Rapid-Response M&V: Creating Feedback Loops for Improved Energy Efficiency Program Results

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ABSTRACT

This paper proposes a rapid, embedded M&V framework for an energy efficiency program implementing operational and maintenance measures in small and medium businesses across 20+ utilities. The approach leverages granular, 15-minute AMI data, updated daily, which is ingested, organized, and run through data filters to identify building performance opportunities through operational improvements like equipment scheduling and setpoint adjustments.

Upon confirmed implementation, facility data enters a unique M&V process that not only evaluates but also regularly monitors savings. An automated process runs full building models five nights a week using updated data, and checks for predefined flags related to extraordinary energy consumption changes or savings trends. These flags are triaged by the M&V team for follow-up with facility contacts. Time-sensitive discussions and AMI data reviews help M&V teams account for Non-Routine Events (NREs), ensuring accurate savings. All facility data is reviewed monthly, regardless of automated flags. And savings data is shared with participants to encourage their activities. Timely results promote buy-in, and reversion detection ensures robust measure implementation for utility savings portfolios.

Drawing from reviews of flagged issues, and M&V theory, this paper analyzes how this method improves energy savings calculation reliability and maximizes efficiency program impact and how rapid, accessible results combined with regular follow-up create feedback loops promoting energy efficiency.

Background and Introduction

Traditional Measurement and Verification (M&V) approaches review projects with an eye towards quantifying the savings from implemented energy efficiency projects. Industry standards coach analysts on statistical rigor, operational coverage and defensible final savings values but often focus on M&V as the end of the implementation process. While extremely valuable, these processes face challenges in capturing dynamic issues and create a lag between implementation and the detection of performance problems, typically at times when this detection can be most valuable. As AMI data continues to provide increasingly powerful opportunities for energy efficiency there is a need for it to translate into real-time feedback within energy efficiency programs.

Rapid response M&V complements end-of-the-line savings with ongoing monitoring of implemented projects to ensure that implementations are comprehensive (capture all possible savings possible within program scope) and in place (driving energy savings as expected), and non-routine events are caught early when information is most available and corrective paths are most apparent.

Power TakeOff has been working to leverage AMI data access into actionable, lasting savings for 10+ years. Our Virtual Commissioning™ program integrates with utilities to ingest regular, ongoing, data connections. We analyze commercial customer AMI data profiles, run data through proprietary analytics, and utilize robust processes for outreach and engagement to provide low and no cost operational savings in traditionally hard to reach customer segments. Historically operating as a custom program, we have had to quantify the energy savings impacts from the changes we are helping customers to make across hundreds of sites annually. To handle this we have built significant internal M&V capacity, running thousands of projects through IPMVP Option C (whole facility metering) regression models to capture statistically significant savings values using industry standard protocols. As these capabilities have grown and developed we have leveraged our data access and engagement strategies to tie together rapid response M&V and customer feedback loops, driving savings and model accuracy even beyond initial implementations.

To demonstrate the power of these processes and encourage others to pair rapid response M&V with traditional approaches, we will explore our methodology, and the impact we feel it provides. We will explore the timeline and scale of implementations as well as our data analytic processes and our modeling methodologies, all within the context of our focus on non-behavioural operations and maintenance measures. We will then review case studies from our work where rapid response M&V and feedback loops have created tangible impact, protecting and creating defensible long term savings.

Opportunity Through AMI

Advanced Metering Infrastructure (AMI) has seen a rapid increase in adoption over the last 10 years, outpacing traditional metering options. Between 2014 and 2023, the U.S. saw a 118% increase in AMI meter count, compared to a total meter increase of 15%. With ongoing replacement and reduced uptake for Standard Meters and Automated Meter Reading (AMR) meters, AMI metering now accounts for 77% of total meters in the U.S., including 73% of all Commercial meters, and 75% of all industrial meters.

