Advanced Measurement and Verification (M&V) Implementation Resource Guide: Final (Commercial)

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Disclaimer

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1. Purpose of This Guide

This document is intended to serve as a resource for utility efficiency program administration and implementation partners who want to implement advanced measurement and verification (M&V) technologies to quantify energy savings. It can be used as an informational and best practice guide. While targeted for commercial building applications, the principles in this guide may also extend to industrial contexts.

This guide addresses the following specific questions:

- What is advanced M&V, what are its potential benefits, and where is it best applied?
- What advanced M&V tools are available, and what methods underlie them?
- What is best practice in implementing advanced meter-based M&V and documenting the results?
- What are key differences and similarities between residential and commercial applications?

Users of this guide are assumed to have professional experience with the M&V methods in common references such as the International Performance Measurement and Verification Protocol (EVO 2016) and ASHRAE Guideline 14 (ASHRAE 2014), utility program savings estimation, and impact evaluation. Familiarity with concepts surrounding building energy baseline modeling, model fitness, and uncertainty are additionally beneficial for those interested in the more specific technical aspects of the material.

2. Introduction to Advanced M&V

The terms *advanced M&V* or *M&V 2.0* are increasingly used to refer to the use of automated analytics in combination with higher granularity data to quantify project or program energy savings. *Higher granularity* may refer to increased sampling frequency, as in the transition from monthly to hourly energy consumption data, increased volume, or increased resolution in moving from whole-building to end-use level measurement from devices or submeters.

Many of the technologies that offer advanced M&V capability are not exclusively tools for energy savings estimation, but rather are multi-featured tools used to support various data-driven approaches to operational efficiency in buildings. These *energy management and information systems* or *EMIS* (an increasingly used term) may offer, for example, interval meter analysis and visualization, system-level fault detection and diagnostics, and benchmarking (Kramer et al. 2013), and afford significant operational savings with short payback (Granderson and Lin 2016). As the technologies have evolved over time and new technologies have emerged, some have been designed and targeted for use by utility program administrators. Those may support program tracking, customer screening, and targeting.

Advanced M&V offers many potential benefits in the context of utility program delivery. First is the ability to access more timely and detailed feedback on performance, i.e., achieved savings. The continuous and automated nature of advanced M&V means that rather than waiting until the end of a program or project, savings can be tracked as they accrue. This enables a practitioner to identify underperforming projects and provides an opportunity to make course corrections, potentially increasing savings realization rates. Second, the use of interval data provides a means to maximize the value of advanced metering infrastructure (AMI) investment, while also offering the ability to location- and time-differentiate savings. This “time- and location-dependent valuation” is becoming increasingly important as policy makers begin to distinguish between the relative value of a kilowatt-hour saved at one time of day versus another time of day, and in locations supplied with diverse generation mixes. It also has implications for understanding loadshapes, and buildings as grid assets with consumption patterns influenced by distributed energy resources.

A third potential benefit of advanced M&V is the ability to scale programs through process streamlining—particularly for whole-building level M&V that relies upon existing condition baselines. Opening the door to accurate whole-building M&V is critical to realizing the next “wedge” of utility program savings, as traditional measures that are relatively simple to deem or calculate begin to saturate. Less common program designs that include a combination of operational, commissioning, and behavioral measures—or multiple retrofit measures—promise to deliver deeper savings, and are also best suited to meter-based savings estimation using existing conditions baselines.[1] This is especially the case when combined with pay-for-performance incentive designs.

3. Advanced M&V Tools and Methods

Over recent years, the market has seen a marked increase in the availability of tools that offer advanced M&V capabilities. As described in Franconi et al. (2017), this array of tools can be understood according to five principal distinguishing characteristics:

1. *Sector focus:* Tools that offer advanced M&V capabilities may be designed for use exclusively in commercial, industrial, or residential buildings, or designed for multiple building types. Currently tools for commercial buildings are the most prevalent, followed by those targeted for use in industrial facilities, with some offerings intended for use in both sectors. It is expected that the number of advanced M&V tool offerings for the residential sector will increase in the near future.
2. *Primary design intent:* Many of today’s advanced M&V tools offer a diversity of capabilities that extend well beyond M&V—and M&V may be only one of many features and not the primary design intent of these tools. A majority of the commercialized tools that offer advanced M&V for commercial buildings are part of a broader set of technologies often referred to as energy management and information systems (EMIS). EMIS technologies comprise building- and portfolio-level meter analytics and, using supplemental data sources, may also tackle fault detection and diagnostics and automated HVAC system optimization. Building owners, energy managers, service providers, and program administrators use these technologies to identify operational and sometimes capital improvement opportunities. The technologies commonly offer a combination of automated data analytics, visualization, reporting, and control.
3. *Degree of automation*: Across the landscape of advanced M&V products, there is a spectrum of the extent to which the M&V is automated. Some products offer fully automated calculations, with little ability for users to configure baseline model parameters and form, while others may allow a higher degree of user input and more user-defined options. Fully automated tools do not require user expertise in data analysis or modeling; however, full automation may increase the difficulty of adding variables or adjusting parameters for a more refined result. Conversely, semi-automated tools offer

[1] Although there are trade-offs between magnitude of savings, duration of the baseline and performance period, and baseline model fitness, whole-building level savings estimation (with interval data) is *generally* recommended for cases in which a year of stable baseline data are available, and in which savings are expected to be greater than 5 percent.

more flexibility, but may not be accessible to all user types interested in tracking energy savings. Fully automated tools are more likely to be delivered as packaged software offerings with continuous data acquisition, higher-end graphics, and operational or other analytics in addition to M&V.

4. *M&V method:* Advanced M&V products use a diversity of M&V methods, or approaches, to calculate savings. For the most part, these methods are implementations of industry-standard approaches, such as those defined in the International Performance Measurement and Verification Protocol, or IPMVP (EVO 2016), in some of the Uniform Methods protocols (Li 2018), or those commonly used for efficiency program impact evaluation. Tools may differ in whether they describe what they calculate as gross or net savings, in the mathematical form and definition of the baseline that they use to determine savings, in their use of interval versus monthly data, or in their ability to operate on whole-building as well as sub-metered data. In addition, some tools are programmed to report accuracy metrics such as baseline model goodness-of-fit or estimations of savings uncertainty.
5. *Transparency*: The majority of tools that offer advanced M&V capability are proprietary, and not available through open-source code licenses. However, the tool developer may offer open documentation of the specific M&V methodology that is implemented even if the code itself is not publicly available, similar to the way current evaluation, measurement, and verification (EM&V) operates today. The degree of specificity varies, and may include method inputs, outputs, and analysis approaches or quantitative model definitions. The level and precise form of transparency and standardization that the industry will ultimately require of advanced M&V tools is an open issue and an ongoing topic of discussion among stakeholder groups.

