on page 11) can be used for this purpose. Because an SPB is the more stringent of a code/standards baseline and a market baseline, use of an SPB quantifies savings only for EE activities beyond what is already typical in the market and beyond the basic level required by existing law or regulation.

Using an SPB is also applicable in contexts where EE program savings are tracked only on a gross basis, without net-to-gross adjustment. When the market average efficiency is better than the code or standard efficiency level, gross savings using an SPB will typically be closer to net savings than are gross savings calculated using a code/standard baseline. This is because customers that would adopt EE on their own are more likely to take EE program rebates or other program support when available than customers who would not implement EE projects and measures on their own. As a result, the typical behavior of EE program participants absent the program tends to favor higher efficiency than what is typical in the market overall. Hence, gross savings with an SPB is typically greater than net savings but smaller than gross savings with a code/standards baseline. The situation is illustrated in Figure 4.

Figure 4. Illustration of Gross Savings with SPB and Net Savings



Determining Baseline Consumption for Purposes of Quantifying Gross Savings

Key Terms for Establishing Baselines above provides applicable baseline definitions. When determining baselines for purposes of quantifying gross savings, it is necessary to take into account:

1. The EE activity type—broadly, whether the activity is a higher-efficiency substitution, an add-on efficiency improvement, or an operational improvement;
2. The EE event type—that is, whether replace on failure, early replacement, or new construction; and
3. The associated operating conditions, such as hours of operation, weather, and equipment set points.

The EE activity and event type determine the baseline efficiency of the equipment, building, or facility, as applicable. An additional step required to establish baseline consumption is to determine the relevant operating conditions.

2.1.2. Applicable Practices

This section outlines applicable practices for establishing a baseline and savings definition.

Determine Baseline and Savings of Interest

- Determine the quantification approach and associated baseline. First, identify the overall objective or context for which EE savings are being quantified. Table 2 below identifies recommended savings definitions for several potential objectives, along with a rationale for each. The savings definitions are for illustrative purposes only, and may differ by jurisdiction based on objective, context, or other factors.

Table 2. Savings Definitions and Baselines for Different Objectives

Objective	Recommended Savings Definition (and Baseline)	Rationale
Determining progress toward an air quality or emissions reduction goal	Additional Savings (with Policy Baseline)	If existing EE initiatives are part of the forecast of electricity sales (policy baseline) used to establish the emissions goal, progress toward the goal needs to reflect reductions additional to the savings embodied in that forecast. See the text box, "Considerations for Air Quality Officials," in Section 2.1.1.
Validating savings achievement for a private EE contract or private program operation	Negotiated	Private contracts may use any basis acceptable to both parties.
Establishing trading quantities for an EE market	Gross Savings (with SPB)	Gross allows public program and private EE to be measured on a common basis. SPB ensures savings are counted only for improvements beyond what is already typical in the market and beyond what is required by existing law or regulation.
Quantifying combined effects of publicly funded EE programs and private EE activity	Gross Savings (with SPB), or Additional Savings (with policy Baseline)	Gross allows public program and private EE to be measured on a common basis. SPB ensures savings are counted only for improvements beyond what is already

Objective	Recommended Savings Definition (and Baseline)	Rationale
		typical in the market and beyond what is required by existing law or regulation. Application of a policy baseline aims to ensure that savings are counted only for additional EE savings beyond what is assumed in setting the baseline. See the text box "Considerations for Air Quality Officials" in Section 2.1.1 for more information.
Determining publicly funded EE program goal achievement	Gross Savings or Net Savings	Gross counts total savings supported by the program. Net counts savings attributable to the program.
Determining publicly funded EE program cost-effectiveness (from the perspective of public purpose objectives)	Net Savings	Cost-effectiveness calculations compare program costs with the value of savings attributable to the program (i.e., net savings) and other program benefits.
As a contractual or performance metric for program administrators or implementers	Gross Savings or Net Savings	Either or both are useful depending on the basis for defining program contractual or operational goals
Energy resource planning	Additional Savings (with Policy Baseline)	For utility resource planning, if state or regional EE initiatives exist, the EE savings of interest result from additional EE activity compared to BAU in the policy baseline.

Recommended Baselines for Gross Savings by EE Event Type

- For quantifying gross savings, apply the appropriate baseline based on the EE event type. Table 3 provides the recommended baseline for common EE event types.

Table 3. Recommended Baseline for Common EE Event Types

EE Event Type	Baseline for Gross Savings	Stringent Practice Baseline
Replace on failure	Code/standards or Market	More stringent of code/standards baseline or market baseline
Early replacement	Dual baseline	Dual baseline with same code/standards baseline or market baseline as for replace on failure
Operation & Maintenance program	Existing conditions	Existing conditions (i.e., practices)
New construction code triggered	Code/Standards or Market	More stringent of code/standards baseline or market baseline

- Where possible, consistently apply the same baseline approach (code/standards, market, or SPB) for all EE activities in a common portfolio or program to promote consistent, transparent, and comparable results. If a market baseline or SPB is used, the applicable baseline may differ by segment.

- When a dual baseline applies, apply the same code/standards or market baseline as for replacement on failure for the same equipment type. The code/standards or market baseline may be different for new construction than for early or on-failure replacement, because code requirements or market practice may be different for these EE event types.

Maintaining Baseline Specifications

- When markets baselines or an SPB are applied, continually re-evaluate the market or SPB value to ensure that new EE activities continue to be additional to what is happening naturally in the market.

When to Establish Baseline Specifications

- Wherever possible, determine and document baselines prior to implementing an EE project or measure.

Operating Condition Specifications

Calculate savings at operating conditions anticipated over the life of the project or measure. Use one of the following approaches:

- Assume the operating conditions in the year after the project or measure installation are the expected average conditions for the lifetime. Calculate baseline consumption at these conditions.
- In cases where the post-implementation operating conditions are not likely to be typical of the long-term average, adjust both the observed actual consumption and estimated baseline consumption to the assumed long-term average operating conditions.
- For weather-dependent energy uses with EE savings accruing over multiple years, adjust both observed actual consumption and estimated baseline consumption to typical weather conditions.

2.2. Selecting a Method

Discussion

There are three broad EM&V methods for quantifying savings, including: 1) **deemed savings** for specific EE measures**,** 2) **direct measurement and verification (M&V)** applied to individual EE projects or measures, and 3) **comparison group** methods relying on analysis of consumption data for an affected group of premises compared to another group. Advanced M&V, a method using automated analysis of consumption data for either direct M&V or comparison group methods, is discussed in a text box at the end of Section 2.2.2 below. Best-practice approaches for applying each of these three broad methods are defined in industry standard protocols or technical guidelines that are commonly used by EE implementers, oversight agencies, and the firms they hire to quantify and verify savings.

Key Terms for EM&V Methods

Deemed savings: An EM&V method that applies estimates of average annual electricity savings for a single unit of an installed EE measure. Deemed savings methods can include:

- **Deemed savings values:** Pre-specified estimates of average annual electricity savings for an EE project or EE measure
- **Deemed formulas:** Pre-specified formulas for quantifying savings, using some deemed parameters and some inputs that are specific to each project or measure
- **Deemed parameter values:** Pre-specified values of parameters (constant terms in formulas) that are applied to quantify savings using a deemed formula

Direct measurement and verification (direct M&V): An EM&V method that uses onsite observations, engineering calculations, statistical analyses, and/or computer simulation modeling using measurements to determine savings from an individual EE project or EE measure

Comparison group: An EM&V method that is based on the differences in electricity use patterns between a population of premises with EE projects or EE measures in place and a comparison group of premises without the EE projects or EE measures; comparison group approaches include randomized control trials (RCTs) and quasi-experimental methods using nonparticipants and may involve simple differences or regression methods

Questions that Air Officials Can Ask—EM&V Methods

This *EM&V Guidebook* is intended to help air officials gain a working understanding of EM&V and support discussions with their counterparts in energy agencies. Air officials interested in using EE in a voluntary or regulatory air quality implementation plan can ask the following questions to learn more about EM&V methods in their jurisdiction:

- What methods are applied to estimate savings from EE programs and policies in my jurisdiction?
- How accurate are EE savings estimates derived from different EM&V approaches, and can these estimates support quantification of emissions reductions?
- What are the opportunities and barriers associated with different EM&V methods?
- Does my jurisdiction run EE programs targeting large populations of similar customers that may be well suited to comparison group approaches?
- How can I get involved in EM&V for purposes of representing my agency's needs and perspective?

Applicable Practices

- Determine which of the EM&V methods to apply for quantifying savings for each EE activity by referring to the *Applicable Practices* in Sections 2.2.1 through 2.2.3 below. The applied EM&V method should be appropriate to the characteristics of the EE project or EE measure, as defined in industry standard protocols or technical guidelines. When selecting methods, consider the objectives of the EE activity being evaluated, the scale of the activity, and the evaluation budget and resources.
- Apply the best-practice protocols and guidelines identified in the applicable subsections below and in Section 3 (*Best-Practice EE EM&V Protocols and Guidelines*). Examples include but are not limited to:
    - International Performance Measurement and Verification Protocol (IPMVP) (EVO, 2016)

    - M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 3.0 (U.S. DOE, 2008)
    - ASHRAE Standards and Guidelines Activities (ASHRAE, 2014)
    - California Energy Efficiency Evaluation Protocols (CIOU, 2016)
    - The California Evaluation Framework (CPUC, 2004)
    - UMP (NREL, 2018)
- If applying specific EM&V protocols or guidelines, provide a list of applicable provisions, a description of the applicable sections and methods, details on how methods were applied, and an explanation of why the selected provisions and methods were chosen. Simply referencing a specific protocol or guideline may not be sufficient for all purposes. For example, the IPMVP provides for four quantification options with flexibility regarding savings calculation assumptions. The details of how a particular protocol or guideline will be applied are critical.
- If applying a combination method that consists of more than one of the three categories of EM&V methods, clearly describe the basis and rationale for combining methods. Examples of combination methods include:
    - Applying comparison group methods to determine savings relative to existing equipment, with engineering analysis applying deemed parameters to adjust the result to savings relative to a code/standards or market baseline, as referenced in Section 2.2.3.
    - Applying deemed savings to determine initial savings, with limited simulation analysis (M&V method, IPMVP Option D) to estimate adjustments for interactive effects.
- Conduct quality assurance and quality control of all data, values, formulas, and calculations used to quantify electricity savings.

2.2.1. Deemed Savings

Discussion

The deemed savings EM&V method applies pre-specified unit savings values or formulas with some pre-specified parameter values as the basis for quantifying savings.

Because deemed savings values are agreed upon in advance, such values can help alleviate some of the guesswork in program planning and design. To ensure that the deemed savings method provides accurate savings estimates, it is important to have a credible basis for the values applied and to ensure that criteria defined in applicable protocols and guidelines are followed. A best practice observed from utility-administered EE programs is to document deemed savings values or deemed formulas in a transparent and freely available manner in a

Ex Post v. Ex Ante Savings

In applying the deemed savings method, it is important to distinguish between ex post savings determined after implementation and ex ante savings projected prior to implementation. Both ex post savings and ex ante savings can be based on deemed savings methods or other methods, such as custom engineering analyses or site-specific observations.

- **Ex ante savings** are projected for a particular program, project, or measure based on projected quantities of installed measures.
- **Ex post savings** are quantified based on verified quantities of installed measures, with the verified mix of measure types and application conditions, rather than projected quantities.

spreadsheet, an online searchable database, or similar resource. The term commonly used for such resources is a technical reference manual (TRM) (U.S. DOE, 2011). As of this document's publication approximately 28 TRMs are in use across the United States at the state and regional levels (SEE Action, 2017). The methodologies for deriving deemed values can vary across jurisdictions. Some TRMs include information based on prior-year EM&V. Some TRMs include values based on computer simulations or engineering algorithms.

Applicable Practices

When to Apply Deemed Savings Methods

- Apply deemed savings methods for relatively simple, well-defined EE projects or EE measures (such as light bulbs or other electrical equipment) for which the average operating characteristics that are the basis for the deemed values are well known, or where there is relatively little uncertainty around average unit savings.
- Do not apply deemed savings methods for unique and custom applications.[15] This includes EE projects encompassing multiple EE measures with complex interactive effects that are challenging to accurately quantify and document.

How to Apply Deemed Savings Methods

- Implement deemed savings methods by applying the following steps:
    1. Establish savings quantification formulas by establishing deemed parameter values, parameter applicability, and conditions for applying the formula. Deemed parameters may include per-unit savings values or average values of savings calculation formula inputs such as hours of use or equivalent full-load hours. The simplest form of a deemed savings calculation formula is savings per unit multiplied by the number of units.
    2. Apply the formulas and documented measure counts to calculate pre-verified savings.
    3. Perform installation verification to confirm that units were installed, verify unit quantities, and confirm appropriate application of deemed values and calculations. Installation verification may consist of reviewing independent third-party reports on measure installation rates based on customer surveys and/or onsite verification that installations were installed according to specification. The verification process may be based on a valid statistical sample that represents the entire population of EE projects or EE measures, that is then scaled appropriately to the population.
    4. Apply the formulas, parameters, and verified units to determine the total quantified savings.
- Ensure that deemed values are:
    - Based on EE activity type, applicability conditions, assumptions, calculations, and references that are publicly documented and available.

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[15] For more complex EE projects or EE measures with significant savings variability, consider the application of direct M&V or comparison group methods instead of deemed savings. While direct M&V and comparison group methods may include the use of deemed values for certain parameters used in the calculation of savings, the incorporation of direct measurement or consumption data analysis moves such methods outside of the deemed savings category.