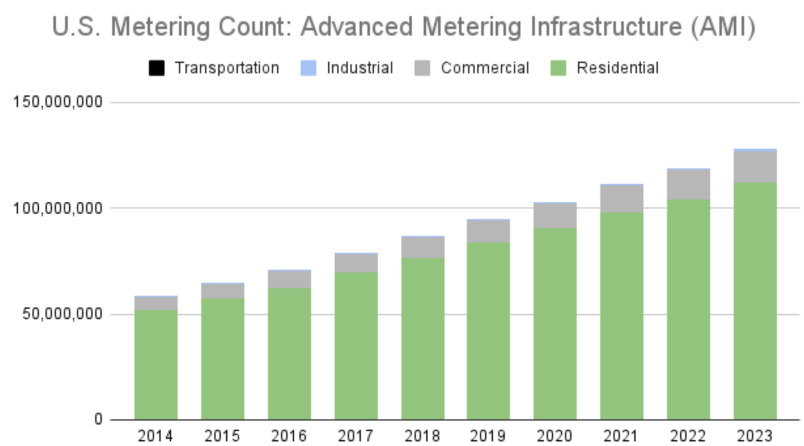

Figure 1. Growth in AMI metering count in the U.S. from 2014 – 2023. *Source:* U.S. EIA 2024

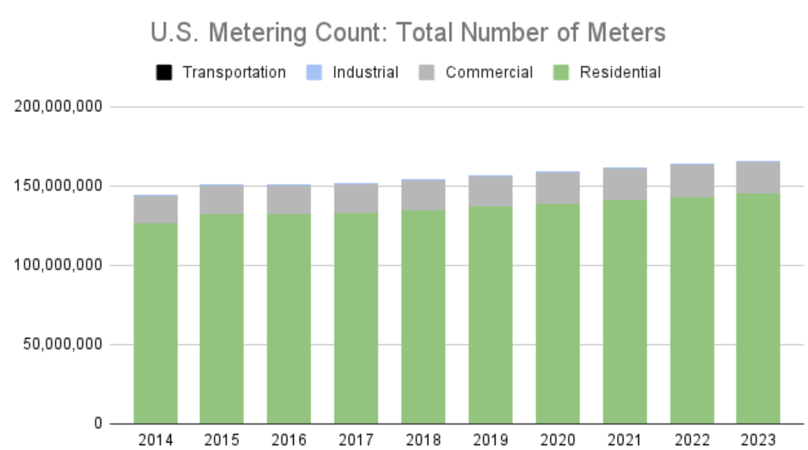

Figure 2. Growth in total utility, electrical meter count in the U.S. from 2014 - 2023 *Source:* U.S. EIA 2024

AMI data presents significant opportunities for energy efficiency program implementers, allowing for detailed reviews of building usage patterns and revealing opportunities hidden behind monthly bills. However, there is also opportunity after implementation.

In part, this opportunity lies in simplified, scalable savings calculations for M&V. The International Performance Measurement and Verification Protocol (IPMVP) presents 4 options for M&V; A, B, C & D. Options A & B focus on creating boundaries and isolating savings in specifically impacted equipment, and suffer from the unavailability of adequate data and/or the expense of collecting it. Option D allows for complicated, expensive, building simulations that toggle on and off changes to calculate expected savings from improvements. Option C (Whole Facility) allows for capturing the savings within whole building data, requiring as little as a single, whole facility, metering point to assess savings from either a single measure, or full suite of changes. Because Option C requires removing noise (variance in energy use not explained by the energy efficiency project) from the whole facility data, to properly isolate the savings, while accounting for changes in consumption that aren't a result of the change being evaluated, regression models are common practice. Given inherent uncertainty in regression modelling, conventional wisdom has been that, given monthly data, savings calculations are only considered reliable when savings depth is greater than 10% (i.e. annual savings are 10% or more of annual usage). With the increased adoption of, and access to, more granular data through AMI metering that convention has begun to change. The IPMVP has provided conservative guidance that savings of 5% can be reliably measured when using hourly data. Additionally, research has shown that it is possible for models to detect savings as low as 3% savings of facility consumption while maintaining adherence to best practices for model fitness (Kelly and Sinnamon 2020). These advantages allow for Option C to be used in even more M&V scenarios, reducing cost and data burdens traditionally associated with M&V when using options A, B and D.