In the rapidly advancing market of energy analytics software tools, new offerings are frequently becoming available, and existing technologies are being improved upon and evolving. Today's market is dominated by proprietary tools that target commercial buildings using IPMVP Option C and in some cases Option D.[2] However, the industry is moving to accommodate expanded combinations of the five distinguishing characteristics described above.

4. Best Practice Implementation

Suggested best practices for implementing advanced M&V are described below, including tool selection, data gathering and preparation, and practitioner workflows.

4.1 Tool Selection

As there are a number of advanced M&V tools available, with varying features and capabilities, practitioners must first select an offering that best meets their needs. The following key questions should be considered:

- Will there be desire to customize models; for example, to consider multiple alternate model forms or include a variety of potential independent variables?

[2] Free or open-source tools such as ECAM, Universal Translator 3, and RM&V are also available. The input to these tools comprises historic data files, as opposed to continuous meter data feeds.

- Can the tool be easily configured to output baseline model goodness of fit metrics? For example, R^2, CV(RMSE), NMBE are commonly used to judge baseline model fit, particularly for building/site-specific savings analyses.[3]
- Does the tool estimate the uncertainty[4] in calculated savings that is due to model error? (This is good practice if using monthly data, though reliable methods are not yet available for daily or hourly approaches).
- Will savings be reported for each building individually, or for an aggregated portfolio of buildings? Does the tool capability align with this intent?
- Is the tool capable of "batch mode" input of and analysis of data from many buildings, or is it configured to execute on one building at a time?
- Is it important that the tool accommodate continuous meter data feeds?
- Has the tool been vetted, for example in prior pilots, third-party testing, or by other means?[5]

Granderson and Fernandes (2017) provided a snapshot assessment of 16 commercially available technologies, characterizing their capabilities across 12 key elements. An excerpt of findings is included in Appendix A as an example of additional features that might be considered in tool selection. While this selection of technologies was representative of the advanced M&V market, it was not comprehensive. Moreover, it is important to recognize that inclusion of a given tool in the assessment did not represent endorsement.

4.2 Data Gathering and Preparation

Advanced M&V tools differ in their design, and therefore in the type and nature of data gathering and preparation that is needed. It is critical to ensure that sufficient resources are allocated to support data gathering and preparation, and tool-compatible formatting—particularly in the initial setup phase. Some issues that may require the attention of the practitioner are discussed below.

Meter data: It is important to ensure that the meter data that are input into the tool, and the tool's baseline modeling algorithm, are correctly mapped to utility accounts, building/project measurement boundaries, and loads served by the building and affected by the installed measures. That is, it is important to bear in mind that buildings may have multiple meters, and that installed measures may only affect the load at some of those meters. Similarly, on-site photovoltaics or other behind-the-meter generation should be identified. Additionally, while utility meters are often assumed to have (and often do have) high measurement accuracy, it is prudent to perform some validation check (automated or visual) to ensure that the data are sound.

Weather data: Some advanced M&V tools will provide services to import weather data and associate it with specific building sites and meters. Others require that the user obtain weather data as an input to the tool. The primary sources used for weather data include National Oceanic and Atmospheric Administration (NOAA) (free)[6], and Weather Underground (fee-based). Challenges that may be encountered in obtaining weather data include sufficiency in proximity of

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3 R^2 is the coefficient of determination, *CV(RMSE)* is the coefficient of variation, and *NMBE* is the normalized mean bias error. These metrics are used to characterize different aspects of model error. Formulas to compute these metrics can be found in common statistical references, and CV(RMSE) and NMBE are described in ASHRAE Guideline 14.

4 ASHRAE Guideline 14 describes this type of uncertainty (along with others) and how to calculate it.

5 For example, through CalTRack guideline compliance (http://docs.caltrack.org/en/latest/) or independent research project.

6 National Oceanic and Atmospheric Administration. National Centers for Environmental Information (NCEI). [Internet]. NCEI, 2018 [cited November 27, 2018]. Available from: https://www.ncdc.noaa.gov

the weather station and the facility, as well as data quality issues such as zero-value, missing, or otherwise faulty values.

Additional variables: Advanced M&V tools differ in whether their baseline models use a pre-specified set of independent variables, or whether they can accommodate user-specified variables (so long as those variables are available to the model from within the tool). Although research has shown that time of day, day of week, and outside air temperature are sufficient to model a large fraction of commercial buildings (for results specific to electricity see Granderson et al. [2015, 2106]), there may be buildings (or building types) for which additional explanatory variables are necessary to obtain reliable baseline models. These may include, for example, production or service-level data such as rooms occupied or meals served, or schedule-related information such as holidays or periods of low occupancy. These data are often difficult or costly to obtain, and often are considered in more custom calculations than those typically used in advanced M&V.

Baseline: For the meter-based analyses that are the foundation of advanced M&V approaches, it is critical to ensure that the implementation dates of each measure are well documented, so the meter data can be correctly divided into the appropriate baseline and performance periods for the savings analysis. Dates captured in program implementation documentation are often not precise enough for the purpose of defining the “pre” and “post” periods; in these cases it may be useful to crop one to two months of data from either side (i.e., before and after) the documented measure installation period, to be sure that data correctly reflect a stable baseline and performance period (see also *Develop the baseline model and review goodness of fit* in Section 4.3.1).

4.3 Recommended Practitioner Workflows

Implementation of advanced M&V commonly entails a practitioner working with a software tool. This practitioner may be a program administrator, implementer, or evaluator, an advanced M&V provider, or some combination of these stakeholders. This section highlights the workflows associated with best practice use of advanced M&V software and discusses considerations and potential differences in the process if using a portfolio aggregate approach, as opposed to building-by-building savings estimates.

4.3.1 General Case

The following elements are prerequisites to the advanced M&V process:

- A well-defined M&V plan that provides the basis for conducting the advanced M&V analysis.
- An advanced M&V tool that has been selected for use.
- Documentation of the dates that will be taken as the start and end of the baseline period, and as the start of the savings performance period (the project implementation period falls between the baseline period and the savings performance period).
- Target goodness of fit thresholds to assess baseline model fit. Commonly used values are $R^2 > 0.7$, CV(RMSE) < 25 percent, and NMBE between -0.5 and +0.5 percent.
- Regional or state requirements that pertain to meter-based M&V.

With these prerequisites in hand, the practitioner will proceed to use the advanced M&V tool, as suggested in the flowchart in Figure 1 and further described below.