    - Quantified based on typical electricity savings and other factors that determine such values over the lifetime of the EE measure, such as average occupancy, typical weather, typical operating hours, and EUL.
    - Developed and vetted by independent third parties and developed applying analytical methods that are widely considered acceptable for the measure, purpose, and data sources (such as prior metering studies).
    - Appropriately adjusted if borrowed from secondary sources from other geographic areas.
- Apply deemed savings methods as follows:
    - Apply deemed values only for EE projects or EE measures similar to the specific EE projects or measures for which the values were developed.
    - When a database or TRM with deemed savings values is updated based on new information, apply the revised deemed values and quantification methods to EE projects or EE measures implemented after the effective date of the update. It is generally not necessary to apply the revised deemed values and quantification methods to EE projects or EE measures for which EM&V has already been completed, unless revision of prior completed EM&V is desired and the revised TRM values are considered to be applicable to the period covered by the prior completed EM&V.
    - Use deemed savings values that were calculated as the difference between the electricity used by the EE project or EE measure and the appropriate baseline for each EE project or EE measure, as defined based on Section 2.1.
    - If savings relative to a particular baseline are desired, and the deemed savings values, parameters, or formulas produce quantified electricity savings relative to a different baseline for that EE project or EE measure, document and justify needed adjustments to the applicable deemed savings values, parameters, or formulas to ensure that electricity savings are quantified relative to the appropriate baseline. For example, if savings are needed relative to a SPB and the deemed values are relative to a code/standards baseline that is less stringent than the SPB, document the adjustments needed to translate the deemed savings values to the SPB.
- Ensure that savings are adjusted for independent variables that affect energy use, as relevant, in accordance with Section 2.6.1 and that they account for the interactions between individual EE measures that comprise the EE project.
- Review the deemed savings values and formulas periodically (e.g., at least every three years), updating them as necessary to reflect more recent and/or accurate data, and applying them to all EE projects or EE measures that are installed or begin operating after such an update occurs.

Documentation

- Describe why deemed savings values and formulas are appropriate for each type of EE project or EE measure.
- Indicate the conditions for which each deemed savings value, parameter, or formula is applicable (e.g., climate, building type, end use, and measure implementation mechanism).

- Include information on the assumed baseline technology and conditions applied to establish the deemed savings values, to ensure that deemed savings values reflect the appropriate baseline.
- Describe the baseline specification as determined in Section 2.1 for each deemed savings value.
- To increase transparency, document the deemed savings values and formulas in a freely available database or spreadsheet (e.g., a TRM) that is accessible on a public website, specifies the conditions for which each deemed savings value or formula may be applied (e.g., climate zone; building type; and implementation strategy, such as retrofit, replacement on failure, or new construction), and specifies the source of each deemed savings value or formula.

Resources

When applying deemed savings methods, apply one or more best-practice protocols and guidelines. Examples include but are not limited to:

- Status and Opportunities for Improving the Consistency of Technical Reference Manuals (ACEEE, 2012)
- Behind the Curtain: Characterization of Measure Technologies within Technical Reference Manuals (ACEEE, 2016a)
- Technical Reference Manuals Best Practices from Across the Nation to Inform the Creation of the California Electronic Technical Reference Manual (eTRM) (ACEEE, 2016b)
- Approach to Texas Technical Reference Manual (PUCT, 2013)
- Energy Efficiency Program Impact Evaluation Guide (SEE Action, 2012a)
- The Northwest Power & Conservation Council Regional Technical Forum (RTF, 2018)
- Using Deemed Savings and Technical Reference Manuals for Efficiency Programs and Projects Webinar (LBNL and U.S. DOE, 2017)

2.2.2. Direct M&V

Discussion

Direct M&V refers to a set of methods that involves obtaining measurements from an individual EE project or EE measure installation site as a basis for quantifying savings. For direct M&V-based savings quantification of individual EE projects or EE measures, the selected measurement technique is applied to a specific piece of equipment, for the site as a whole, or both. When applying direct M&V to an EE program or group of EE projects or EE measures, analysis may be conducted for each project or measure in the group. It may also be conducted, as is more common, for a sample of projects or measures, with the sample results then used to quantify savings for the full group.

The application of direct M&V methods can establish accurate savings for most EE activities. However, these methods tend to be more expensive than deemed savings or comparison group methods. The cost for direct M&V is driven by factors such as the measurement equipment required, the measurement duration, the number of sample points needed at an individual project or measure site, and the number and complexity of sites to obtain the targeted accuracy. The selection of direct M&V versus other methods therefore involves tradeoffs between cost and level of uncertainty in the EE savings values.

Several protocols and guidelines (e.g., the IPMVP) are widely considered industry standards. They typically define terms, establish procedures, and serve as an overall framework for conducting direct M&V for savings quantification of individual EE projects and EE measures. These best-practice protocols and guidelines also define the type of consumption data and analysis used to quantify savings and provide information about which options to apply for different types of EE activities. Common options and applications are summarized in Table 4 below. See the IPMVP for details.

Table 4. Common Direct M&V Options and Applications

Option	Name	Basis for Savings Calculation	Common Applications
A	Partially Isolated Retrofit	End-use measurements of some parameters, with other parameters deemed	Lighting, with hours of use metered and kW savings deemed based on wattage of installed equipment with code/standards or market baseline
B	Retrofit Isolation	End-use measurement of electricity use or proxy, with no deemed parameters	Systems with variable loadings such as motors
C	Whole-Facility	Metered electricity use for a whole facility, before and after EE is installed	Complex or combination measures affecting multiple systems, where combined savings are at least 10 percent of whole-facility use and the baseline can be justified as based on existing conditions
D	Calibrated Simulation	Simulated whole-facility electricity use with and without the EE in place, where the simulation model is calibrated to metered electricity use for the post-installation period	Complex or combination measures affecting multiple systems, where prior existing equipment efficiency is not the appropriate baseline, or where operating conditions are not the same in the post-installation period as in the pre-installation period

Each of the direct M&V options above quantifies savings as the difference in electricity use for an EE activity with the EE in place compared to the baseline case. The quantification uses combinations of engineering formulas and regression models to estimate annual electricity use, and is based on the metered or measured data for the post-installation operating conditions. Routine variations in independent variables such as occupancy, weather, production levels, and other interactive factors are captured in the range of measured or metered data or are accounted for by the formulas and modeling to derive annual electricity use under the specified conditions. The analysis used to translate the observed measurements into annual consumption values for the average post-installation condition of the independent variables is considered a "routine" adjustment.

Regardless of the direct M&V option applied, the M&V process may also involve a custom or "non-routine" adjustment if the conditions for which savings are to be quantified are different from the conditions that were metered in ways that are not accounted for by the basic formula or regression model. For example, one-time changes to a building's occupied floorspace, operating shifts, or equipment types may involve non-routine adjustments.

Analysis of whole-premise metered consumption data (Option C of the IPMVP) may use similar building-level models to those applied for comparison group analysis described in Section 2.2.3. Two differences between building-level models for site-level direct M&V and the comparison group approach are:

1. Site-level direct M&V is designed to estimate savings relative to the appropriate baseline for the individual site. The comparison group analysis produces savings for a program or group of similar projects.
2. Site-level direct M&V uses additional information either to confirm that no other changes affected the facility over the analysis period, or else to support customized analysis to make any non-routine adjustments to savings estimates required to address changes. This type of custom, non-routine adjustment is not typically included in comparison group analysis.

Applicable Practices

When to Apply Direct M&V

- Consider the resources available for EM&V and the need for accurate savings values when considering the application of direct M&V.
    - If resources are available and there is a need for highly accurate savings values, direct M&V may be the most appropriate quantification approach.
    - To determine cost, consider the measurement equipment required, the measurement duration, the number of sample points needed at an individual project or measure site, and the number and complexity of sites to obtain the targeted accuracy.
- Apply direct M&V only when the physical address(es) of installed measures are known, and these facilities (or a sample of them) are accessible for conducting the necessary data collection.
- Apply direct M&V methods for:
    - EE activities for which reliable deemed savings approaches are not available or not applicable, and for populations of EE projects or EE measures that are not in sufficient number or homogeneity for comparison group EM&V methods to be applicable or feasible, such as because a control group cannot be identified.
    - EE activities that have high savings variability or uncertainty due to differences in physical or behavioral characteristics across individual sites and applications. Large, complex projects or installations typically have such variability or uncertainty.
    - Other situations where the cost is justified by the value in terms of improved reliability and confidence in the results.

How to Apply Direct M&V

- To quantify savings from an EE program or portfolio of related EE projects applying direct M&V, do one of the following:
    - Conduct direct M&V for each project or measure in the program and sum the results to determine program-level savings.

  - Conduct direct M&V for a randomly selected sample of sites and apply statistical sample expansion[16] to determine program-level savings from the sample results.
- Refer to the IPMVP, listed in Section 3, for two direct M&V options applied in the EE industry:
  - **Retrofit isolation:** Assessing savings from each EE measure individually (IPMVP Options A & B).
  - **Whole facility:** Analyzing savings from each EE measure in a project/facility collectively (IPMVP Options C & D).
- If statistical sampling and expansion will be applied, ensure there is a large enough sample of EE projects within an EE program, a sufficient number of EE measures within an individual EE project site, and sufficient measurement quality across the EE program to meet statistical accuracy requirements.
- Ensure that direct M&V is conducted by staff who have the appropriate expertise, including:
  - Metering and measurement equipment selection, installation, sensing, and calibration.
  - Statistical sampling and estimation methods for data collection related to facility electricity use.
  - Engineering analysis for facility electricity use, including baseline specification.
  - Field data collection quality control.
- When measured or metered data results are combined with deemed parameters, ensure that the appropriate deemed parameters are applied for each metered case to ensure accurate results.
- Ensure that savings quantified by direct M&V methods apply the appropriate baseline as defined in Section 2.1.[17] Before selecting a direct M&V method for EE activities with a baseline that is not existing conditions,[18] ensure that a viable approach exists for modifying existing condition baseline energy use measurements to equate to the correct baseline. In some instances, this may not be viable. In other instances, modification can be made. For example:
  - With a motor replacement project where the baseline is a new standard-compliant motor, IPMVP Options A and B can be used to measure existing motor electricity use. These measurements can then be adjusted using a ratio of the efficiencies of a standard-compliant motor and the existing motor efficiency.
  - With a whole house retrofit project, where the baseline is a building energy code, IPMVP Option D can be used with a baseline building energy model calibrated to the

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[16] Sample expansion is statistical estimation of results for the whole group of interest—in this case the EE program or portfolio—based on the results for the random sample.

[17] Direct M&V is often conducted by equipment installers to confirm that measures are working correctly or to demonstrate to utility customers that they are achieving the expected improvements from the new equipment. These applications of direct M&V tend to use the existing equipment as the baseline, which may or may not be the appropriate baseline for the intended EM&V purpose.

[18] In the context of utility EE programs and privately implemented EE activities, direct M&V methods are commonly applied for EE projects and EE measures for which existing condition baselines are appropriate.

post-retrofit whole-premise consumption and then adjusted to code-compliant levels to estimate consumption at the baseline condition.

- Ensure that savings are adjusted for independent variables that affect energy use, as relevant, in accordance with Section 2.6.1.
- Quantify savings for the long-term, post-installation operating condition. If ongoing measurement is not used, use appropriate engineering and statistical methods to adjust the metered and measured data to the long-term annual average condition, normalizing results for weather, productivity, and other routine and non-routine factors as needed.
- Follow best practices for statistical sampling of sites, EE projects, or EE measures. Also follow good practices for sample design, sample management, and sample expansion to the full EE project or full EE program level.
- Because the quantification process ordinarily involves direct observation of installed equipment or of its effects on whole-facility consumption, a separate step verifying implementation is not needed for the EE measures subject to this process.
- If direct M&V is conducted for a sample of EE projects or EE measures, an option that can provide more certainty of savings is to conduct (less expensive) verification for a larger sample than the direct M&V sample. In this case, combine the quantified savings per measure from the direct M&V with the verified quantity of measures (e.g., equipment counts) to determine the total quantified savings.
- Follow rigorous quality assurance, quality control, and training procedures.
- For an EE activity that is an operational improvement, derive the baseline from the efficiency of the affected equipment without the operational improvement. If the operational improvement can be cycled on and off at intervals over a full year, calculate the baseline from the periods when the improvement is off. This approach can be especially useful for EM&V of grid-side EE activities.[19]
- Use tools designed to apply an automated analysis of consumption data[20] to quantify savings consistent with guidelines and protocols for the applicable direct M&V method, as well as the practices described in this section. In particular, describe quantification methods transparently and show how the automated analysis can provide savings relative to the appropriate baseline specification. (See the text box on page 30.)

Documentation

Document the following when applying direct M&V:

- Approaches for determining, identifying, and isolating measurement variable(s), including a description of the measurement variable and why was it selected (e.g., duty factor for a residential air conditioner, on/off schedule for an industrial process).

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[19] Examples of grid-side EE activities include voltage and VAR optimization (VVO) and conservation voltage regulation (CVR), which produce electricity savings by reducing voltage at various points along the transmission and distribution system.

[20] Examples of such tools and their uses and performance in EM&V and other contexts are described in DNV GL (2015); LBNL (2015); and ACEEE (2015).

- Sampling and expansion procedures, including how the sample was selected, how the number of sample points was determined, how the case weights were developed, identification of and reasoning for the coefficient of variation used to design the sample, how the individual measurement results were expanded to the population, and how the statistical error metrics were quantified (e.g., confidence and precision levels).
- Planning documents that describe how direct M&V will be applied at the level of the EE activity, as appropriate. Planning should address questions such as: What type of direct M&V approach was applied (e.g., one or more of the four IPMVP methods, a combination, an alternative method)? How were baselines selected and estimated, including how they conform to the specifications in Section 2.1? How were metering and monitoring conducted, including for how long? How was the data collected? What quality assurance and quality-control procedures were applied? How were electricity savings estimated?
- Reporting procedures, including how the savings results were compiled to produce overall reported savings estimates relative to the appropriate baseline.