AMI data presents additional opportunities after implementation, with rapid response M&V. The same granular data that sheds light on building consumption patterns to reveal energy savings opportunities, can also reveal the energy savings themselves. Visual verification of savings (altered usage patterns visible in AMI data) can provide confidence in implementation (especially in cases where operations & maintenance, and behavioural savings are shifting usage patterns) well ahead of the time where savings calculations can be accurately compared against expectations. More granular data from AMI metering typically means that data frequency increases. With proper integration data can be collected daily, providing continuous updates to analysis, rather than once per month in traditional billing analyses.

Scope

While applicable to many program types, this rapid response M&V framework and methodology has been developed and fine tuned within the context of Power TakeOff's Virtual Commissioning program. This program leverages AMI data to find low and no cost operational improvement opportunities to building consumption through HVAC and lighting scheduling changes, setpoint changes, and a variety of other non-behavioral opportunities involving programmable controls. Primarily targeting small and medium commercial buildings, the program has generated hundreds of millions of kWh savings across thousands of facilities over the last 7 years, in 20+ utilities across the US.

The focus on AMI data for finding energy savings opportunities has necessitated a robust data integration process and system. We receive revenue grade, AMI meter data directly from utilities through automated, daily processes and securely store it, satisfying rigorous utility requirements.

A typical project implementation starts with automated reviews of data and eligible candidates with the strongest opportunities for savings, are engaged virtually by the implementation team. Once a contact confirms that they have implemented all or some of the recommendations, the project moves into our M&V framework. Projects in the M&V phase benefit from rapid feedback loops between M&V and implementation staff. Savings are considered verified and projects move out of M&V when the post implementation (reporting) period has enough data to provide insight covering the full operational cycle as it pertains to both the measure and building.

Typical timelines for this full cycle is as follows;

- 1 week in automated opportunity identification and prioritization
- 3 - 4 month engagement cycle
- 1 day to 1 week implementation period
    - Can be as simple as a one-time adjustment to the building automation system
- 3 - 18 month M&V period

While it is clear that projects often spend the majority of their lifespan in M&V and performance monitoring, this is the stage that is most often neglected by analysis, resources and attention. Our rapid response M&V framework is working to close that gap.

Rapid Response M&V Framework

The rapid response M&V framework we employ consists, at a high level, of the following components;

- Data Cleanup
- Regression Analysis
- Automated Model Runs & Alerts
- M&V Analyst Ongoing Review
- Feedback Loops Between Building Contacts and M&V

Data Cleanup

Given how critical the ongoing flow of reliable data is to this framework it must start with data cleanup and infrastructure. The program relies on sub-hourly advanced metering infrastructure (AMI) electric interval data for all eligible participants fed on an ongoing basis into the process. Missing data can be identified at many points throughout a project's lifecycle. Once a project has begun modeling, data sufficiency is required to accurately model energy savings. The amount of data that is sufficient is typically project dependent. A project with very high savings and a long reporting period can have more periods of missing data than a project with smaller savings (more sensitive to uncertainty) and with little reporting period data. We attempt to fill in missing data following standard missing data procedures like omission or interpolation. Potential outliers are manually reviewed for cause and are typically treated the same way as non-routine events. Cause for outliers may be meter errors, power outages, or other non-routine events. They are manually identified and treated on a case-by-case basis, with guidance from the IPMVP's application guide on non-routine events and adjustments. Other key considerations include; accounting for time zones, daylight savings shifts, and understanding whether data is labeled as interval starting, or interval ending. The framework also relies on outdoor, dry-bulb, temperature as a key independent variable in our regression analysis. As such, it is key that weather data is available and can be integrated into the infrastructure with near-real time availability, in line with the AMI data.