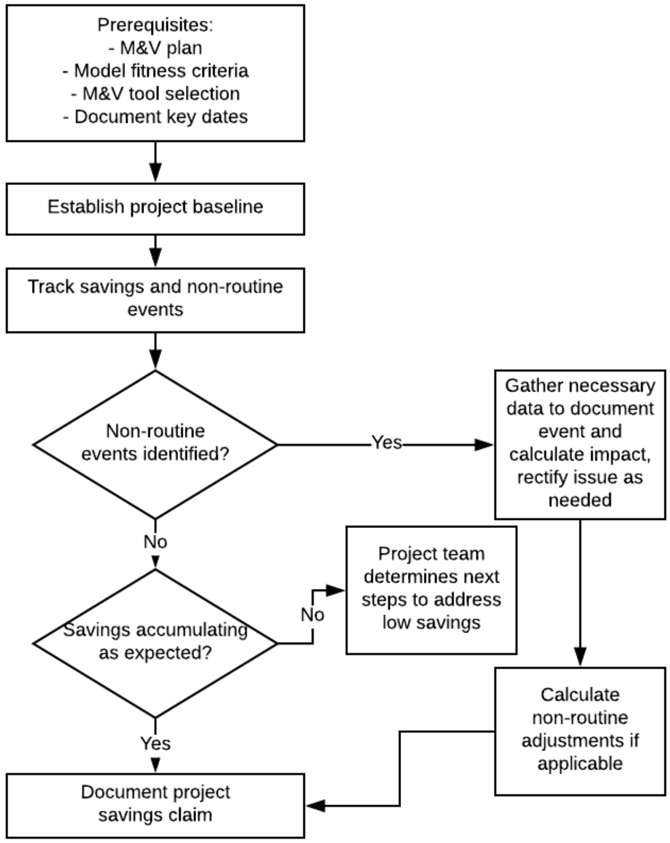

Figure 1: Schematic diagram illustrating recommended practitioner workflows using advanced M&V tools for a general case

Develop the baseline model and review model goodness of fit: For whole-building level M&V, common practice is to pair 12 months of energy consumption data with independent variable data. Advanced M&V applications typically use variables such as time of day, day of week, and outside air temperature. If 12 months of data are not available, check the independent variables' coverage factor[7] to assess whether the data represents a sufficient range of operating conditions (see also *"Coverage Factor Analysis"* in Section 5).

It is good practice to review model fitness statistics and visually review plots that contain time series of the baseline meter data, independent variable data, and the fit model, as illustrated in Figure 2.[8] Other charts that may be useful for visual review include scatter charts of consumption versus outside air temperature, or charts of residual values.

If model fitness metrics meet (or are close to) the fitness targets, and if the charts indicate that data are consistent and complete, proceed with the savings estimation process. If model fitness is too poor for use (in light of expected depth of savings, and tolerance for uncertainty), or if the plots indicate data quality problems, consider another model, additional/different independent

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7 An explanation of coverage factor can be found in Lawrence Berkeley National Laboratory's draft M&V 2.0 guidance, posted at http://eis.lbl.gov/auto-mv.html.

8 A primary objective of advanced M&V is to streamline the delivery and quantification of efficiency savings. However if deeper analysis is desired, additional plots that may be useful for visual review include scatter charts of consumption versus outside air temperature, or charts of residual values.

variables, or a different M&V method. (A poorer model fit may be acceptable for individual buildings if using an aggregated portfolio approach across many buildings; see Section 4.3.2).

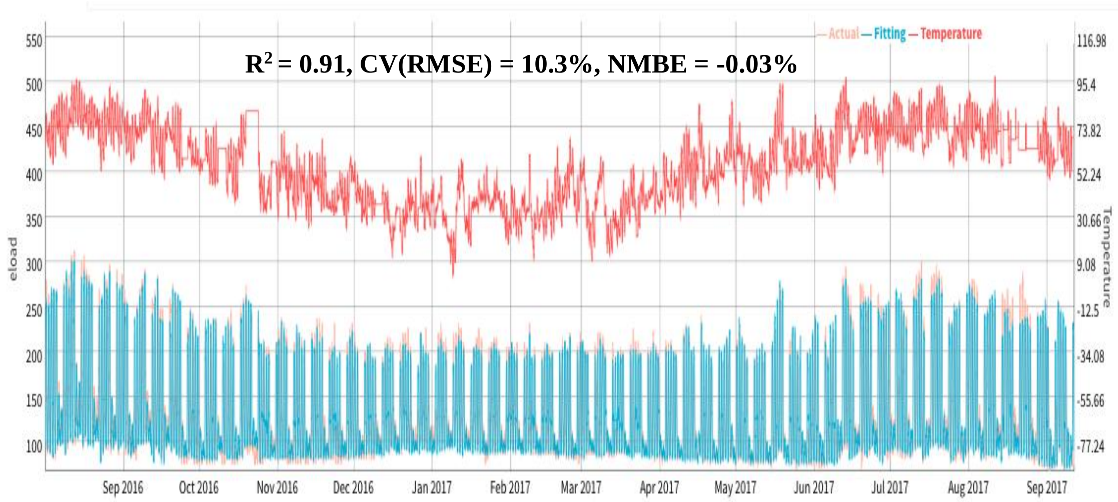

Figure 2: Example of a plot showing metered baseline data (pink), a fitted baseline model (blue), the independent variable (temperature, red), and the baseline model goodness of fit metrics R^2, CV(RMSE), and NMBE

Track savings and potential "non-routine" events: Establish a regular schedule (e.g., every 2–4 weeks) for reviewing savings as they accrue for the project site(s). Cross-check to-date savings data against expected savings, to determine whether they are in line with expectations. Savings that are unexpectedly low, or that "drop off" outside of seasonal or other anticipated variations, could indicate measures that have problems. Similarly, large changes in savings could indicate non-routine events. Robust identification and adjustments for non-routine events is one of the key unresolved issues in advanced M&V implementation, and is an area of ongoing work in industry and research (Touzani et al. 2019). Today's advanced M&V tools do not tend to explicitly address them. Appendix B provides additional information on defining and assessing non-routine events. Depending on which specific tool is used, a variety of visualizations may be provided to support this step in the workflow. Some example plots are shown in Appendix C.

Document savings: By the time the savings performance period has concluded it is important to ensure that documentation for *record keeping* purposes is complete. The level of detail may depend on the scale of the M&V effort, and the documentation can be conducted earlier in the process (for example as baselines are being developed). This documentation may also include information such as:

- Site name and address.
- Unique site ID information (utility identifier for site/account/customer).
- Baseline period start and end date.
- Independent variables' data source and location.
- Performance period start and end date (the date from which savings are tracked).
- Project information (e.g., measure descriptions, initial expected savings range if available, and project reference number if applicable).

Once the performance period has concluded (for whole-building M&V a 12-month or longer performance period is typical), the savings are also documented. If monthly data were used in the analysis, it is recommended to calculate the uncertainty in the savings that is due to model error. Although few advanced M&V tools provide this calculation, it is based on the savings estimate, model fitness in the baseline period, and the number of data points in the baseline and performance period; ASHRAE's Guideline 14 (ASHRAE 2014) is a useful reference, but its calculations should be used only for monthly data/models. The IPMVP's Uncertainty Assessment for IPMVP (EVO 2018) offers further guidance. Section 5 contains a more detailed discussion of recommended *technical* documentation to support third-party review of the savings analysis.