Resources

When applying direct M&V methods, apply one or more best-practice protocols and guidelines. Examples include but are not limited to:

- International Performance Measurement and Verification Protocols (IPMVP) (EVO, 2016)
- UMP, Chapter 11 – Sample Design Cross-Cutting Protocols (NREL, 2017b)
- California Energy Efficiency Evaluation Protocols (CPUC, 2006), see Measurement and Verification Protocol and Sampling and Uncertainty Protocol
- California Evaluation Framework (CPUC, 2004), see Chapter 7: Measurement and Verification and Chapter 13: Sampling
- FEMP protocols and guidelines (U.S. DOE, 2018)
- ASHRAE protocols and guidelines (ASHRAE, 2018)

References for statistical sampling and estimation include the following:

- UMP, Chapter 11 – Sample Design Cross-Cutting Protocols (NREL, 2017b)
- Load Research Manual (AEIC, 2017), see Chapters 4 "Sample Design and Selection" and Chapter 7 "Data Analysis"
- Sampling Techniques (Cochran, 1977)
- Survey Sampling (Kish, 1995)
- Introduction to Variance Estimation (Wolter, 1985)
- Encyclopedia of Survey Research Methods (Lavrakas, 2008)

Advanced M&V as Direct M&V and Comparison Group Methods

Advanced M&V (also known as “Auto-M&V” or “M&V 2.0”) refers to a set of approaches to analyzing consumption data and estimating savings using automated data retrieval and analytics. These approaches are being used with increasing frequency as jurisdictions deploy advanced metering infrastructure (AMI) in homes and businesses and gain access to daily, hourly, or finer-resolution consumption data.[21] In situations where whole-premise consumption analysis is appropriate, the use of Advanced M&V can be considered a direct M&V method. In situations where comparison group methods are appropriate, Advanced M&V can likewise be applied.

One advantage of using an automated approach is the ability to provide frequent savings estimates starting almost immediately after measure installation. While these early estimates may not be a good basis for quantifying annual savings (especially if the savings vary seasonally), they can give early warnings if EE installations are not performing as well as was projected prior to installation. This allows for opportunities to correct problems and increase savings up to expected levels. Importantly, discrepancies between projected savings and observed consumption reductions shortly after installation may also be due to unrelated changes at the facility, data errors, or seasonal or short-term effects. These possibilities should be ruled out prior to determining that a problem exists with the EE project or measure itself.

Use of daily or hourly data does not necessarily require an automated, near-real-time analysis. However, automated M&V becomes essential when rapid, frequent reporting is desired. Advanced M&V capable of processing very large volumes of data is necessary when analyzing daily or finer data across a large number of premises. Use of daily, hourly, or finer-resolution consumption data together with large-scale data processing capabilities can make it possible to identify smaller levels of savings that might be lost in the noise when analyzing monthly data using traditional approaches to estimating savings.

When applying Advanced M&V to analyze whole-premise consumption data as a direct M&V method, processes are needed to ensure that non-routine events are identified and adjusted for.

When applying Advanced M&V as a comparison group method, all issues and caveats related to comparison group analysis apply. In particular, careful specification of the comparison group is critical to the validity of results. Automated systems can identify potential customer matches from a pool of customer data, but detailed review is needed when determining which ones should be included in the comparison group. (See Section 2.2.3 and Chapter 8 of UMP.)

Current guidelines such as ASHRAE 14 for conducting whole-premise consumption analysis are based largely on experience with monthly consumption data. Recent research also explores good practices for automated tools and incorporating daily and hourly data (LBNL, 2017a; LBNL, 2017b; CPUC, 2018; RMI, 2017).

2.2.3. Comparison Group

Discussion

As an EE EM&V method, comparison group methods are applied to measure the effect of an EE activity on a group of end-use electricity consumers. This approach is most commonly applied to evaluation of publicly funded EE programs (e.g., publicly funded programs typically implemented by utilities). The same methods can also be applied to quantify savings for a group of end-use customers or sites that initiate their own (privately implemented) EE activities.

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[21] Rocky Mountain Institute identifies “two key features of M&V 2.0: (1) automated analytics that can provide ongoing, near-real time savings estimates, and (2) increased data granularity in terms of frequency, volume, or end-use detail.” (RMI, 2017)

Comparison group methods involve the analysis of whole-premise metered consumption data[22] for a group of customers who participate in an EE program (the treatment group or program participants) and another group who did not participate (the comparison group). The comparison group provides a basis for quantifying the consumption or change in consumption the participating group would have had without the EE program (baseline for net savings), or without the specific projects and measures installed through the program (baseline for gross savings). Savings is then the difference between consumption with the EE activity in place and the estimated consumption without—that is, the difference from the gross or net baseline. Thus, depending on how the analysis is structured, and which baseline it provides, the savings estimated may be the gross effect of the participants' projects or measures, or may be the net effect of the program.

When comparison group analysis is correctly applied, the analysis provides a "no-EE-activity" consumption estimate that represents the combined effect of the changes other than the EE activity being measured. To the extent the comparison group adequately accounts for other changes on average, explicit knowledge of and adjustment for these other changes is not necessary.

An appropriate comparison group has minimal identifiable theoretic or empirical systematic differences from the treatment group, apart from the effect of the EE activity itself. The ideal basis for establishing a comparison group is by random assignment prior to implementing the EE activity. This technique avoids the potential for bias and has statistically measurable accuracy. However, random assignment is compatible only with limited types of EE activities.

When comparison groups are established by methods other than random assignment, two common risks to comparison group validity should be addressed. These are applicability and self-selection. Documenting how the comparison method produces savings relative to the appropriate baseline includes explaining how these two risks are addressed by the comparison group specification and analysis.

1. **Applicability** – In addition to being similar to those who participate in an EE activity in other ways, the comparison group should consist of energy-using consumers or facilities for which the EE activity would have been applicable. Identifying such consumers or facilities can be challenging.
2. **Self-Selection** – Even if the entire pool of consumers is considered eligible, those who choose to implement an EE activity at a particular time may be different from those in the general population in ways that can affect electricity use. For example, participants in an EE program who are interested in installing energy-efficient equipment may have more efficient buildings to begin with and their consumption may respond differently than that of the typical non-participant to changes in weather, the economy, or other factors affecting all customers.

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[22] Analysis of whole-premise metered consumption data can also be applied as a site-level direct M&V method (IPMVP Option C) as described in Section 2.2.2. Additionally, Advanced M&V (see text box on page 30) is of potential interest for EE implementers. The automated consumption data analysis tools used in Advanced M&V may be used to implement direct M&V method "Option C" of the IPMVP protocol as described in Section 2.2.2, or comparison group approaches as described in Section 2.2.3, provided they are applied consistently with the guidance for those methods. These tools and approaches are not a different category of EM&V method. Instead, they can be a means of implementing whole-building consumption analysis for individual cases that is consistent with the direct M&V category of methods.

After random assignment, a next-best basis for a comparison group is a “natural experiment” in which there are two very similar groups. An example is one group who has a particular EE program offering available to them and another group who does not. Another example is to implement the natural experiment over time, using customers who participate in a subsequent year as a comparison group for the participants who participate in a current year. This approach can be effective provided:

- The EE program and other major economic conditions are similar over the measured year and the year of subsequent participation.
- There are minimal changes associated with the decision to participate in an EE activity in a particular year.

Where neither random assignment nor a natural experiment are possible, a matched comparison group is commonly used. With this approach, one or more “nearest matches” are selected for each participant, from the overall pool of customers who were eligible for the program but did not participate. The basis for establishing a nearest match can include any known characteristics such as geography or premise type, as well as similarity of energy consumption patterns in the pre-participation period. Matching controls for some but not all self-selection effects.

In jurisdictions where advanced metering infrastructure (AMI) systems or “smart meters” have been installed for the applicable customer sectors, using daily or hourly consumption data can reduce statistical uncertainty for the estimated savings. This improvement can make it possible to apply comparison group methods for smaller magnitude savings than would otherwise be possible. On the other hand, use of daily or more frequent data involves more complex techniques to determine correctly the statistical accuracy of the savings estimate.

Comparison group methods are most commonly applied in contexts where the baseline for gross savings is based on existing conditions. This is because directly calculating savings relative to a market or codes baseline would require a comparison group of customers who recently installed the market or code-level new equipment; such customers are challenging to identify. However, with the appropriate analysis structure, baselines other than existing conditions can also be addressed by comparison group methods. See Goldberg, Michelman, & Dickerson (1997) and Agnew, Goldberg, & Wilhelm (2009) for examples.

Applicable Practices

When to Apply a Comparison Group

- Apply comparison group methods to measure impacts of an EE program or portfolio of projects as a whole, not to determine savings for individual EE projects or EE measures.
- Apply comparison group methods only if the following are all true:
    - The proposed comparison group with the planned analysis structure will provide a good representation of the participating group absent the EE activity.
    - The expected statistical accuracy is adequate based on a power analysis or on the results from a prior study with similar analysis and conditions to the planned study.

    (Appendix D of the California Protocols provides an example of how this analysis can be implemented).[23]
  - Whole-facility metered electricity consumption data are available for the participating and comparison groups, with at least bimonthly meter reads spanning summer, winter, and shoulder periods before and after the EE activity.
  - Key likely systematic differences between the comparison group and participant group can be controlled for via observable variables.
  - There are minimal identifiable theoretic or empirical systematic differences from the treatment group, apart from the effect of the EE activity itself.
  - The comparison group and analysis method yields savings relative to the appropriate baseline, per Section 2.1. If this condition is met, separately determining the baseline efficiency of individual pieces of equipment is not needed.

How to Apply a Comparison Group

- Ensure that practitioners hired to prepare such analysis have the specialized expertise needed to implement a random assignment process or specify a comparison group, as well as the expertise needed to perform analysis to isolate the intervention effect to produce savings relative to the appropriate baseline.
- Where possible, specify comparison groups applying random assignment following best practices such as those described in resources from SEE Action (2012) and CALMAC (2016). Specify the random assignment design in advance of delivery of the EE activity, and ensure that the EE delivery process follows the design and random assignments.
  - If a random assignment process is not practical for the program:
    - Specify the basis for establishing the comparison group.
    - Describe likely self-selection effects and qualitatively assess the resulting effects on savings.
  - If random assignment is applied:
    - Document the random assignment design.
    - Document the steps taken to ensure delivery of the intervention according to the random assignments.
- In cases where the comparison group for a particular program-year or set of EE activities is re-analyzed in successive years to provide direct quantification of savings from surviving EE projects or EE measures, include a discussion of the basis on which the comparison group remains appropriate and valid.
- Describe the calculation methods transparently, and provide the basis for interpreting the results as savings relative to the appropriate baseline.

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[23] Qualitatively, attaining good statistical precision depends on having sufficiently large savings with a sufficiently large and homogenous group of facilities or installations, such as several hundred residential or small commercial customers. That is, the magnitude of expected savings is large compared to the expected random differences between the participant and comparison group averages (CPUC, 2006).

- Design the sample sizes to be large enough to ensure statistically significant savings values.
- Ensure that savings are adjusted for independent variables that affect energy consumption, as relevant, in accordance with Section 2.6.1.
- Collect sufficient consumption data from before and from after the intervention to include observations from each season and all operating patterns in each of the two periods (before and after). Typically, this coverage involves 9 to 12 months of data from each of the two periods.
- If the comparison group consists of participants who did not replace equipment and the appropriate baseline corresponds to standard new equipment, conduct a separate adjustment to produce savings relative to the correct baseline. For examples of adjustment processes, see Goldberg, Michelman, & Dickerson (1997) and Agnew, Goldberg, & Wilhelm (2009).
- If daily or more frequent consumption data are used, document the steps taken to ensure correct calculation of statistical accuracy.
- If applying tools designed for automated analysis of consumption data[24] to quantify savings by comparison group methods, ensure the general considerations described in this section are addressed. In particular:
    - Describe the calculation methods transparently.
    - Clearly describe the comparison group selection process and show the process is appropriate for the EE activity.
    - Show how the analysis can provide savings relative to the appropriate baseline specification.

Documentation

Include the following as part of a comparison group analysis documentation:

- If random assignment is applied, a description of the randomization design, how it was implemented, what steps were taken to ensure adherence to the random assignments, and what deviations, cross-contamination, or dropouts occurred.
- The rationale for the comparison group specification, what the comparison group represents, what conditions are controlled for by the analysis.
- The estimation method and rationale, including how the analysis provides a valid estimate of savings with respect to the appropriate baseline, per Section 2.1.
- The metrics of statistical accuracy.
- A description of the data screening criteria used, and the data attrition at each screening stage.
- The response rates if survey data are used in the analysis.
- A discussion of the threats to validity of the analysis, including systematic errors and their potential magnitude.

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[24] Examples of such tools and their uses and performance in EM&V and other contexts are described in DNV GL (2015), LBNL (2015), and ACEEE (2015).

Resources

When applying comparison group methods, apply one or more best-practice protocols and guidelines. Examples include:

- Energy Efficiency Program Impact Evaluation Guide (SEE Action, 2012a)
- UMP (NREL, 2018)
- A White Paper: Residential Portfolio Impacts from Whole-Premise Metering (CIOU, 2016)
- A Pacific Northwest Efficient Furnace Program Impact Evaluation (Agnew, Goldberg, & Wilhelm, 2009).
- Can We Rely on Self Control? (Goldberg, Michelman, & Dickerson, 1997)

2.3. Determining the Time and Location of Energy Efficiency Savings

2.3.1. Discussion

Assessing the timing and location of energy efficiency savings can provide additional value to an EE portfolio, particularly if those savings address air quality concerns or electrical grid needs at particular times and locations. The *timing* of EE savings from EE projects and measures is determined by collecting and analyzing data on how the operating characteristics of the efficient equipment reduce or shift energy consumption predictably during certain periods of time. For example, efficient air conditioners can reduce energy consumption during peak summer use. The *location* of EE savings is determined by collecting and analyzing data on the geographic distribution of EE projects and measures. Locations of interest may vary from the regional level to neighborhood-level grid distribution points.