Regression Analysis

Using an IPMVP Option C regression modeling approach, in which baseline (12+ months pre-implementation) and reporting periods (time post-implementation) are modeled to understand the relationship between relevant variables and building consumption, is core to the rapid response M&V framework. To simplify and scale our framework we choose to apply a consistent methodology across all projects, adding in non-routine adjustments (NRA's) as indicator variables, or through data omission, as needed. Following the methods proposed by Mathieu et al. (2011) and the Lawrence Berkeley National Lab, we incorporate hour-of-week indicator variables and binned temperature features into our regression model. These techniques offer flexibility in capturing the temporal and climatic patterns of energy use without requiring explicit occupancy or equipment scheduling data. The hour-of-week terms effectively absorb recurring occupancy trends, while temperature bins model non-linear load responses to outdoor air temperature, facilitating weather-normalized M&V consistent with Option C principles. This methodology is especially useful in modeling commercial buildings with consistent operating patterns week-to-week.

Regression models are assessed against industry standard statistical fitness metrics (NMBE (Normalized Mean Bias Error), CV(RMSE) (Coefficient of Variation of the Root-Mean-Square Error) & FSU (Fractional Savings Uncertainty) with thresholds based on industry guidelines discussed in Ashrae-14, the IPMVP Core Concepts guides, and the Lawrence Berkeley National Lab's Site-Level NMEC Technical Guidance. Not only do they allow for appropriate, defensible savings claims but they also aid in performance analysis through model residuals, savings comparisons, and visual identification of changes.

Automated Model Runs & Alerts

Our software tools and data infrastructure allow us to ingest building information and implementation dates and details, alongside AMI and weather data, for initial modelling by M&V analysts. Once set up, these models are run automatically, 5 nights each week, with updated AMI and weather data. Baseline periods will typically remain static while reporting periods continue to add data that provides further insight into the impact of the energy efficiency implementation.

To actualize the value from granular additions to performance analysis, without overburdening analysts, alerts are set up that generate automated flags if any predetermined conditions are met. These flags include;

- Savings drops below previous analyst review and project expectations
    - This identifies potential reversions in implementation, or changes to building operations which may have increased usage. Identifying these issues allows for timely interventions to retain savings and allows for timely information gathering inquiries that may aid in the application of defensible NRA's to more accurately quantify savings.
- Changes in model statistical fitness metrics as projects are modeled with additional data that bring them above threshold
    - This identifies major changes in building operations that are reducing correlations between the dependent and independent variables, which allows for timely information gathering inquiries that may aid in the application of defensible NRA's to improve model fit.

If any projects are flagged in an automated run they are pushed to the attention of our M&V analysts for triage, and a more detailed review. If necessary, the analyst can then take steps to have an energy advisor reach out to the building contact to gather further information, or work with them to correct any issues.

M&V Analyst Ongoing Reviews

While powerful, automated model flags cannot replace the trained review of an M&V analyst. In this framework, M&V analysts set up projects and perform initial reviews to ensure they are correctly running in the system and that there aren't any immediate opportunities for more information to improve the model, or to create deeper savings. In addition to triaging any projects that are flagged in automated model runs, analysts also review projects monthly throughout the reporting period for deeper performance analysis. This analysis is completed in several ways beyond simply evaluating the aforementioned statistical fitness metrics, including AMI data analysis, residual analysis and savings extrapolation.

Ongoing M&V Analysis Techniques

AMI Data Analysis:

As discussed, AMI data at granular intervals (15-minute or hourly) provides operational insight to drive energy efficiency changes, and it provides the power to Option C regression models to accurately quantify savings at more shallow depth than monthly data. It also acts as a powerful tool for M&V analysts reviewing the performance of projects during their reporting periods. Load profiles compared against similar time periods, or more accurately against adjusted baselines (baseline models applied to reporting period conditions), can reveal changes in ways that are much more tangible than the results of regression models. Figure 3 shows a project where a school adjusted their start up and shut down times to reduce energy consumption during unoccupied times. Scheduling changes are clear in the data at the start and end of each day between actual use and the modeled use before the change.