4.3.2 Portfolio Aggregation

Portfolio approaches that consider savings for an aggregated cohort of buildings (as opposed to building-by-building individual approaches) are a topic of increasing industry discussion and interest. Aggregation provides a means of reducing uncertainty in the final savings result, and of hedging against poor savings performance or model fit that may occur in some buildings. It also aligns with ambitions to deliver programs at new levels of scale. Aggregated savings analyses may be conducted in a number of ways. Buildings may be modeled individually, with savings summed for each, in a "bottom up" approach. Alternatively, comparison groups may be used to analyze changes in energy use between program participants and non-participants. Comparison groups are more commonly used in residential applications, due to challenges in defining meaningful comparison cohorts for non-residential facilities. Pooled regression approaches may also be used. These analyses fit a single model across a large group of buildings. The pooled regression works best when the buildings within the group are fairly similar.

The general workflow presented in Section 4.3.1 draws heavily from best practice and industry protocols and guidelines for single-building savings analyses. As such, elements of the workflow would change if using a portfolio aggregate approach. For illustration, potential variants to the workflow are provided in the paragraphs below, assuming a bottom-up summed savings aggregation approach. Although these illustrations are provided to acknowledge current areas of industry interest, it is important to note that formal guidance and requirements for aggregated approaches are still being defined.

Project record keeping: For larger scale cohort-based delivery models, project-specific record keeping may be conducted before, and separately from the savings analysis process. Due to the larger scale, it may also be the case that records are less detailed than for site-specific approaches.

Fitness metrics: For a portfolio of fairly similar buildings it is possible to compute a fitness metric that aggregates the fitness for each building in way that meaningfully reflects the fitness for the portfolio. However, this is a relatively new concept in the field, and there is not consensus on acceptable thresholds for these aggregated fitness metrics, as there generally is for single-building metrics. Similar to single-building analyses, if monthly data are being used, analysis of uncertainty due to model error provides further insight into the reliability of the result. Uncertainty for an aggregated savings result can be computed using published formulas.[9]

[9] By supposing that the results for each building are statistically independent, the fractional savings uncertainty for a portfolio is defined as:

$$\frac{\Delta E_{save}^{portfolio}}{E_{save}^{portfolio}} = \frac{\sqrt{\sum_{i=1}^{N}\left(\Delta E_{save}^{i}\right)^2}}{\sum_{i=1}^{N} E_{save}^{i}}$$

In this equation, E_{save}^{i} is the estimated energy savings in the post-retrofit period for building i and ΔE_{save}^{i} is the corresponding uncertainty in the savings.

Non-routine events: It is not yet clear how regulatory policy will evolve to address requirements for handling non-routine events under the aggregated portfolio approach. Some stakeholders have hypothesized that for large portfolios, it may be the case that non-routine events that decrease savings are counterbalanced by those that increase savings; were this true they reason that events would cancel out, making adjustments unnecessary. Studies have not yet been conducted to test this hypothesis. It has also been suggested that non-routine events could be addressed exclusively in, and not until, the impact evaluation stage, and this is also a matter of regulatory policy that may be treated differently in different regions.

Data inspection and visualization: Similar to *project record keeping*, depending on the size of the portfolio that is being aggregated, site-level data inspection and visualization might be conducted less frequently or for fewer buildings when pursuing a portfolio approach.

5. Documentation Guidance

Once the savings analysis is completed, savings results should be transparently documented to enable review. Suggested elements of this documentation are described below. Similar to the workflows that were presented in Section 4, these documentation principles may be aligned to the capabilities of specific advanced M&V tools used, and to the use of portfolio aggregated approaches.

Modeling Narrative:

- The mathematical form of the model(s), e.g., piece-wise linear regression, or artificial neural network.
- The dependent variables (e.g., therms, kilowatt-hours [kWh], whole building combined Btu) and the independent variables used to predict consumption; the logic for including the specified independent variables, as well as logic for excluding others.
- The time resolution (hourly, daily, etc.) of input data and output predictions.
- How missing, erroneous, or outlier data are handled.
- How the model is implemented, e.g., in a packaged tool (provide the tool name and provider name, version number), coded in R or SAS, or other implementation.
    - Whether the tool or method has undergone any validation tests.
    - Fixed versus user-defined model parameters.
- How the meters used in the savings analysis were mapped to accounts, premises, project measurement boundaries, and loads served in the building, as well as how any on-site generation was treated.
    - There are many possible configurations of buildings, customers, and meters, and this portion of the narrative addresses these practical complexities.
- Whether the meters used were utility account meters; and if not, any calibration process that were used to ensure data accuracy.

Coverage Factor Analysis: Coverage factor refers to the range in observed values of independent variables during the baseline period. Baseline model projections for values of independent variables that are beyond those observed in the baseline period may under- or over-estimate the counterfactual and associated savings estimates. For example, if a baseline model is constructed with baseline data that spans 50°F –75°F, it may not prove reliable in predicting consumption for 90°F conditions in the performance period. Analogous considerations apply to other potential independent variables, such as those related to production. The risk of insufficient coverage factor is commonly minimized by leveraging a 12-month minimum baseline period to capture annual variations in the baseline model's independent variables. If less than 12 months data are used, or if there is other reason to question sufficient coverage factor:

- Analyses may leverage ASHRAE Guideline 14 (ASHRAE 2014), which advises: *"Apply the algorithm for savings determination for all periods where independent variables are no more than 110% of the maximum and no less than 90% of the minimum values of the independent variables used in deriving the baseline model."*
- Alternative or enhanced assessments of coverage factor may also be presented, with explanation sufficient to justify the approach.

Modeling and Savings Plots:

- A list and description of measures implemented and dates of implementation is useful to accompany the plots to provide interpretive context; these may be accompanied by a description of any measure verification activities that were conducted.
- A plot of the baseline period, as in Figure 3, that shows
  - Metered baseline data
  - The fitted baseline model
  - The independent variables
  - The model fitness metrics, e.g., CV(RMSE), NMBE, and R^2
- A plot of the post-measure performance period, as in Figure 4, that shows
  - The projected baseline model and the metered data, and/or the residual, i.e., the difference between the projected baseline and the metered data
  - The independent variables used in the baseline model and projection
- Inclusion of additional plots such as plots of residuals or scatter plots of consumption versus independent variables could be included to supplement fitness statistics, and modeling narratives and to facilitate review and evaluation.