Key Terms for Time- and Location-Differentiated EE

Time and locational savings: energy savings quantified by time of day (e.g., morning or evening), by season (e.g., summer or winter), or annually, or by geographic area.

Peak demand savings: energy savings that occur at the time of the electricity system's peak demand. Peak savings are typically quantified as the average hourly savings (kWh/h or kW) over the time block in which the system peak typically falls.

Savings shape: the distribution of annual energy savings over the year. The savings shape may be represented by the fraction of annual savings falling into each hour of the year.

Costing periods: time blocks over which avoided costs are similar. Costing periods are typically defined by individual utilities, ISO, or RTO, and tend to be defined by combinations of time of day, day type (e.g., average weekday, peak weekday, weekend/holiday), month, and season.

Knowing when and where EE projects and measures save energy can support a jurisdiction's near-term EE portfolio planning, as well as longer-term energy and air quality planning. Data on time and location can also enhance electricity system planning and operations, in which electric supply must be balanced with customer demand at each second of the day during each day of the year. Planning with knowledge of the time and location of EE savings can support the following objectives:

- Establishing accurate forecasts of energy demand that include EE and help ensure that energy supply resources and other infrastructure are not overbuilt
- Achieving air quality and public health goals by prioritizing EE projects and measures that displace generation from high-emitting sources
- Reducing customer electricity rates and bills by avoiding the need to ramp up additional power plants or buy more expensive power or fuel from the market

- Understanding how targeted investment in EE savings can alleviate electric grid congestion (or natural gas pipeline capacity constraints)

Given the benefits of using time and locational data for different objectives, jurisdictions can consider whether and how to design EE programs and EM&V plans to ensure that the necessary data are collected to quantify the time and locational value of the EE programs or measures. State and local agencies and their utility partners may also wish to assess whether supplemental research or evaluation is needed.

Time Periods of Interest for EE Savings

The amount of energy used in homes and businesses varies based on the hour, day, and season, as well the weather. Grid operators and electric utility companies work together in real time to match EGU generation with fluctuating demand during these periods and at different locations. When demand increases, operators have historically responded by increasing production from EGUs already in use, by purchasing additional power or by adding generation units that are available on reserve or standby (i.e., already running at a low level).[25]

For regional electricity grids, ***peak demand*** is defined as the highest electric use during the year or other period of time. Electricity supply tends to be constrained at times of annual peaks, because systems are built large enough to meet peak demand with limited excess capacity. These conditions typically result from extreme summer or winter weather, depending on the region. For example, many areas experience their highest or peak need for electricity on hot summer afternoons ***(summer peak)*** when homes and businesses maximize their air-conditioning use. In areas where electric heating is prevalent, a ***winter peak*** may occur during very cold weather. In areas where natural gas heat is dominant, the combined demand for natural gas heating and natural gas-fueled power generation during periods of extreme cold can constrain regional or local supplies.

In each of these cases, the goal of system planning is to ensure that generation and transmission and distribution (T&D) capacity are sufficient to serve peak demand. A key step in this process is assessing the tradeoffs among resource choices such as adding generation capacity, adding transmission capacity to increase import capability, and reducing demand. Better understanding when system peaks are likely to occur and whether EE can help reduce these peaks is therefore a common reason why jurisdictions are interested in evaluating the timing of EE savings.

Supply constraints can also occur not because demand is high but because supply is low. For example, certain areas of the country that experience supply-constrained conditions—due to a mismatch between the time when electricity use is highest and the time when large quantities of low-cost solar generation are available[26]—are examining ways in which targeted demand reductions from EE may be useful in mitigating such constraints.

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[25] For more information about the U.S. electricity system and its impact on the environment, see: https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment

[26] Areas of the country that rely heavily on renewable electricity may experience low "net loads" during sunny afternoons when EGUs are ramped down to accommodate abundant solar generation. This situation can result in system constraints in the early evening as the sun goes down, the workforce returns home, and electricity loads spike. During these hours, utilities and system operators must quickly ramp up EGUs to replace solar generation

Savings Shapes vs. End-Use Load Shapes

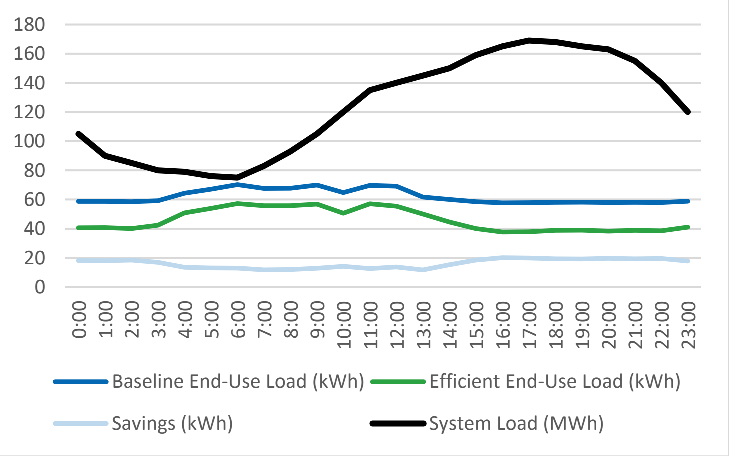
To apply time and location data for energy and environmental planning, it is necessary to understand the distribution of energy savings over the period of interest for an EE project or measure. This is referred to as a ***savings shape.*** The savings shape is typically developed from the consumption pattern of the affected equipment (e.g., residential lighting, commercial cooling), with and without the EE project or measure in place, during periods of interest. The equipment use pattern is referred to as the ***end-use load shape***.

For many EE projects or measures, energy savings are not proportional to the end-use load (i.e., the savings shape differs from the end-use load shape). In general, savings shapes do not match end-use load shapes for measures that alter the operation of the end use (e.g., occupancy sensors or smart thermostats) or the pattern of equipment runtime (e.g., economizers). However, the savings shape is the same as the end-use load shape if the EE measure affects only the wattage of an end use (e.g., replacing a 40-watt fluorescent lamp with 32-watt fluorescent lamp).

The savings shapes can be compared with overall ***system load shapes*** at the regional transmission level (i.e., RTO or ISO), or corresponding load shapes at a more local distribution level such as a substation or individual feeder to assess the value that EE can provide for addressing various objectives.

Figure 5 shows illustrative end-use load shapes, a savings shape, and a system load shape for variable speed drives (VSD) on an air compressor load in the summer. The baseline and efficient end-use load shapes for the air compressor look similar, but the savings shape shows that the savings are highest during the hours the baseline use is lowest. Thus, while the air compressor use is highest between 6 am and 2 pm, the VSD savings is greatest between 5 pm and 11 pm, including the time of the system peak.

Figure 5. Illustrative End-Use Load Shape, Savings Shape, and System Load Shape



The box below identifies methods for quantifying the timing of savings that are currently being applied throughout the country.[27] Section 2.3.2 provides additional information on these methods, including an assessment of relative costs and relative potential accuracy.

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and meet customer loads. Relying on EGUs for this brief evening period before demand again drops off at bedtime is typically inefficient and expensive. Jurisdictions may therefore wish to better understand the timing of system peaks and evaluate the timing of EE savings as strategy for mitigating system constraints.

[27] For additional information on these methods, see NREL (2017b).

Methods for Quantifying Time-Differentiated EE Savings

The following methods are currently being applied around the country to estimate savings for peak periods, or to estimate savings in individual hours of the year, depending on the availability and granularity of data.

Factor transfer: apply factors from savings shapes developed in other territories to estimate peak demand savings from the quantified energy savings.

Engineering algorithms: apply a formula to estimate peak demand savings based on characteristics of the installed equipment and its operating patterns.

Hourly building simulation models: estimate hourly energy savings by estimating consumption with and without the EE project or measure in place for each hour of a standard year, based on detailed specifications of building characteristics and operating conditions.

Whole-premise interval meter data analysis: estimate energy savings by hour or for peak periods, by analyzing hourly consumption data.

End-use metered data analysis: estimate hourly energy savings using metering of the affected end use, together with engineering analysis. The ability to estimate savings for all hours of the year depends on the specific time period metered and whether this metering period can be credibly extrapolated to represent the full year.

Derivation from annual savings shapes: use a library of existing savings shapes established by simulation or other methods to estimate hourly savings from annual energy savings.

Locations of Interest for EE Savings

The locational scale of interest for EE savings depends on the jurisdiction's objectives and circumstances. For example, the timing of peak demand on the regional electricity system often differs from the timing of individual peaks on distribution feeders. Therefore, the value of an EE measure in the context of regional system capacity planning may differ from its value for addressing localized congestion. The locational scales at which EE savings are typically quantified are listed below. In each case, EE competes in some way with other strategies for addressing system requirements. These strategies may include traditional supply investment, new or upgraded T&D infrastructure, or DERs[28].

- **Regional Transmission Organization (RTO):** At present, four RTOs allow EE to be included in capacity auctions for system resources. EE "suppliers" can submit bids into capacity auctions that obligate the suppliers to reduce demand as specified. In this way, bids for EE projects and measures are serving as an alternative to bids for generation from EGUs. The clearing prices for EE provide a market-based value of its contribution to grid reliability (ACEEE, 2018b).
- **Utility Service Territory:** Utilities that own and operate integrated systems—generation, transmission, and distribution—are sometimes required to conduct periodic integrated resource planning (IRP). Models are used to determine future capacity needs, as well as the lowest-cost resource mix to meet those needs. Prioritizing cost-effective EE can lower the overall cost of the resource mix.

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[28] A DER is a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load. Examples of different types of DER include solar PV, wind, CHP, energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE). See NARUC (2016).

- **Congestion Zone:** Congestion zones are areas in which local constraints on the distribution grid impede the flow of electricity. Adding or upgrading the existing T&D infrastructure in these areas can be expensive and disruptive. Utilities can avoid or delay the need for T&D upgrades by investing in geographically targeted DERs, including EE. In these cases, the costs and benefits of the DER alternatives are compared with those of new or upgraded T&D infrastructure.

Quantifying and tracking EE savings by geography may be accomplished by geo-coding EE projects and measures and aggregating them to the appropriate geographic scale. For certain EE project and measure types, the physical location is likely to be known and data are likely to be readily available (e.g., for a typical program where rebate applications provide customer addresses). In other cases (e.g., an upstream mass-market residential lighting program where the program discounts prices paid by all customers and has no way to identify purchasers), the geographic distribution of savings impacts needs to be determined by market characterization studies or models.

For planning and analysis, the geographic distribution of savings can be combined with characteristics and conditions of the electricity grid serving the area in which the EE project or measure is located. Examples of the circumstances in which geographic differentiation of EE savings may be useful are provided in Table 5 in Section 2.3.2.[29]

Additional Considerations for Quantifying the Time and Location of EE Savings

One consideration that may influence a jurisdiction's decision to collect and analyze time and location savings data is that using EE to displace the operation of fossil-fuel EGUs can provide air quality benefits during particular periods or at particular points of interest. EE savings may be even more valuable if the associated fuel costs and air pollutant mitigation costs are taken into account. In general, jurisdictions have found that collecting and analyzing the time and location of EE savings is more valuable in areas where air quality concerns are present and generation is more costly (see *Considerations for Air Officials* box).

Determination of the time and location of savings is easier and more useful if these factors vary predictably over the period and in the location being analyzed. Commonly used costing periods (time blocks over which avoided costs are similar) include on- and off-peak periods in winter and summer but may also be derived for weekends/holidays or even individual hours for the whole year if that level of detail is useful for forecasting. Peak demand savings are typically quantified as the average hourly EE savings (kWh/h or kW) during an on-peak costing period.

Another consideration is that time blocks or locations of interest may vary depending on the planning objective. For example, the time blocks for electricity system planning may not be the same as those of most interest for estimating emission reductions. That is, while avoided capacity costs and emission rates may both vary over time, these factors may not vary in the same way. In such cases, jurisdictions may wish to establish two or more distinct sets of time blocks for planning—one for costing and one for emissions.

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[29] The National Standard Practice Manual is one resource that provides more information on how jurisdictions can quantify and apply time and locational EE values for various objectives and circumstances.

Considerations for Air Officials

State, local, and tribal air officials are frequently interested in reducing emissions, improving air quality, and enhancing public health during specific periods or in certain locations. For example, air officials may wish to reduce emissions in areas that are in “nonattainment” with national air quality standards, or on days with particularly high ozone concentrations. In addition, air officials may be interested in achieving reductions in locations and at times when high-emitting EGUs are dispatched to meet load. Even if the total quantity of emissions during peak hours is small when compared with total annual emissions, the public health effects of these pollution spikes may be significant.

To estimate emissions reductions from EE during specific periods, air officials can pair EE savings shapes with information about which EGUs are the marginally dispatched units during the period(s) of interest. These are the EGUs whose emissions are likely reduced by the electricity reductions. One resource for quantifying the emissions reductions by region and end-use savings shape is EPA’s AVoided Emissions and geneRation Tool (AVERT) (U.S. EPA, 2018a). States, locals and tribes can use AVERT to quantify emissions reductions from EE savings that occur over an entire year, a season, or a single hour. Jurisdictions can then view these emissions reduction results at different geographic scales (i.e., at the county, state, or regional levels).

When considering the range of pollution effects and timing, location matters more for some emissions (e.g., criteria air pollutants) than for others (e.g., greenhouse gases). These effects typically depend on meteorology and how well-mixed the gases become in the atmosphere. Notably, the location of emissions reductions occurs at the point of electricity generation (e.g., the EGU) rather than at the location in which the EE project or measure is installed or operating. Air officials can work with their energy counterparts to determine whether and how EE can be used to support their jurisdiction’s air quality goals.