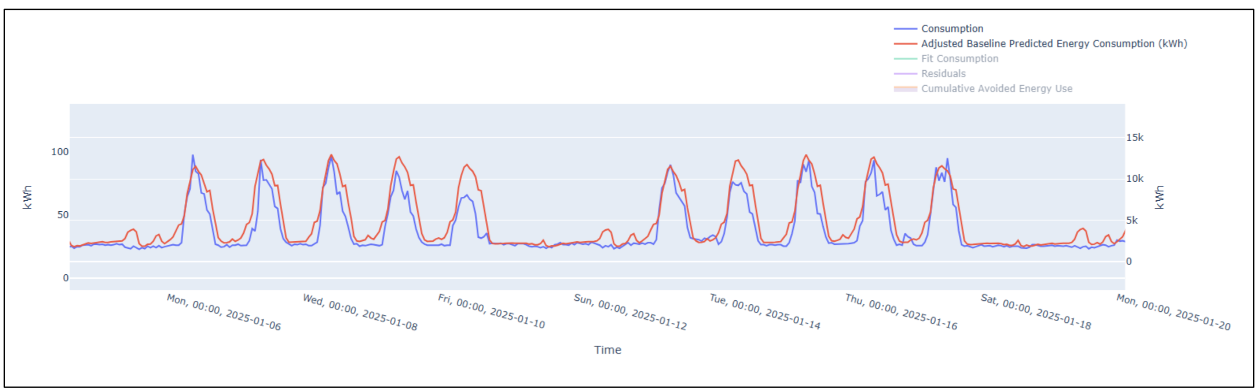

Figure 3. Startup schedule change in AMI data

Residual Analysis:

Residuals in regression analysis represent the difference between observed and predicted dependent variable values. Their analysis helps evaluate model assumptions, identify issues, and gauge how well the model fits individual data points. Residual analysis can take on many forms, usually beginning with a plot of residuals vs. time:

- Cumulative Sum (CUSUM) of residuals during the baseline period
    - Reveals areas where the model may struggle to predict usage indicating anomalous activity that may need to be addressed with an NRA

- CUSUM of residuals during the reporting period
    - In a forecast model this is also the CUSUM of avoided energy use and provides significant insight into the trends by which savings are accumulating
    - Shifts, plateaus, or declines in this trend can indicate issues with measure implementation to be addressed with the building contacts
- Residuals across baseline and reporting periods using a pre-post model that assesses the change (ie. savings) as independent, indicator variables
    - Swings up and down can indicate anomalous activity or building trends not related to the implementation that may need to be addressed with an NRA

Savings Extrapolation Techniques:

Understanding savings as an annualized value can be helpful in comparing savings across a portfolio of projects and for comparing against estimated or expected savings targets. Deviations from estimated or expected savings can prompt further analysis that uncovers potential issues with implementations. Several options are available for extrapolation depending on chosen model frameworks.

Forecast models compare adjusted baseline models to actual consumption, and aren't inherently well set up for extrapolation, but simple extrapolation, where avoided energy use is averaged into a daily value and multiplied by 365 days, can yield reliable results, especially as a full operational cycle is satisfied for the measure or building.

Normalized operating conditions models yield baseline and reporting models that can be normalized to relevant, normalized, annual datasets (ie. typical meteorological year) that provide the models annual data on which to calculate annual values, with the difference between the models yielding an annualized savings value.

Pre-post models yield coefficients for change variables that can be applied through simple multiplication against the relevant granularity (8760 for hourly models, or 365 for daily models) along with any relevant interacted change variables, to produce annual savings values.

Feedback Loops Between Building Contacts and M&V

The depth and frequency of this analysis during the performance period allows for any issues or information requests to be addressed quickly, while building contacts remain engaged and relevant details about implementations and changes to building operation are fresh in their minds. In this framework, M&V analysts identify any issues and bring them forward to energy advisors who use their relationship with building contacts to gather info and encourage investigation and adjustments.

While ideally uncommon, issues do arise post-implementation, examples include, changes reverting due to one off scheduling adjustments for events, improper commissioning of equipment and misalignment across operating teams. More common are changes to building consumption that need to be resolved to model accurate savings. Examples include; new tenants in commercial spaces, construction projects using additional power, installation of new equipment that either draws more, or generates power and holiday shut down events.