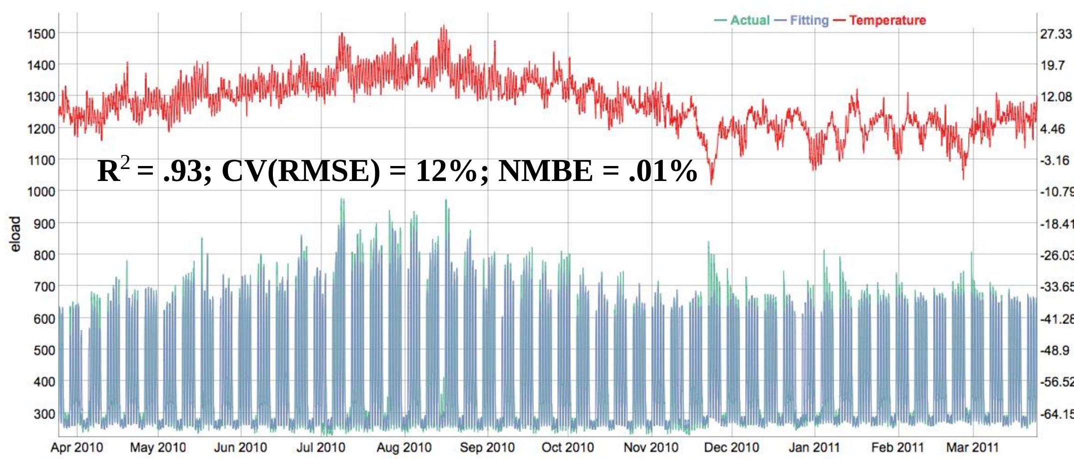

Figure 3: Example of a plot showing metered baseline data, a fitted baseline model, the independent variable (temperature), and the baseline model goodness of fit metrics R^2, CV(RMSE), and NMBE

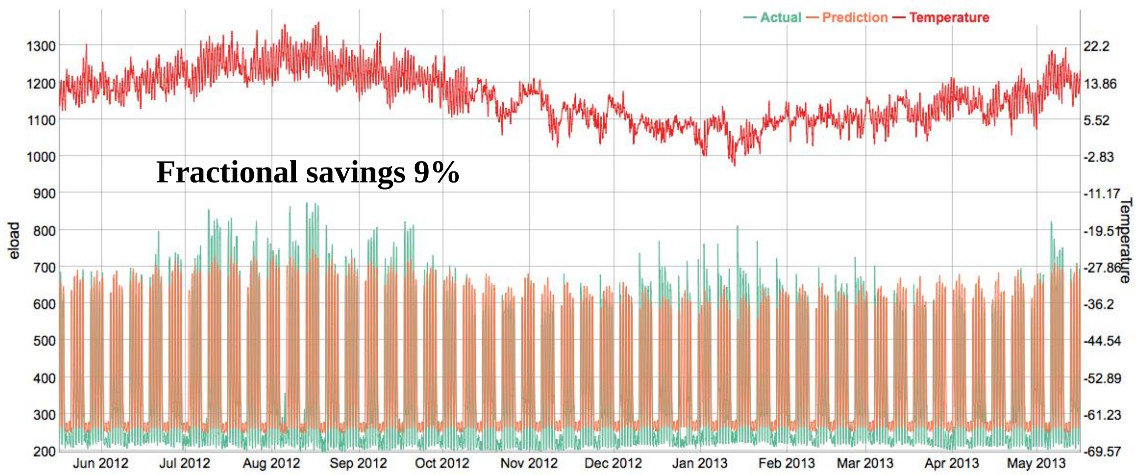

Figure 4: Example of a plot showing metered data, the projected baseline model, the independent variable (temperature), and the fractional savings (avoided energy use)

Savings Summary Information:

- Meter-based avoided energy use (prior to any non-routine adjustments), and if monthly modeling was used, the uncertainty due to model error at a specified confidence level.[10] Commonly, 90 percent confidence is used, but others may be desired for a specific application context.
- A description of any non-routine events that occurred and accounting of non-routine adjustments that were made; documentation should enable review of the adjustment, calculations, or models used, and describe or provide the data used in the analysis.
    - Annotated plots of data are useful for third-party reviewers.
- Adjusted savings, after accounting for non-routine events.
- Data, calculations, models, and tools must be sufficient to enable review by a third party; for many model types, provision of coefficients can support replication of results.

6. Getting Started with Advanced M&V

Application of advanced M&V will vary based on program/regulatory requirements, the tools and services used, available resources, risk tolerance, and other factors. This guide provides an overview of the advanced M&V process and best practice recommendations, and suggests other resources that may be helpful in using advanced M&V. While the M&V steps are straightforward, and accurate software tools are available, it must be understood that there is a learning process involved in applying the process. References such as (Goldman 2018) were designed explicitly to assist in determining whether advanced M&V can potentially address context-specific problems in efficiency programs.

It is strongly recommended to take a collaborative process when planning programs or pilots that will use advanced M&V. Early and continuous collaboration among stakeholders can help ensure, for example, that meter and other data will be accessible in a consistent format, that data management and confidentiality requirements are addressed, and that reporting and

[10] Specific program requirements may further require that savings claims include normalization to typical weather conditions, or incorporation of expected useful lifetime.

documentation will meet internal stakeholder and regulatory needs. Implementers of advanced M&V should plan to dedicate time and resources for data collection, review and interpretation of results, and follow up to address performance issues that may be identified. These resources are likely worth the investment, but must be allocated to ensure that maximum benefit is derived from the process.

Pilots can be a useful way to get started with advanced M&V, and (Crowe at al. 2019) summarizes results and lessons learned from a pilot conducted in partnership with the Connecticut Department of Energy and Environmental Protection, Eversource, United Illuminating, Northeast Energy Efficiency Partnerships, and Lawrence Berkeley National Laboratory. Finally, the initial pilot or program planning process can be further enhanced by considering how to fully leverage the benefits of advanced M&V methods, for example by sharing ongoing savings data with customers, obtaining early feedback on project performance, or capturing time-of-use changes to loadshapes.

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Appendix A. Characteristics and Capabilities of Tools that Offer M&V 2.0