2.3.2. Applicable Practices

Determining the Need to Collect and Analyze Time and Locational EE Savings

- The value and usefulness of estimating time or locational EE savings can be determined by asking the following questions.
  - Time-differentiated EE savings data may be useful and valuable if the answer to any of the following questions is yes:
    - Do **emissions factors** for the state or region vary substantially and systematically by time of day or type of day (e.g., weekend) or season?
    - Do **avoided costs** for the state or region vary substantially and systematically by time of day or type of day?
    - Are there forecasted system or subsystem **capacity constraints** that increase the value of quantifying energy reductions at peak hours or at other highly constrained times?
  - Locational EE savings data may be useful and valuable if the answer to any of the following questions is yes:
    - Do the **emission factors** vary by location of the EE activity?
    - Do **avoided costs** for the state or region vary substantially and systematically by location?
    - Are there forecasted system or subsystem **capacity constraints** that increase the value of quantifying energy reductions by location for purposes of mitigating local congestion, emissions, or T&D upgrade needs?

    - Is it important to show the geographic distribution of EE savings to stakeholder groups or constituencies?

- Refer to Table 5 for a summary of when time or locational EE savings may be useful.

Table 5. Summary of Circumstances in Which Time or Locational EE Savings May be Useful

Circumstance	Time Differentiation Useful	Geographic Differentiation Useful
Emissions factors vary by time	X	
Emissions factors vary by location		X
Avoided costs vary by time	X	
Avoided costs vary by location		X
Capacity constraints	X	X
EE used to mitigate local emissions		X
EE used to mitigate local T&D congestion or defer upgrades		X
Geographic distribution of EE benefits important to stakeholders		X

EE Savings Shape Development

- If time-differentiated EE savings data are useful (based on the above considerations), select a method for estimating savings shapes from the methods defined in the "Methods for Quantifying Time-Differentiated EE Savings" text box on page 38 and listed in the first column of Table 6 below. Consider the relative cost, relative accuracy, and issues summarized in Table 6 when selecting a method.

Table 6. Summary of Approaches for Estimating EE Savings Shapes or Peak Demand Reductions[30]

Approach	Relative Cost	Relative Potential Accuracy	Comments
Factor Transfer	Low	Low-Moderate	Accuracy depends on the applicability of the transferred factors
Engineering Algorithms	Low	Low-Moderate	Accuracy depends on the quality of input assumptions as well as the algorithm used
Hourly Building Simulation Modeling	Moderate	Moderate	Accuracy depends on the quality of input assumptions (e.g., may be appropriate for HVAC and shell measures, and HVAC interactive effects)
Whole-Premise Interval Meter Data Analysis	Moderate, depending on availability of metering data	High	Interval data are becoming more widely available with the proliferation of AMI
End-Use Metered Data Analysis	High	High	Requires careful sampling and consideration of the period to be metered
Derivation from Annual Savings Shapes	Low once shapes are developed; high to develop a comprehensive library	Moderate-High	Accuracy depends on the level of detail of the savings shape library, and applicability to the EE actions

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[30] Modified from NREL (2013), Table 1, 10-10.

- If hourly simulation modeling is used to estimate savings shapes, calibrate models to actual metered electricity use.
- Determine whether there are recent or planned analyses or data sources that can contribute to EE savings shape development. If using existing sources, consider how well they align with the most recent end-use load shapes for the area of interest.
- For simplicity and consistency, apply EE savings-shape methods that make use of data collection and analysis already planned or conducted as part of routine EM&V activities, where possible. Table 7 below indicates how time-differentiated savings calculation methods can align with key EM&V methods.

Table 7. Time-Differentiated Savings Methods Aligned with EM&V Methods

EM&V Method	Time-Differentiated Savings Method	Time Granularity Typically Supported
Deemed Savings	Factor Transfer	Peak period; Other broad costing periods
Direct M&V – Partially Isolated Retrofit	End-Use Interval Meter Data Analysis	Hourly
Direct M&V – Fully Isolated Retrofit	End-Use Interval Meter Data Analysis	Hourly
Direct M&V – Whole-Facility Metering	Whole-Premise Interval Meter Data Analysis	Hourly
Direct M&V – Partially Isolated Retrofit	Hourly Simulation Modeling	Hourly
Comparison Group	Whole-Premise Interval Meter Data Analysis Factor Transfer	Hourly; Peak period; Other broad costing periods

Quantifying EE Savings Location

- If location-differentiated savings data are useful (based on the above considerations), determine locational savings using directly tracked addresses of premises in which EE projects and measures are operating, where possible, then aggregating savings to the geographic levels of interest (e.g., Zip code, county, service territory). For EE projects or measures without tracked locations, use market characterization studies or models to estimate the geographic distribution of savings.
- If considering the emissions impacts of EE savings, identify the location in which energy generation (and therefore the associated emissions) is occurring.

Valuing EE Savings by Time and Location

- Once EE savings shapes or locational distributions are quantified, determine the emissions or cost impacts by applying time- or location-specific emission factors or costs. AVERT (U.S. EPA, 2018a) can be used in conjunction with EE savings shapes to quantify emissions reductions (see the "Considerations for Air Officials" box on page 40).

2.4. Determining Duration of Savings (i.e., EUL)

2.4.1. Discussion

Key Term for Duration of Savings

Effective useful life (EUL): the duration of time an EE activity is anticipated to remain in effect with the potential to save electricity.

Electricity savings from an EE activity implemented in a particular year accrue for the duration of time it is in effect with the potential to save electricity. For equipment, "in effect" means in place and operable. For a structural change, "in effect" means in place and performing as intended (e.g., windows are not broken). For operational practice, "in effect" means the practice is still actively implemented.

The length of time over which savings are counted is referred to as the EUL. The EUL used should be an estimate of the typical duration of time (typically in years) over which EE savings from an EE activity can reasonably be expected to occur.

An alternative to specifying an EUL up front is annual verification. Annual verification means conducting installation verification activities on an annual basis and determining savings for each year using these new data. For relatively simple measures, the quantified and verified savings for each year may be the average savings per EE project or EE measure scaled by the counts of the number of installed or operating measures. For more complex EE projects or EE measures, annual direct M&V may be applied to determine changes in operating parameters. If the annual verification approach is applied, it is important to document in advance how the results of the annual verification will be used to adjust the quantified and verified savings for each year.

Questions that Air Officials Can Ask—Duration of Savings

This *EM&V Guidebook* is intended to help air officials gain a working understanding of EM&V and support discussions with their counterparts in energy agencies. Air officials interested in using EE in a voluntary or regulatory air quality implementation plan can ask the following questions to learn more about EM&V practices in their jurisdiction:

- How long are savings from EE projects and measures that are installed today expected to continue?
- How does this EUL compare to the timing of emissions reductions goals?
- Will EE projects and measures continue to be installed in each year of the emission planning period?
- Once EE projects and measures "expire," are they likely to be replaced with equally or more efficient equipment and technology?
- How will the magnitude of emissions reductions from EE change as the mix of EGUs changes over time?

The ideal basis for determining a pre-specified EUL is by conducting field observation (i.e., annual verification) and subsequently applying the findings to similar projects and measures on a going-forward basis. In addition to field observation, there are three accepted methods for specifying a pre-specified EUL:

- Based on a recent, applicable persistence study conducted according to a best-practice protocol for determining EUL values (e.g., CPUC, 2006; NREL, 2017c).

- Deemed, as documented in a database or spreadsheet (e.g., a TRM) that aligns with practices for documentation of deemed savings values and formulas described in Section 2.2.1.
- Based on an independent third-party laboratory test.

A best-practice persistence study typically results in the greatest level of accuracy. A common interpretation and basis for estimating EULs from such a study is that an EUL is the median length of time that EE projects or EE measures are in place and operable. Interpretation of the EUL as a median or average life means that some projects or measures will fail or go out of service sooner and some will last longer.

Example EULs for particular EE activities are provided below. Table 8 identifies EULs based on a variety of industry sources. They are provided for illustration only and should not be assumed as best-practice EUL values for a particular EE activity.

Table 8. Illustrative Examples of EULs for Various EE Measure Types[31]

Sector	Measure Type	Illustrative EUL
Residential	Clothes Dryers*	12
Residential	Clothes Washers	11
Residential	Dishwasher	10
Residential	Faucet Aerator	10
Residential	Low Flow Shower Head	5
Residential	Pipe Insulation	13
Residential	Room Air Conditioners*	9
Residential	Water Heater – Heat Pump	11.2
Residential	Water Heater – Tankless	17.5
Nonresidential	Chiller	23
Nonresidential	HVAC Controls, VFD, Motors	15
Nonresidential	Walk-in Equipment (Nonres); Refrigerator and Freezers (Res)	12
Res/Nonres	Air Sealing (Package AC, Chiller Space Cooling, Heat Pump, Boiler)	11
Res/Nonres	Boilers	20
Res/Nonres	Furnaces*	15
Res/Nonres	Building Shell (Windows, Doors, Insulation)	19
Res/Nonres	Cool Roofs	15
Res/Nonres	Energy Management Controls	10
Res/Nonres	HVAC	15
Res/Nonres	Lighting – CFL*	5
Res/Nonres	Lighting – Other	11
Res/Nonres	Water Heater – Storage	13

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[31] Values marked with an asterisk (*) are from U.S. EPA ENERGY STAR (U.S. EPA, 2018b). All other values are from the Savings Calculator Tool (DNV GL, 2015).

Considerations for Air Officials

Air officials may wish to understand how the EUL of EE projects and measures (i.e., the duration of EE savings) compares to the future "emissions attainment year" or year of the emission reduction goal. This information can then be used to quantify the impact that EE savings are likely to have on emissions levels over the period of interest. There are several key issues to consider. One is that, over the EUL of the EE activity, the mix of EGUs affected by EE projects and measures may change over time. This in turn may affect the magnitude of the avoided emissions from a given quantity of EE savings. Another issue to consider is that the quantity of EE savings may change over time with the level of EE implementation (for example, certain state EERS targets escalate over time). An additional consideration for air officials is how end-use energy consumption changes as EE projects and measure expire at the end of their EUL. That is, are EE projects and measures replaced with equipment and technologies that are equally or more efficient? In practice, the efficiency levels of equipment have steadily increased in recent decades due to policies such as appliance standards and building energy codes, as well naturally occurring market changes. Air officials can work with their energy counterparts to examine assumptions about how EE levels and associated emissions impacts are anticipated to change over time.

2.4.2. Applicable Practices

Cross-Cutting

- Select whether a pre-specified EUL or an annually verified EUL will be applied for each EE project and EE measure. Describe why that EUL approach is appropriate for the EE project(s) and/or EE measure(s) to which it is applied. When selecting between a pre-specified EUL or an annually verified EUL, consider:
    - **Availability of pre-specified EULs:** If it is not possible to pre-specify an EUL using one of the three accepted methods, annual verification may be required.
    - **Resources available:** Pre-specified EULs will generally be simpler and less resource-intensive to implement.
    - **Annual EM&V activity:** Where annual EM&V methods are already being applied for other purposes, such as a performance contract implemented by a private ESCO, EE implementers may prefer to apply annual verification.
    - **Complexity of EE activity:** For relatively simple measures, the quantified and verified savings for each year may be the average savings per EE project or EE measure scaled by the counts of the number of installed or operating measures. For more complex EE projects or EE measures, annual direct M&V may be applied to determine changes in operating parameters.
- For EE projects, account for differences in EUL values among the EE measures included in the EE project, as applicable.
- Participate in collaborative and joint research to improve the breadth and quality of EUL values (several such research activities are ongoing in states around the country).

Annual Verification

- If annual verification is applied:
    - Specify in advance:

        - That the quantity of installed EE measures still in place and operating will be determined each year, via empirical data collection.
        - How the annual verification results will be used to determine the quantified and verified savings for each year.
        - A methodology for empirical data collection to be applied to determine the number of EE projects and EE measures that remain installed and operating at the end of each preceding reporting period.
    - For the initial year of installation and for each year thereafter, conduct verification in accordance with Section 2.5 to determine what portion of the total installed EE projects or EE measures remain in place and operable. Quantify savings based on the portion that is found to still be in place and operable.

Pre-Specified EUL

- If pre-specified EULs are used, document the source of each pre-specified EUL for EE equipment installation or operational improvement, consistent with one of the three following categories. Note that the first category is preferable to the second, which is preferable to the third.
    1. Based on a recent, applicable persistence study conducted according to the provisions of a best-practice protocol for determining EUL values and with EUL estimated at the appropriate level of confidence and precision. An example of a best practices protocol for such studies is the Effective Useful Life Evaluation Protocol of the California Energy Efficiency Evaluation Protocols (CPUC, 2006).
    2. Based on an applicable TRM, meeting the Applicable Practices for specifying and updating deemed values under Section 2.2.1.
    3. Based on an independent third-party laboratory lifetime testing protocol.
- When a pre-specified EUL is used, the following lifetime equivalent EUL calculation may be applied to simplify annual quantification for dual baseline or combination measures. To apply this calculation, use a single lifetime equivalent annual savings (LEAS). Apply that savings quantity for each year from the first year of a dual-baseline EE project or EE measure installation through the full EUL, or for the longest EUL of a combination of measure denoted below by EUL_{max}.[32]

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[32] The LEAS may be calculated as follows:

- For a dual baseline measure with annual savings S_1 from the first year through the RUL, and annual savings S_2 for the remainder of the EUL, calculate the LEAS as: $\text{LEAS} = (S_1\text{RUL} + S_2(\text{EUL-RUL}))/\text{EUL}$
- For a combination measure with annual savings contributions S_c with EULs EUL_c for different measure components c, the LEAS is quantified as: $\text{LEAS} = \Sigma_c(S_c\text{EUL}_c)/\text{EUL}_{max}$
- The LEAS formulas may be applied to successive levels of aggregation of measures using a previously quantified LEAS in place of the savings S_c, and the corresponding full EUL or EUL_{max} on the right-hand side of either formula.