These inputs drive more accurate M&V which in turn helps to better understand buildings, and engage contacts with more detailed information, creating feedback loops that drive deeper savings, more accurate models, and savings persistence.

Case Study

The effectiveness of this framework is best demonstrated through a case study of a real world, anonymized energy efficiency project.

- Building: Medical Office Building
- Change: HVAC scheduling adjustments
    - Weekdays (tightened schedule with occupied hours set later in the morning, and earlier in the evening)
    - Weekends (tightened schedule Saturday and shifting to fully unoccupied Sunday).
    - Unoccupied heating and cooling setpoints were adjusted as well.
    - Scheduling adjustments were more aggressive in cooling season due to tenant comfort concerns in heating season
- Model Specification: Hourly, pre-post model utilizing Time-Of-Week indicators, and 8 total cooling and heating bins for dry-bulb, outdoor air temperature, as independent variables.
- Timelines:
    - One day implementation (BMS adjustment) in late October 2022
    - Project enters rapid response M&V framework in early December 2022
    - Model runs through the winter and spring suggest extrapolated annual savings around 50,000 kWh
    - In May – June 2023, as cooling season begins, M&V team review reveals;
        - More aggressive cooling season HVAC scheduling adjustments not visible in AMI data
        - CUSUM continued its upward trend showing that setpoint adjustments were still in place and accumulating some savings
    - Customer engagement
        - Customer notes that scheduling changes appear to be in place but continues to investigate
        - BAS vendor completes review and finds controls issues which are overriding scheduling adjustments
        - Controls issues fixed and more aggressive, cooling season, adjustments begin to show their impact
    - M&V continues to model savings through the cooling season and sees annual savings value rise to 100,000 kWh with additional impact of expected scheduling changes

Results:

As seen in figures 4 and 5, quick engagement with the building contact after expected savings were not seen in the AMI data, yielded deeper savings than would not have otherwise been realized. Regular review by the M&V team meant that they were familiar with the site, and change, and knew what to look for as the building entered cooling season. Had traditional M&V only been done once or twice, and with less granular data, it is likely that the controls issues would have been missed, and the building's full savings potential would not have been realized.

Figure 4 shows modeled building consumption alongside actual consumption in June 2023. After controls issues were resolved on June 12 there is a clear change in the building's profile. High overnight baseload, and Sunday usage, are replaced with new patterns. Overnight setbacks become both longer and deeper than seen in the modeled building consumption, and full Sunday shutdowns become apparent.

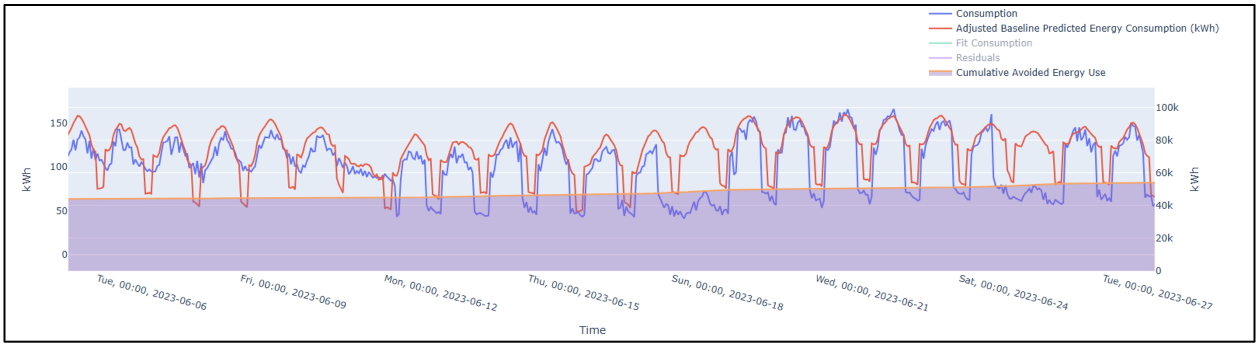

Figure 4. HVAC schedule adjustments clear in AMI data after controls issues were resolved

Figure 5 shows modeled building consumption alongside actual consumption through to October 2023 and a CUSUM of avoided energy use with a clear step change in slope, indicating accelerated, deeper, savings after the identification, and resolution, of the controls issue.