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
Lucid, BuildingOS	Commercial	Building or portfolio owner / manager / operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option C Whole Building	Machine learning (ensemble approach combining nearest neighbors)	Interval	CV(RMSE), R^2, AIC, BIC, Adjusted R^2, t-values, and confidence intervals	User	NA	NA	Independent variables, baseline time period, type of model	Yes
Gridium, Snapmeter	Commercial, Industrial	Building or portfolio owner / manager / operator	Interval meter analytics and visualization, Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option C Whole Building	Non-linear model, advanced regression including a near term for drift	Interval	CV(RMSE), R^2, MAPE	Back end	No	Yes	Baseline time period	No, prefer to keep proprietary
Buildings Alive, Rapid Energy Feedback	Commercial	Building or portfolio owner / manager / operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Machine learning (Support vector machine and Random forest)	Interval	CV(RMSE), R^2, Skewness, standard deviation	Back end	Yes	No	Baseline time period	No, prefer to keep proprietary
Cascade Energy, Sensei Energy Efficiency Software	Industrial	Utility program administrator, Building or portfolio owner / manager / operator	Interval meter analytics and visualization, Customer engagement	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear model	Monthly, Interval	CV(RMSE), R^2, NMBE, Standard Error, Auto-correlation coefficient	Back end	Yes	Yes	Independent variables, Choice of fitness metrics, Baseline time period, Type of model	No
Rodan Energy Solutions, Energent EMIS Solution	Commercial, Industrial	Building or portfolio owner / manager / operator	Interval meter analytics and visualization	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear regression of multiple variables (9 independent variables)	Monthly, Interval	CV(RMSE), R^2, NMBE, F values	Back end	Yes	No	Independent variables, Baseline time period	Not yet considered
Bractlet, Advanced measurement and verification	Commercial	Building owner / manager / operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option D Calibrated Simulation	Physics-based simulation with machine learning on submeter data to calibrate the model	Monthly, Interval	CV(RMSE), NMBE	User	Yes	Yes	Independent variables, Baseline time period, Choice of fitness metrics	Yes

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
EnergyCAP, EnergyCAP cost avoidance module	Commercial	Energy efficiency service provider, Building or portfolio owner / manager / operator	Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building	Linear model with variable base degree days	Monthly	R^2	User	Yes	No	Baseline time period, Degree day balance point temperature	Yes
eSight Energy, Esight Platform	Commercial, Industrial	Utility program administrator, Energy Efficiency Service Provider, Building or portfolio owner / manager / operator, Operations / plant manager / director / supervisor	Interval meter analytics and visualization, Measurement and verification, Program tracking	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear, Multi variable linear	Monthly, Interval	CV(RMSE), R^2, N and P values	User	Yes	No	Baseline time period, Independent variables	Yes
EnergySavvy, M&V 2.0 and program optimization	Small commercial, Residential	Utility program administrator	Customer screening and targeting, Measurement and verification, Program tracking	IPMVP Option C Whole Building	Linear and Machine learning (Random forest for bias correction)	Monthly, Interval	CV(RMSE), R^2	Back end	No	Yes	NA	Yes, available for the public
Ecova, Efficiency Track	Commercial, Small commercial	Utility program administrator, Building or portfolio owner / manager / operator	Customer screening / engagement, Measurement and verification	IPMVP Option C Whole Building	Linear and machine learning	Monthly, Interval	$R^{2,}$ CV(RMSE), NMBE	Back end	No	No	Independent variables, Baseline time period, Choice of fitness metrics	No, prefer to keep proprietary
BuildingIQ, Automated Measurement & Verification	Commercial, Small commercial	Energy efficiency service providers, Building or portfolio owner / manager / operator	Interval meter analytics and visualization, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear and machine learning (Support vector machine), Advanced regression including a term for thermal mass	Interval	R^2, RMSE, NMBE, confidence intervals	User	Yes	No	Independent variables, Baseline time period, Type of model	No, prefer to keep proprietary
Open energy efficiency, OpenEEmeter	Small commercial, Residential	Utility program administrator, Energy efficiency service provider	Measurement and verification, Program tracking	IPMVP Option C Whole Building	Linear	Monthly, Interval	CV(RMSE), R^2	User	Yes	Yes	Choice of fitness metrics, Baseline time period, Type of model	Yes
PSD Consulting, Building Performance Compass	Commercial, Small commercial, Residential	Utility program administrator	Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building, IPMVP Option D Calibrated Simulation	Linear, (piecewise linear), Physics based simulation	Monthly, Interval	CV(RMSE), R^2	User	Yes	Yes	Independent variables, Baseline time period, Type of model	Yes

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
Universal translator 3	Commercial	Utility program administrator, Building or portfolio owner / manager / operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option C	Linear	Interval	CV(RMSE), R^2	User	No	Yes	Type of model	Yes
FirstFuel, First Engage/ First Advisor	Commercial, Small commercial	Utility program administrator	Interval meter analytics and visualization, Customer screening/ engagement, Energy disaggregation, Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building	Machine learning	Monthly, Interval	CV(RMSE), R^2, NMBE	User	Yes	Yes	NA	No, prefer to keep proprietary
Envizi, Program reporting, Measurement and verification	Commercial	Energy Efficiency Service Provider, Building or portfolio owner / manager / operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building, IPMVP Option B Retrofit Isolation	Linear	Monthly, Interval	R^2, Adjusted R^2, Standard error, p-value, t and f statistic	User	No	No	Independent variables, Choice of fitness metrics, Baseline time period	Not yet considered

* Transparency indicates the tool provider's willingness to document the M&V algorithm in further detail and make it available publicly.
AIC = Akaike information criterion; BIC = Bayesian information criterion; MAPE = mean absolution percent error,

Appendix B. Additional Reference Information on Non-Routine Events

Non-routine changes in building energy use are those that are not attributable to changes in the independent variables used in the baseline model, or to the efficiency measures that were installed. In the case of a non-routine event, the savings determined by subtracting the metered use in the performance period from the baseline-predicted load may have to be adjusted to accurately determine the savings due to the installed measures. Figure B-1 illustrates the presence of a potential non-routine event, as indicated by the building load profile.

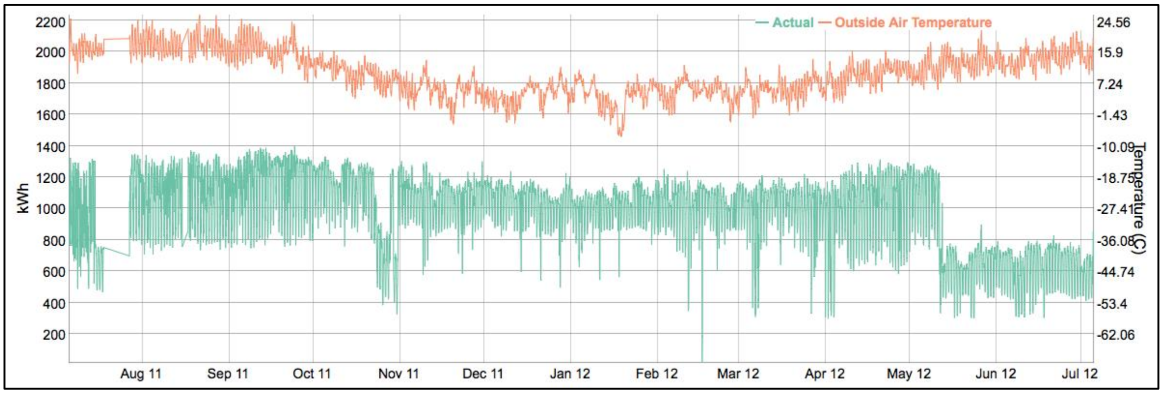

Figure B-1: Approximately one year of metered electric load data (green) and outside air temperature (orange); the change in load in mid-May does not appear to be correlated with weather, and could indicate the presence of a non-routine reduction in consumption.