2.5. Verifying Savings

2.5.1. Discussion

Determining MWh savings from an EE activity involves both verification that an EE project or EE measure has been installed and quantification of total savings for the group of verified installations. Verification is applied for purposes of confirming both that the EE project or EE measure is in place and that it has the potential to save electricity. This means that the equipment or affected facility is in regular use. Site inspections, phone and mail surveys, and desk review of program documentation are typical verification activities. Verification may also include assessing baseline conditions and confirming that the EE projects or EE measures are operating according to their design intent.

Key Term for Verifying Savings

Verification (of EE project or EE measure installation): an assessment by an independent entity to ensure that the EE activities have been installed correctly and can generate the predicted savings.

2.5.2. Applicable Practices

- Select the verification method based on:
    - The number of installed units or number of affected facilities
    - The type of EE activity
    - The type of EUL used (pre-specified or annually verified)
    - The EM&V method used
- Document the best-practice approaches that will be applied to verify electricity savings from the EE resource, including that the EE resource is installed and operating.
- Where practical (e.g. for an EE activity involving the installation of a small number of units or affecting a small number of facilities), conduct verification for each EE project or EE measure to confirm that the applicable equipment and systems are in place, capable of operating as intended, and have the potential to deliver the projected savings. “Capable of operating as intended” means that the equipment or affected facility is in regular use.
- In cases where verifying each EE project or EE measure is not feasible or practical:
    - Design a sample of such EE projects or EE measures, including corresponding sample expansion methods, applying established statistical sampling and estimation practices. An example is described in Appendix B of the IPMVP.
    - Conduct verification for the sample.
    - Use the sample data and sample expansion methods to determine installation rates and other adjustment factors for the full EE activity.
- For an EE program consisting of the installation of multiple EE projects or EE measures at different locations, verify the quantity of each type of EE project or EE measure that is installed and operating during the period for which the EM&V plan applies.
- For EE projects that may become partially operational (for example, if a fraction of the component EE measures fails over time), verify what portions of the EE project are installed and operational during the period for which the EM&V plan applies.

- For the following common EE activities, apply these verification strategies:
    - For **EE retrofits** or **early replacement**, confirm (1) installations of the indicated EE measures, (2) the efficiency levels and operating conditions of the installed measures and baseline, and (3) that the measures are operating correctly such that they can generate the predicted savings.
    - For **EE new construction projects** involving whole-building efficient design, confirm the building’s actual specifications as built, confirm that the baseline specifications are appropriate, and review and confirm commissioning documentation.
    - For **EE point-of-sale rebate** or **distributor incentive programs**, confirm the sales data used for determining equipment counts and verify installation and operations with a sample of end-user purchasers.
    - For EE projects or EE measures intended to influence **consumer behavior**, verify that the projects or measures continue to have the intended effect on consumer behavior.
- As described in Section 2.4:
    - If a **pre-specified EUL** is established, conduct verification once as part of the overall savings quantification and verification process.
    - If **annual verification** is applied, repeat the verification each year for a given EE project or EE measure, and quantify a revised savings value for the surviving units based on verification findings.
- If **comparison group methods** are applied as described in Section 2.2.3 or **direct M&V methods are applied using whole-facility analysis** as described in Section 2.2.2, the analysis is considered to provide a combination of savings quantification and verification. That is, the electricity savings quantified applying a comparison group or direct M&V is based on electricity consumption data that reflect both what was actually installed and operating as well as the operational practices that affect savings. Separate verification activities are therefore not necessary.

2.6. Accounting for Additional Aspects of Savings Quantification

2.6.1. Independent Variables

Discussion

Observed changes in electricity consumption are the result of changes in a variety of independent variables and influences, in addition to the effect of the EE activity. These independent variables range from the outdoor temperature to occupancy levels in a building to industrial production levels. To isolate the electricity savings that result from an EE activity, EM&V practitioners should control for each of these independent variables that is material to the savings determination. Controlling for independent variables is critical to the credibility of savings estimates, and distinguishes properly quantified savings values from a simple and unreliable comparison of electricity use before and after implementation of an EE activity.

Key Term for Independent Variables

Independent variables: variables (e.g., weather, occupancy, production levels) that affect electricity consumption and savings, and vary independently of the EE activity under study.

Controlling for the independent variables means ensuring that:

- The quantified savings do not inadvertently include effects of changes in independent variables.
- The savings are quantified for correct values of the independent variables.

Independent variables are controlled for either by confirming that they are constant over the quantification periods, or by explicitly adjusting consumption or savings calculations to what would have occurred at other levels of the variables, applying engineering or statistical methods. For independent variables that are constant over the periods of interest—and that are consistent with assumptions used when applying one of the three allowable EM&V methods—no explicit analysis or adjustment is called for.

As described in Section 2.1, determination of the baseline consumption level depends on both the baseline and the operating conditions. Operating conditions are specified in terms of independent variables.

Many EE activities affect equipment and systems in place, but do not affect how the equipment or facility is used (e.g., hours that a piece of equipment is operating). For such activities, the operating hours or other indicators of how the equipment is used are among the independent variables that should be considered in calculating savings. Operating conditions for determining baseline consumption are the post-installation operating conditions.

Other EE activities, such as installation of equipment control systems or new operating practices, do affect how equipment or facilities are used. For these activities the operating pattern for determining baseline consumption consists of the practices that would have been in place during the post-installation period without the effect of the EE activity. In these cases, the independent variables that are important to control for may be due to the level of activity in the facility, rather than the runtime of the equipment. Since the runtime of the equipment is affected by the EE activity, it is not an independent variable.

For example, if the efficient lighting installed does not affect hours of lighting use, baseline consumption is calculated for the post-installation hours of use. If the efficient lighting activity includes new controls to reduce hours of lighting use, baseline consumption is calculated for the hours of lighting use that would have occurred in the post-installation timeframe absent the new controls. If the facility operating hours are different between the pre- and post-installation periods, the hours of lighting use for the baseline consumption calculation are based on the hours of use that would have occurred in the post-installation period, if the lighting controls were not present.

Each of the three EM&V methods described in Section 2.2 has a mechanism for accounting for independent variables. For deemed savings values, independent variables are implicitly controlled for through the associated applicability conditions. For direct M&V, these variables are adjusted for via the use of regression analyses, computer simulation modeling, or engineering calculation (non-routine) adjustments. For comparison group methods, independent variables are controlled for through the comparison group specification and consumption data regression analyses.

Applicable Practices

- Identify the independent variables that affect energy consumption and savings for the EE activity. At a minimum, consider the following and control for them as described below, unless they can be assumed to be constant over the life of the EE activity, or they will not affect energy savings for the activity:
    1. Weather
    2. Equipment or facility hours of operation
    3. Facility activity level as measured by variables such as occupancy, number of shifts, manufacturing production level, or number of meals served
- Document the methodology for adjusting electricity consumption and savings values to account for the effects of independent variables that can affect energy consumption over the EUL of the EE project or EE measure.
- Within a single EE program, quantify savings for the constituent EE projects or EE measures using consistent assumptions for independent variables across different projects and measures. For example, use consistent forecasts of future weather within a given geographic area, and use consistent operating hours assumptions within a given market segment. Assumptions may vary across market segments and geographies based on known characteristics.
- Quantify EE savings using values of independent variables that are expected to apply over the life of the EE activity, applying one of the following two approaches:
    1. Actual conditions that exist over the period when EE savings occur, if these conditions are measured throughout the EUL (e.g., via ongoing direct M&V or annual verification).
        - ▪ With this approach, adjust baseline electricity consumption data to reflect actual independent variables observed after the measure is in place and fully operating.
        - ▪ Examples of independent variables based on actual post-installation conditions are:
            - Observed weather conditions for a residential heating efficiency project
            - Observed occupancy rates for a commercial building lighting efficiency project
            - Observed equipment production rates for an industrial efficiency project
    2. Normalized or standardized (typical) conditions that can be reasonably expected to occur throughout the EUL.
        - ▪ With this approach, both baseline and performance period data on electricity consumption are normalized to data on the independent variables, where reasonable and appropriate. Examples of normalized independent variables based on typical conditions are:
            - Typical weather conditions for a residential heating efficiency project

  - Typical occupancy rates for a commercial building lighting efficiency project
  - Typical equipment production rates for an industrial efficiency project
- Where first-year savings values—derived by applying first-year independent variables—are used to represent annual savings for the EUL of the EE project or EE measure, provide a justification for why this is a reasonable assumption (i.e., justify why first-year independent variables can be shown to represent standard/typical conditions over the life of the measure).

2.6.2. Interactive Effects

Discussion

EE activities often have indirect impacts on electricity and fossil fuel use in end-use systems not directly affected by the subject measures. There are three primary types of interactive effects:

Key Term for Interactive Effects

Interactive effects: indirect impacts of EE activities that increase or decrease the use of electricity or fossil fuels in end-use systems outside of the targeted end use. Interactive effects include "multi-measure effects" or equipment and facility improvement interactions, "other-system effects" or inter-end-use interactions, and "EE program overlap."

- **"Multi-measure effects" or equipment and facility improvement interactions:** When multiple EE measures are installed in the same facility at the same time, affecting the same energy-using system(s), the savings from the combination of measures is often different (usually less) than the sum of the savings that would result from installing each one individually without the others. For example, savings from the combination of high-efficiency electric equipment, building shell improvements, and building controls is less than the sum of the savings from installing each of these without the others.
- **"Other-system effects" or inter-end-use interactions:** Certain EE measures designed to reduce the electricity use of one system indirectly affect the electricity use of an end use or system other than the one directly affected by the measure. For example, installing efficient lighting in a building's cooled and heated space can decrease the electricity use of cooling systems and increase energy use in heating systems.
- **"EE program overlap":** Certain EE projects or EE measures are influenced or encouraged by more than one EE program, meaning that the electricity savings resulting from that project or measure might improperly be counted partly or wholly by more than one program if the program overlap is not addressed. Electricity savings from a single EE project or EE measure may be apportioned to more than one EE program (for example, if that project or measure is jointly funded), but the total savings claimed for that EE measure across all programs should not exceed the actual measured savings when the combined effect of multiple programs is being calculated. For example, if an EE program focused on changing consumer behavior results in greater participation in existing EE rebate programs, the same electricity savings for certain projects or measures can potentially be attributed to both programs. EE program overlap, also called "double counting," is addressed further in Section 2.6.4.

Applicable Practices

- Consider the following key questions to determine if interactive effects are relevant:

    - Have multiple EE measures been installed in the same facility at the same time?
    - Do installed EE measures indirectly affect energy use of another end use or system?
    - Are the EE projects or EE measures influenced by more than one EE program?
- For **multi-measure effects**, address the interactive effect in one of two ways:
    - As an **integrated calculation**. Determine consumption with the combination of measures and without any of the measures in place, and take the difference.
    - As a **sequence of EE measure-specific calculations**. In this case, the order in which the measures are assumed to be installed matters. In the example above, taking the measures in the indicated order, savings would be calculated for the following:
        - The high-efficiency electric equipment by itself
        - The building shell improvements with the high-efficiency electric equipment included in the baseline specification
        - The building controls, with the high-efficiency equipment and building shell improvements included in the baseline specification

  Both methods should produce the same savings for the combination, but the second method allocates savings to the separate EE measures, according to the assumed installation sequence.

  If **comparison group** methods are used to quantify savings, do not make an additional adjustment for multi-measure effects on the same fuel. With these methods, these interactive effects are automatically incorporated in the savings calculations

- Calculate **other end-use** interactive effects using methods appropriate to the broad EM&V methods used to quantify savings.
    - Identify the other end uses affected by the projects and measures, and calculate the associated effects. Apply the UMP (NREL, 2018) or other applicable protocols and methods. (See for example UMP Chapter 2 on Commercial and Industrial Lighting Evaluation.)
    - If other end-use interactive effects are treated as zero, justify why this is an appropriate assumption.
    - If **deemed savings** methods are used to quantify savings, include other end-use interactive effects in the deemed savings values or separately estimate these effects applying deemed methods.
    - If **direct M&V** methods are used to quantify savings:
        - Quantify other end-use interactive effects explicitly if methods based on sub-facility measurements, such as isolated retrofits or partially isolated retrofits, are applied.
        - Incorporate other end-use interactive effects directly into the savings calculations if building simulation is applied. Most building simulation tools and approaches are designed to incorporate interactive effects in their savings calculations.

    - If whole-facility consumption analysis methods are used to quantify savings, do not make an additional adjustment for other end-use interactive effects on the same fuel. With these methods, these interactive effects are automatically incorporated in the savings calculations.
  - If **comparison group** methods are used to quantify savings, do not make an additional adjustment for other end-use interactive effects on the same fuel. With these methods, these interactive effects are automatically incorporated in the savings calculations.
- For **EE program overlap**, see Section 2.6.4 on Double Counting.

2.6.3. Transmission and Distribution Savings and Adders

Discussion

The difference between the electricity generated (busbar value) and consumed (end-user meter value) is due to losses in the T&D system. U.S. Energy Information Agency (EIA) data from 2013 to 2017 indicate that national, average annual T&D electricity losses are about five percent of the electricity that is transmitted in the United States (U.S. EIA, 2019). Every unit of electricity consumption avoided through EE activities at an end-use site also avoids losses that would have occurred as that electricity was delivered through the T&D system. Applicable practices on how T&D savings can be added to end-use electricity savings values follows.