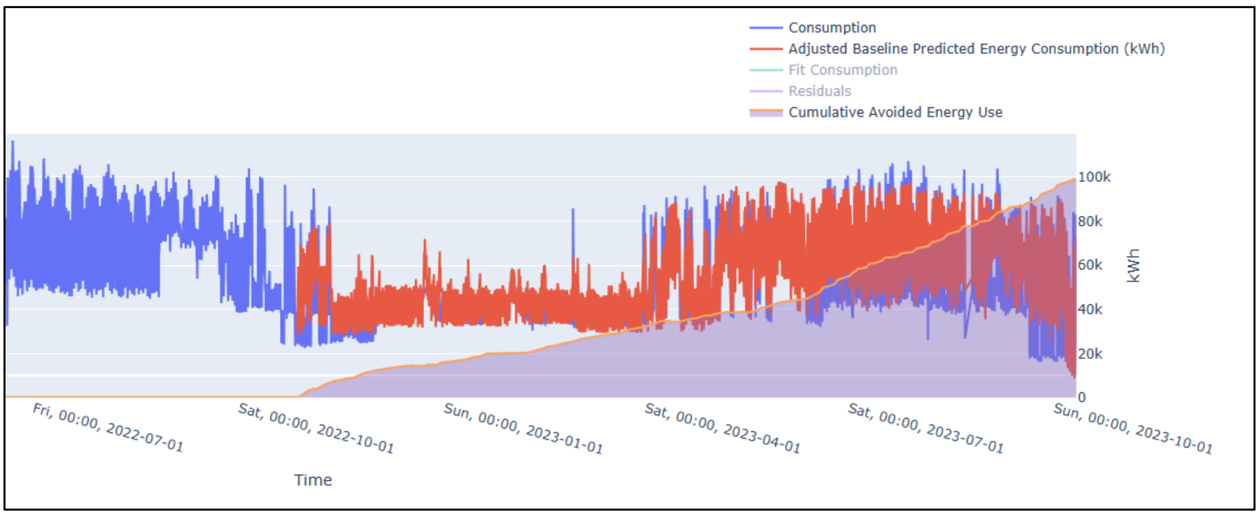

Figure 5. Increase in CUSUM slope after controls issues were resolved

Conclusions

Through this exploratory review of a rapid response M&V framework it is clear that it can provide benefit and alignment across program implementers, building contacts, and evaluation teams. Rapid response to changes in building consumption patterns can yield insight that may prove invaluable to the accuracy and defensibility of savings calculations and persisting program impact. Through timely engagement with building contacts non-routine events can be identified and confirmed, and any issues with measure implementation or reversion can be caught early, preserving savings.

Leveraging the increased adoption of granular AMI data and advances to data and software infrastructure, the reviewed rapid response M&V framework regularly ingests, securely stores, and cleans data for ongoing use. Option C regression modeling allows for best-practice M&V that scales easily, while providing deep insight, even for projects with minimal savings depth. Automated model runs are leveraged through flags and alerts capturing shifts in building consumption patterns. Trained M&V analysts review any project flags alongside regular, ongoing reviews of projects, to understand; savings in load profiles, patterns in residuals, avoided energy use, and extrapolated savings. Any issues are rapidly communicated to building contacts, helping them to triage any issues, while confirmation of non-routine events allow for NRA's that build deeper insight into the models themselves, further increasing accuracy that can yield further action.

Often seen as the bow tied on the end of a successful implementation, M&V can go deeper. Typically representing the longest stage of a project's life, a rapid response M&V framework can engage building contacts, deepen savings, and promote both buy-in and persistence. Wider adoption by implementers, evaluators and utilities could yield significant impact, enabling already potent energy efficiency programs to optimize performance, maximize savings claims and drive a sustainable future.

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