Some of the more frequently encountered types of non-routine events in commercial buildings include, but are not limited to the following:

Services	# of rooms/beds
	food cooking/preparation
	# of registers
	#of workers
Equipment Loads	# of computers
	# of walk-in or standard refrigeration units or open and closed cases
	# of MRI machines
	# or capacity of HVAC units
Operations	hours of operation
	weekend operations
	heating and cooling setpoints
	system control strategies
Site Characteristics	size
	% of building heated and cooled
	envelope changes

Non-routine events may be characterized as temporary or permanent, as load added or removed, and as constant or variable. A framework of assessing non-routine events may include the following considerations:

1. Determine whether an event is present.
2. Determine whether the impact of the event is material, meriting quantification and adjustment (the threshold for what is considered "material" should be specified in the M&V Program Plan).
3. Determine whether the event is temporary or permanent. Temporary events may be removed from the data set; however, no more than 25 percent of the measured data should be removed, per ASHRAE Guideline 14, provided that a justifiable reason is provided.
4. Determine whether the event represents a constant or variable load.
5. Determine whether the event represents an added or removed load.
6. Based on 3–5 above, the approach to measuring and quantifying the impact of the event may be determined.

General notes on non-routine events:

- Several methods may be used to determine whether an event is present or has occurred. These include but are not limited to inspection of meter data, time series change detection or breakout analysis, periodic site visits and short-term measurements, and site surveys.
- Determination of whether the impact of the event is material, and therefore whether an adjustment is needed, depends on engineering expertise; this might be addressed in the M&V Program plan.
- Permanent events are those that are expected to last through the duration of the M&V analysis period.
- Constant loads are those that do not fluctuate or change during a period of interest, such as the 'on' state of operation.
- Added loads are those that increase site energy consumption, while removed loads decrease site energy consumption.
- Analogous to detecting the presence of an event, several methods may be used to quantify the impact or magnitude of the event. These include but are not limited to, engineering calculations, IPVMP Options A and B, simulation models, time series analysis, and the use of indicator variables in models fit to data before and after the event.
- Non-routine adjustments must be applied without bias, including adjustments that increase savings as well as those that decrease them.

Appendix C. Savings Tracking Visualization Examples

The following plots illustrate a variety of visualizations of the type that can be used in the savings tracking stage of the advanced M&V application workflow.

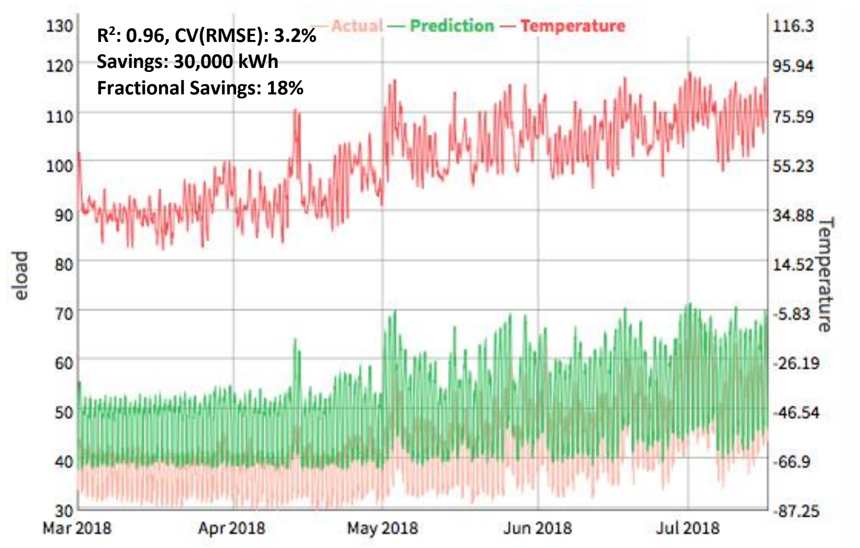

Figure C-1: Example of a plot for post-measure performance period showing metered data (orange), the projected baseline model (green), and the independent variable (dry bulb temperature, red). Actual data are consistently lower than predicted, indicating the occurrence of savings.

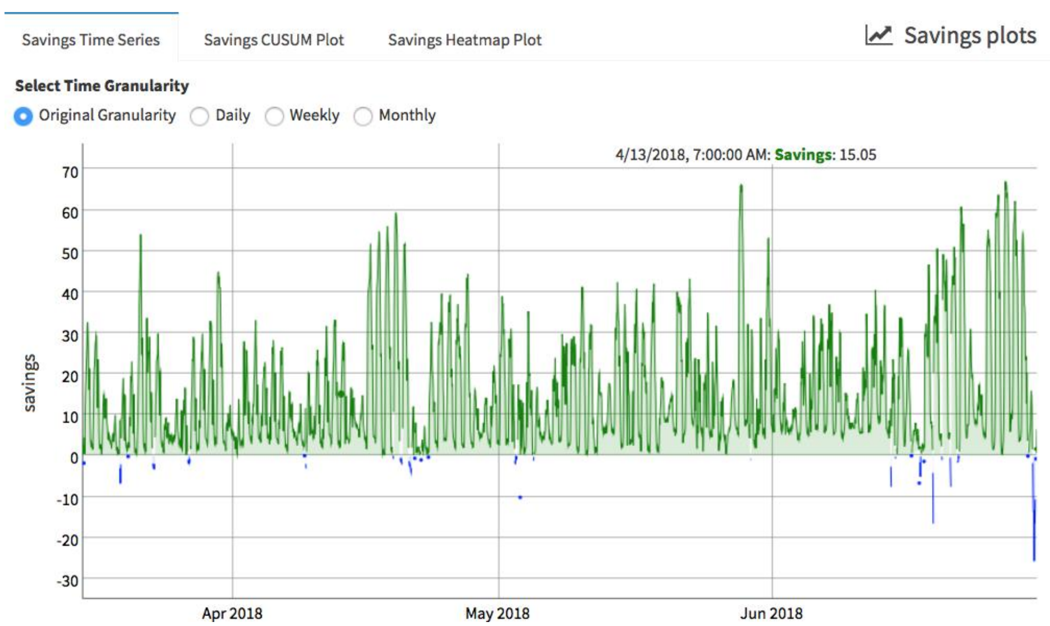

Figure C-2: Time series chart of hourly savings (baseline projected use minus actual metered consumption). Green indicates points in time when savings are being generated, while blue indicates negative savings (actual consumption is above baseline prediction). This example shows values for each hour, but chart data may be aggregated to daily, weekly, or monthly totals.