Questions that Air Officials Can Ask—T&D Savings and Adders

This *EM&V Guidebook* is intended to help air officials gain a working understanding of EM&V and support discussions with their counterparts in energy agencies. Air officials interested in using EE in a voluntary or regulatory air quality implementation plan can ask the following questions to learn more about EM&V practices in their jurisdiction:

- Does my jurisdiction account for the energy and emissions impacts of EE on T&D?
- What assumptions and data sources are used to support this analysis?
- What is the magnitude of emissions reductions resulting avoided T&D losses?

Applicable Practices

- Document the method for adjustment to the quantified electricity savings to account for T&D losses as well as the numerical value of the T&D loss factor, as applicable.
- For EE projects and EE measures that do not otherwise incorporate avoided T&D losses in their quantification, a T&D loss factor may be calculated. The total savings for an EE project or EE measure can then be adjusted by multiplying the total verified energy savings by the T&D loss factor. The T&D line-loss rate should be rounded to the nearest thousandth (i.e., expressed in no more than three decimal points) before applying the adjustment.
  - For example, if total savings were 100,000 MWh and the calculated T&D loss factor was 0.050, then total claimed energy savings inclusive of T&D losses would be 105,000 MWh.
- When applying a T&D loss factor, use one of the following:

- **National average T&D loss factor** (expressed as a percentage) using the most recent data published by the U.S. EIA State Electricity profile, Table 10.[33] Note that the national average factor was about 5% for 2013–2017 (U.S. EIA, 2019)
    - **A calculated state-specific annual average T&D loss factor** (expressed as a percentage) using the most recent data published by the U.S. EIA State Electricity profile, Table 10[34]
    - **A local utility average T&D loss factor** (expressed as a percentage) using the most recent data published by the U.S. EIA State Electricity profile, Table 10[35]
- Include references to the source data and explicit variables used in calculation of the T&D loss factor, the type loss factor applied (i.e., utility-specific or statewide), and rationale for selection of the loss factor.

Considerations for Air Officials

In designing or implementing air quality plans that include EE, it is important to account for all sources of electricity savings. This includes quantifying the avoided losses that would occur in the absence of an EE activity as electricity is transmitted and distributed from the EGU to the electric service delivery point (i.e., a household or business). In this way, EE projects and EE measures avoid not only the generation required to supply the level of electricity demand that would otherwise occur, but also the T&D losses that occur as electricity is supplied to customers. Air officials interested in quantifying emissions reductions associated with EE can therefore appropriately account for the avoided emission impacts associated with generation lost to T&D.

2.6.4. Double Counting

Discussion

Double counting occurs when the MWh savings from a single EE program, EE project, or EE measure are counted more than once. It is critical to prevent this type of error to maintain programmatic integrity and credibility, and to ensure that EE activities result in real and permanent reductions in emissions. Tracking, accounting, and quality checks are steps that are routinely undertaken in states and regions

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[33] To access data to calculate a national average T&D loss factor, visit the U.S. electricity profile accessible at: https://www.eia.gov/electricity/state/. Select "U.S. Total." To access Table 10: Supply and Disposition of Electricity, scroll to the bottom of the web page and select the link below Table 1 titled "Full data tables 1-14" and download the file. In the file, select worksheet 10. To calculate the T&D loss percentage using the data from Table 10, divide "Estimated Losses" by the result of "Total Disposition" minus "Direct Use" i.e., Estimated Losses / (Total Disposition – Direct Use). The result is the T&D loss factor for the United States.

[34] To access data to calculate a state-specific T&D loss factor, visit a state-profile page at: https://www.eia.gov/electricity/state/. Select the state of interest. To access Table 10: Supply and Disposition of Electricity, scroll to the bottom of the state profile page and select the link below Table 1 titled "Full data tables 1-14" and download the file. In the file, select worksheet 10. To calculate the T&D loss percentage, using the data from Table 10, divide "Estimated Losses" by the result of "Total Disposition" minus "Direct Use" i.e., Estimated Losses / (Total Disposition – Direct Use). The result is the T&D loss factor of that state.

[35] To access data to calculate the local utility average T&D loss factor, visit https://www.eia.gov/electricity/data/eia861/. Select the year of interest and download the associated zip file. Extract the file titled "Operational Data" [Year Selected]. To calculate the T&D loss factor, select the utility of interest, then divide "Total Energy Losses" by Total Disposition. The result is the local utility average T&D loss factor.

across the country to avoid double counting of EE activities. The purpose of these steps is to avoid the following circumstances:

- Savings from a single EE activity being claimed by more than one EE implementer. For example:
    - Some or all savings from the same retrofit being claimed both by a residential behavior-based program and a retailer point-of-sale incentive program.[36]
    - Savings from a single retrofit project being claimed by a utility incentive program and the ESCO that implemented the retrofit.
- Two or more EE activities operating during different years both claiming savings from the same EE projects or EE measures.
- Two or more EE activities claiming savings that result from interactive effects between EE projects or EE measures, as described in Section 2.6.2.
- Inconsistent baselines across a portfolio of EE programs. For example:
    - One EE program claiming savings from enacting a Building Energy Code and Equipment Energy Standard (C&S) with 100-percent compliance that results in savings above a prior C&S or common practice, and another program claiming savings with a baseline defined below the new C&S (e.g., a baseline defined by a prior C&S) for the same types of EE activity.
    - A state claiming credit for federal actions such as building code determinations or appliance standards.

Applicable Practices

- Implement systematic tracking and accounting procedures, including the use of well-structured and well-maintained tracking and reporting systems such as those already being used by many states and EE implementers. Document procedures and systems.
- Implement the following procedures to avoid or correct for double counting:
    - For EE activities with identified consumers, conduct tracking (type and number of EE projects or EE measures implemented) at the utility-customer level using customer name, address, account number (where available) and applicable dates for each activity.
    - For EE activities without identified consumers, such as point-of-sale rebates and retailer or manufacturer incentive programs, track applicable vendor, retailer, and manufacturer data. Include the appropriate specifications and quantities of EE equipment sold or shipped.
    - Where practical, such as where multiple EE implementers share a common tracking database, use the consumer-level data to identify and correct for duplicate EE activity records across programs with “trackable” consumers and across non-program projects such as private-sector transactions for projects sponsored by an ESCO.

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[36] This potential for double counting is particularly important in the context of randomized encouragement programs, where part of the savings seen in treatment/control differences is due to increased participation in general offering programs.

    - Where it is not practical to identify overlap by matching records from tracking data, conduct surveys to collect information to estimate the degree of overlap.
    - Identify and correct for duplicate EE activity records across EE programs and non-program projects such as private-sector transactions for projects sponsored by an ESCO.
    - Identify instances where tracked consumer activity is likely to be double counted with upstream activity and subtract the estimated overlap from one or the other's savings claims. See the next bullet for more detail.
- For EE activities with identified consumers but without identified equipment or installations (e.g., an information or behavioral program), apply the following steps to eliminate double counting with EE activities that do not have identified consumers (e.g., upstream programs):
    - Use surveys of the participating and control groups to estimate the extent of incremental non-tracked EE activity (such as from upstream EE programs) among the participating group.
    - Subtract the savings from this incremental non-tracked activity amount from either the informational/behavioral EE program or the upstream program total, or split the amount to be subtracted between the two.
    - See the SEE Action Guide (SEE Action, 2012a) or the UMP (NREL, 2018) for evaluating behavioral programs for further information.

2.7. Characterizing Accuracy

2.7.1. Discussion

A typical practice for EM&V planning among publicly funded EE programs administered by utilities is to characterize the accuracy of the EE savings that will be determined based upon the selected EM&V methods. The accuracy of quantified savings is a function of the following two types of error:

Key Term for Accuracy

Accuracy: How close an estimate is to the true value it estimates. The term can be used in reference to a point estimate resulting from a sequence of analytic steps, model coefficients, a set of measured data, or a measuring instrument's capability.

- **Systematic error:** estimation errors that may cause an estimate (such as an electricity savings value) to be consistently either overstated or understated. Systematic errors are also referred to as bias, and may result from incorrect assumptions, a methodological issue, or a flawed reporting system.
- **Random error:** estimation errors occurring by chance that may cause an estimate (such as an electricity savings value) to be overestimated or underestimated with no systematic tendency in either direction, resulting from uncontrolled and unobservable factors affecting the underlying measurements.

The magnitude of random error can be quantified based on the variations observed across different EE projects or EE measures. It is important to report such random error, describe the steps that have been taken to minimize the potential for systematic error, and provide a subjective assessment of the potential effects of both types of error.

The key sources of quantifiable random error that can result from applying EM&V methods include:

- **Random sampling error**, including error that results from the selection of samples of customers, EE projects, or EE measures within an EE program; selection of individual EE measures to be observed within a facility; and random assignment in the context of comparison group methods.
- **Modeling or estimation error**, when a regression model or other statistical estimation is used to estimate savings or savings parameters.

2.7.2. Applicable Practices

- Document the approaches used to assess the accuracy of quantified electricity savings and to control the types of error inherent to the applied EM&V methods. Specify how measurement error is controlled, as well as how quantifiable random error is estimated. Identify potential sources of systematic error, plan steps to minimize these sources as practical, and report on the sources, the mitigation steps taken, and any qualitative assessment of their likely effects.
- Establish targets for the measured accuracy of quantifiable errors, in terms of the relative precision of a statistical confidence interval. Such targets may be expressed in the form of confidence level/relative precision. A common target is 90/10, meaning that a 90 percent confidence interval for estimated savings should be no wider than + 10% of the estimate itself. Another common target is 80/20, meaning an 80% confidence interval no wider than ± 20% of the estimate. Confidence/precision targets may be based on established jurisdictional requirements. Apply such targets for the total savings addressed by an EM&V effort, such as an overall program or portfolio (i.e., not just for individual projects or measures). Design EM&V studies to meet these confidence/precision targets, using reasonable assumptions based on prior similar studies.
- Design assumptions needed for savings quantification to provide neither optimistic savings estimates (aiming to err on the high side) nor conservative estimates (aiming to err on the low side).
- If sampling is used to quantify savings values, report the achieved confidence/precision of the associated estimates.
- Apply and cite applicable best-practice protocols and guidelines documents for sampling. Examples of best practices for statistical sampling are described in the following resources:
  - UMP Sample Design Cross-Cutting Protocol, Chapter 11 (NREL, 2017b)
  - Load Research Manual (AEIC, 2017), Chapters 4 “Sample Design and Selection” and Chapter 7 “Data Analysis”
  - Sampling Techniques (Cochran, 1977)
  - Survey Sampling (Kish, 1995)
  - Introduction to Variance Estimation (Wolter, 1985)
  - Encyclopedia of Survey Research Methods (Lavrakas, 2008)
- For states tracking or trading emissions reductions across borders, coordinate across jurisdictions to apply the same or consistent EM&V approaches to the extent practical, to ensure the savings values are quantified with comparable levels of accuracy.

- For all EM&V methods, document potential sources of quantifiable statistical error (and associated quality-control measures).
- For **deemed savings**:
    - Describe reasons the deemed savings values or parameters may not be valid in the context of their applicability conditions.
    - Quantify random errors if applicable.
    - Calculate and report the statistical error of any EM&V parameters determined using sampling.
- For savings determined by **comparison group** methods, report the statistical confidence intervals or confidence and relative precision levels of the program savings measured by the comparison group analysis. Examples of protocols and guidelines that describe how this can be implemented include:
    - SEE Action Guide on evaluating behavior programs (SEE Action, 2012b)
    - UMP Sample Design Cross-Cutting Protocol, Chapter 11 (NREL, 2017a)
    - UMP Whole-Building Retrofit Evaluation Protocol, Chapter 8 (NREL, 2013)

Formulas for determining the accuracy of combinations of components or factors

The following approximations to the relative precision of a sum or product of separately estimated components are useful. In these formulas, RP(S) denotes the relative precision of a savings quantity S at fixed confidence level such as 90%. That is, RP(S) is the half-width of the (say, 90%) confidence bound for S, as a percent of the point estimate.[37] These formulas may be used to calculate relative precision at any fixed confidence level; that is, when the same confidence level applies to the relative precision of S and to all of the components.

- If S is the sum of separate component savings estimates S_1, S_2, …, S_k that were all based on independent samples or data sets:

  For $S = S_1 + S_2 + \ldots + S_k$, all independent

$$RP(S) \cong \sqrt{(\frac{\boldsymbol{S_1}}{\boldsymbol{S}})^2\boldsymbol{RP(S_1)}^2 + (\frac{\boldsymbol{S_2}}{\boldsymbol{S}})^2\boldsymbol{RP(S_2)}^2 + \cdots + (\frac{\boldsymbol{S_k}}{\boldsymbol{S}})^2\boldsymbol{RP(S_k)}^2}$$

- If S is the product of a series of adjustment factors to an ex ante estimate, where the factors are all determined from different independent data sets, the following approximation may be used:

  For $S = A_1A_2 \ldots A_kS_0$, where S_0 is known (not statistically estimated)

$$RP(S) \cong \sqrt{\boldsymbol{RP(A_1)}^2 + \boldsymbol{RP(A_2)}^2 + \cdots + \boldsymbol{RP(A_k)}^2}$$

3. EE EM&V Protocols and Guidelines

Standard practices for quantifying EE savings are documented in a series of publicly available EM&V protocols and guidelines. These resources have been developed and refined over time primarily to support the integrity of publicly funded EE programs and private-sector ESCO projects in states across

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[37] For example, if the 90% confidence interval is 50 ± 10, the relative precision at 90% confidence is 10/50 = 20%. The half-width is 10, the "±" quantity, since the confidence interval width, from 50–10 to 50 +10, is twice this quantity.

the country. Table 9 lists a set of standard protocols and guidelines that define, provide instructions for, and generally govern the application of EM&V methods.