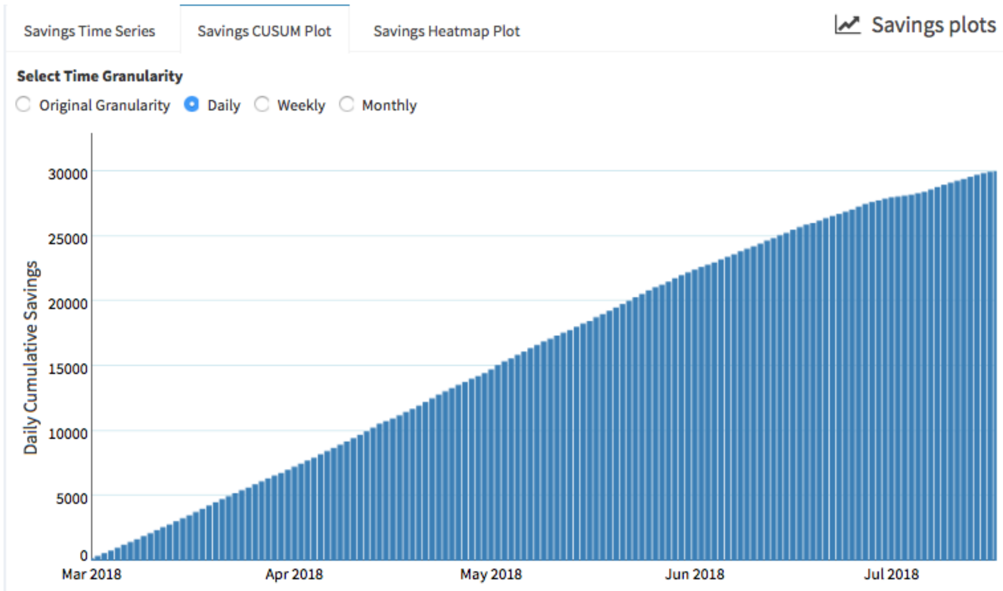

Figure C-3: Example of a cumulative sum (CUSUM) plot of daily savings in kWh. A positive slope indicates positive savings versus baseline consumption (pictured), a flat slope would indicate no savings, and a negative slope would indicate an increase in energy use versus the baseline.

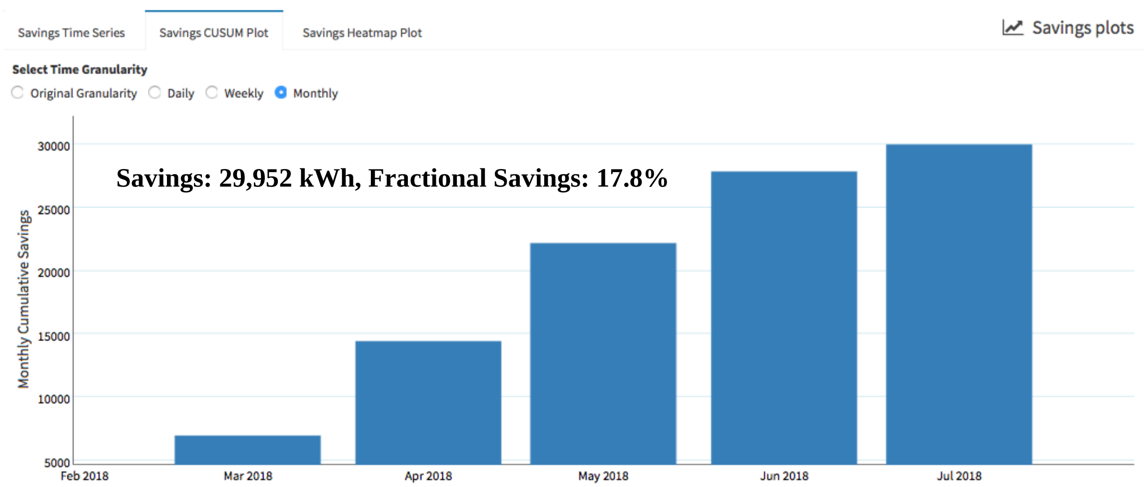

Figure C-4: Alternate CUSUM chart option, indicating monthly cumulative savings, as opposed to daily cumulative savings.

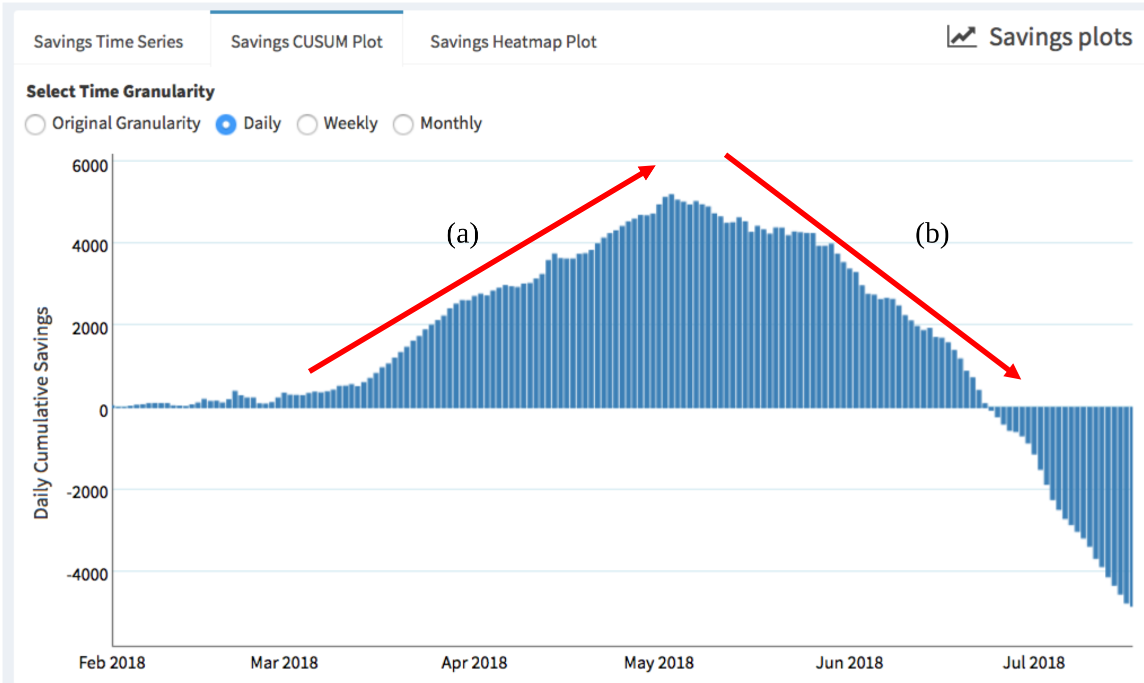

Figure C-5: CUSUM chart illustrating cumulative energy savings until May 2018 (a), at which point something occurs and savings begin to decrease (b). This type of change may be cause for further investigation to determine whether the cause is attributable to a non-routine event, a failed measure, or perhaps something else.