Table 9. Examples of Standard EE EM&V Protocols and Guidelines

Protocol/Guideline ***Sponsor***	**Website**	**Summary**
Federal Resources		
The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures (2018) *U.S. Department of Energy*	https://www.nrel.gov/docs/fy18osti/70472.pdf http://www.energy.gov/eere/about-us/ump-protocols	Applied protocols for quantifying savings from common EE programs, measures, and technologies based on widely accepted methods
Uniform Methods Project (UMP) Whole-Building Retrofit Evaluation Protocol. Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol (2017) *U.S. Department of Energy*	https://www.nrel.gov/docs/fy17osti/68564.pdf	Applied protocol for quantifying savings from whole-building retrofits
Energy Efficiency Program Impact Evaluation Guide (2012) *State and Local Energy Efficiency Action Network – U.S. Department of Energy and U.S. Environmental Protection Agency*	https://www4.eere.energy.gov/seeaction/publication/energy-efficiency-program-impact-evaluation-guide	Information resource and guide describing common terminology, methods, and assumptions used to determine electricity savings, avoided emissions, and other non-energy benefits resulting from facility (non-transportation) EE programs
Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans (2012) *U.S. Environmental Protection Agency*	https://www.epa.gov/sites/production/files/2016-05/documents/eeremanual_0.pdf	Information resource and guide for incorporating EE and RE policies and programs into state and tribal implementation plans (SIPs/TIPs)
Evaluation, Measurement, and Verification (EM&V) of Residential Behavior-Based Energy Efficiency Programs: Issues and Recommendations (2012) *State and Local Energy Efficiency Action Network – U.S. Department of Energy and U.S. Environmental Protection Agency*	https://www4.eere.energy.gov/seeaction/system/files/documents/emv_behaviorbased_eeprograms.pdf	Information resource and guide that describes methodologies for quantifying savings from residential behavior-based EE programs
FEMP M&V Guidelines (2008) *U.S. Department of Energy Federal Energy Management Program*	http://portal.hud.gov/hudportal/documents/huddoc?id=doc_10604.pdf	Applied protocol for quantifying EE savings associated with federal agency performance contracts
Other Resources		
International Performance Measurement and Verification Protocol (IPMVP) (2016) *Efficiency Evaluation Organization*	https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp	Applied protocol for determining savings from EE projects and measures; does not apply to EE programs consisting of many EE projects or measures

Protocol/Guideline ***Sponsor***	**Website**	**Summary**
Regional Technical Forum (RTF) (2018) *Northwest Power and Conservation Council*	http://rtf.nwcouncil.org/	Advisory committee established to develop standards for quantifying savings from a wide range of EE projects and measures; maintains an extensive and well-documented database of deemed savings values
PJM Manual 18B: Energy Efficiency Measurement & Verification (2016) *PJM Interconnection*	https://www.pjm.com/~/media/documents/manuals/m18b.ashx	Applied protocol for quantifying and verifying the demand reduction value of EE programs, projects, and measures for the PJM capacity market
ASHRAE Guideline 14, Measurement of Energy and Demand Savings (2014) *American Society of Heating, Refrigerating, and Air-Conditioning Engineers*	http://www.ashrae.org	Applied protocol for quantifying EE savings from EE projects and measures
ISO-NE Measurement and Verification of Demand Reduction Value from Demand Resources – Manual M-MVDR (2014) *Independent System Operator – New England*	https://www.iso-ne.com/static-assets/documents/2017/02/mmvdr_measurement-and-verification-demand-reduction_rev6_20140601.pdf	Applied protocol for quantifying and verifying the demand reduction value of EE programs, projects, and measures for the forward capacity market (FCM) administered by ISO-NE
NEEP Regional-Common EM&V Methods and Savings Assumptions Guidelines (2010) *Northeast Energy Efficiency Partnership*	http://www.neep.org/regional-emv-methods-and-savings-assumptions-guidelines-2010	Information resource and guide that describes best-practice approaches for quantifying gross energy/demand savings and identifying input assumptions for key EE program types
California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals (2006) *California Public Utility Commission*	http://www.calmac.org/publications/EvaluatorsProtocols%5FFinal%5FAdoptedviaRuling%5F06%2D19%2D2006%2Epdf	Applied protocol and guide that documents acceptable EM&V approaches and procedures for quantifying and verifying savings from California's EE programs and program portfolios

It should be noted that EM&V protocols and guidelines typically do not provide a step-by-step "recipe" for quantifying savings. The application of EM&V protocols and guidelines requires professional judgment and assessment of the EE activities to determine the appropriate EM&V method and assumptions to apply. For this reason, it is common for jurisdictions and utility EE implementers to clearly document how such protocols and guidelines are applied.

Glossary of Terms

This glossary includes only terms that are applied in this *EM&V Manual*.[38]

Accuracy: How close an estimate is to the true value it estimates. Accuracy can be used in reference to a point estimate resulting from a sequence of analytic steps, model coefficients, a set of measured data, or a measuring instrument's capability.

Additional savings (for energy or air quality planning): Energy savings additional to the savings explicitly or implicitly assumed in an energy or air quality policy baseline, such as the SIP emissions baseline.

Baseline condition: The efficiency level and operating conditions that would have occurred without the EE activity.

Baseline consumption: The electricity use that would have occurred at the baseline efficiency level and operating conditions.

Baseline efficiency: The efficiency level that would have been in place without implementation of a specific EE activity.

Code: Legal EE requirements that apply to the design and construction of buildings, usually for new buildings and for renovations and additions to existing buildings.

Code/standards baseline: A baseline corresponding to an efficiency level based on applicable federal, state, or local equipment standards or building codes.

Comparison group (EM&V method): Based on the differences in electricity use patterns between a population of premises with EE projects or EE measures in place and a comparison group of premises without the EE projects or EE measures; comparison group approaches include randomized control trials (RCTs) and quasi-experimental methods using nonparticipants and may involve simple differences or regression methods.

Compliance (Code): Meeting the code requirements and demonstrating that these requirements have been satisfied. Compliance is the responsibility of the builder or contractor.

Costing periods: Time blocks over which avoided costs are similar. Costing periods are typically defined by individual utilities, ISO, or RTO, and tend to be defined by combinations of time of day, day type (e.g. average weekday, peak weekday, weekend/holiday), month, and season.

Deemed formulas: Pre-specified formulas for quantifying savings, using some deemed parameters and some inputs that are specific to each project or measure.

Deemed parameter values: Pre-specified values of parameters that are applied to quantify savings using a deemed formula.

Deemed savings EM&V methods: An EM&V method that applies estimates of average annual electricity savings for a single unit of an installed EE measure; deemed savings values are developed from certain

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[38] Certain states, EE implementers, and other stakeholders may currently apply variations of these terms. For additional information, readers can consult the glossary of the SEE Action EM&V Guide (SEE Action, 2012b).

data sources and analytical methods that are widely considered: (1) acceptable for the measure, and (2) applicable to the situation and conditions in which the measure is implemented. Deemed savings methods can include deemed savings values, deemed formulas, deemed parameter values.

Deemed savings values: Pre-specified estimates of average annual electricity savings for an EE project or EE measure.

Derivation from annual savings shapes: Use a library of existing savings shapes established by simulation or other methods to estimate hourly savings from annual energy savings.

Direct measurement and verification (M&V) EM&V method: An EM&V method that uses onsite observations, engineering calculations, statistical analyses, and/or computer simulation modeling using measurements to determine savings from an individual EE project or EE measure.

Dual baseline: A baseline used for programs targeting early replacement; corresponds to existing efficiency up to the remaining useful life (RUL) of the existing equipment, systems, or construction; and to either code/standards or market baselines for new installations for the remainder of the effective useful life (EUL) of the EE activity.

Effective useful life (EUL): The duration of time an EE activity is anticipated to remain in effect with the potential to save electricity.

Electricity savings: The difference between electricity consumption with an EE activity in place and the consumption that otherwise would have occurred during the same period.

End-use metered data analysis: Estimate hourly energy savings using metering of the affected end use, together with engineering analysis. The ability to estimate savings for all hours of the year depends on the specific time period metered and whether this metering period can be credibly extrapolated to represent the full year.

Energy efficiency activity (EE activity): An EE measure, EE project, or EE program.

Energy efficiency measure (EE measure): A single technology, energy-use practice, or behavior that, once installed or operational, results in a reduction in the electricity use required to provide the same or greater level of service at an end-use facility, premise, or equipment connected to the delivery side of the electricity grid. EE measures may be implemented as part of an EE program or an EE project.

Energy efficiency program (EE program): Organized activities sponsored and funded by a particular entity to promote the adoption of one or more EE projects or EE measures that, once installed or operational, result in a reduction in the electricity use required to provide the same or greater level of service in multiple end uses, facilities, or premises.

Energy efficiency project (EE project): A combination of measures, technologies, and energy-use practices or behaviors that, once installed or operational, result in a reduction in the electricity use required to provide the same or greater level of service. EE projects may be implemented alone or as part of an EE program.

Engineering algorithms: Apply a formula to estimate peak demand savings based on characteristics of the installed equipment and its operating patterns.

Evaluation, measurement, and verification (EM&V): The set of procedures, methods, and analytic approaches used to quantify the impacts of EE activities, renewable energy, and other measures, to ensure that these impact estimates are reliable.

Ex ante savings: Projected savings prior to implementation of an EE activity.

Ex post savings: Savings determined after implementation of an EE activity.

Existing conditions baseline: A baseline corresponding to the efficiency level of equipment, systems, or construction in place prior to the EE activity.

Facility: All buildings, structures, or installations located in one or more contiguous or adjacent properties under common control of the same individual or organization.

Factor transfer: Apply factors from savings shapes developed in other territories to estimate peak demand savings from the quantified energy savings.

Gross savings: The difference in energy consumption with an EE project or EE measure in place versus the baseline consumption without the project or measure in place.

Hourly building simulation models: Estimate hourly energy savings by estimating consumption with and without the EE project or measure in place for each hour of a standard year, based on detailed specifications of building characteristics and operating conditions.

Incremental savings (e.g., for SIP compliance): *See Additional savings*.

Independent variables: Variables (e.g., weather, occupancy, production levels) that affect electricity consumption and savings, and vary independently of the EE activity under study.

Interactive effects: Indirect impacts of EE activities that increase or decrease the use of electricity or fossil fuels in end-use systems outside of the targeted end use. Interactive effects include "multi-measure effects" or equipment and facility improvement interactions, "other-system effects" or inter-end-use interactions, and "EE program overlap."

Load shape: The distribution of annual energy used over the year. It may be represented by the fraction of annual energy falling into each hour of the year.

Market baseline: A baseline corresponding to an efficiency level based on the common practice for new equipment or installations in the market.

Measurement: (a) The act of metering or monitoring, or (b) a measured or monitored metric (dimension).

Metering: The collection of energy-use data over time. These data may be collected at the end use, a circuit, a piece of equipment, or a whole building (or facility).

Monitoring: The collection of data relevant to how a piece of equipment operates, including but not limited to energy use or emissions data (e.g., energy and water use, temperature, humidity, volume of emissions, hours of operation).

Net savings: The difference in energy consumption with an EE program in place versus the consumption without the program in place.

Operating conditions: The conditions in which the EE project, measure or facility is operated, including but not limited to weather, occupancy, and hours of operation.

Peak demand savings: Energy savings that occur at the time of the electricity system's peak demand. Peak savings are typically quantified as the average hourly savings (kWh/h or kW) over the time block in which the system peak typically falls.

Policy baseline: A baseline corresponding to business-as-usual projected conditions (e.g., energy consumption, emissions) used to assess the effect of a potential new policy or policy change.

Post-installation operating conditions: The average operating conditions in the period after the EE activity is implemented, over the EUL of the activity.

Random error: Estimation errors occurring by chance that may cause an estimate (such as an electricity savings value) to be overestimated or underestimated with no systematic tendency in either direction, resulting from uncontrolled and unobservable factors affecting the underlying measurements.

Savings shape: The distribution of annual energy savings over the year. The savings shape may be represented by the fraction of annual savings falling into each hour of the year.

Site inspections: Site visits to facilities at which an EE project or EE measure was implemented. Inspections document the existence, characteristics, and operation of baseline or EE project equipment and systems and the factors that affect energy use.

Standards efficiency (baseline efficiency level): The efficiency level for the applicable federal, state, or local equipment standard or building code (if any) in place prior to the EE activity.

Stringent practice baseline (SPB): A baseline corresponding to the more stringent[39] of any applicable codes or standards, and the common market practice for the situation.

Surplus savings (e.g., for SIP compliance): *See Additional savings*.

Systematic error: Estimation errors that may cause an estimate (such as an electricity savings value) to be consistently either overstated or understated. Systematic errors are also referred to as bias, and may result from incorrect assumptions, a methodological issue, or a flawed reporting system.

Technical reference manual (TRM): Resource document that includes information used in program planning and reporting of EE programs. It can include savings values for measures, engineering algorithms to calculate savings, impact factors to be applied to calculated savings (e.g., net-to-gross ratio values), source documentation, specified assumptions, and other relevant material to support the calculation of measure and program savings—and the application of such values and algorithms in appropriate applications.

Time- and locational savings: Energy savings that occur at different times of the day (e.g., morning or evening), by season (e.g., summer or winter), or annually, or in a defined geographic area.

Time-differentiated savings: Annual savings split out by time period. The time periods may be broad costing periods, or may be individual hours for a year with a specified calendar.

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[39] Most stringent means requiring the lowest energy use.

Transmission and distribution (T&D) loss: The difference between the quantity of electricity that serves a load (measured at the busbar of the generator) and the actual electricity use at the final distribution location (measured at the onsite meter).

Verification (of EE project or EE measure installation): An assessment by an independent entity to ensure that the EE activities have been installed correctly and can generate the predicted savings. Verification may include assessing baseline conditions and confirming that the EE activities are operating according to how they were designed to operate. Site inspections, phone and mail surveys, and desk review of program documentation are typical verification activities.

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