PG&E M&V Requirements for Site-Level NMEC

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1. Introduction

1.1. Purpose

Site-level normalized metered energy consumption (site-level NMEC) is the methodology for estimating energy and demand savings for two program offerings from Pacific Gas and Electric Company (PG&E), the Public Sector NMEC offering and the Commercial Whole Building (CWB) NMEC offering. Given the diverse range of premises, energy efficiency measures (EEMs), modeling algorithms, and other factors that may influence the potential outcome of site-level NMEC projects, both PG&E and its regulator, the California Public Utilities Commission (CPUC) require that implementers wishing to participate in these programs submit a site-level M&V Plan for each project application package that meets PG&E's requirements. This document describes the requirements for project-level M&V plans, savings reports, and serves as a reference for implementers wishing to participate in these two PG&E NMEC program offerings. As such, this document serves the role of a program level M&V plan for these types of projects.

The quantification of achieved energy and demand savings after the installation of EEMs is based on the analysis of pre- and post-installation metered energy data. The savings methodology follows the established Option C Whole Building approach as documented in the International Performance Measurement and Verification Protocol (IPMVP).[1] Under the Public Sector and the CWB offerings, savings will be determined for each project following guidance and requirements for site-level NMEC projects as documented by the CPUC (CPUC Rulebook 2.0).[2] Each project will have its own project-level M&V plan that complies with the guidance and requirements described in this program-level plan and describes specific details and methods to be employed for that project. Each project-level M&V Plan shall include the proposed data collection, analysis methodologies, and documentation for an individual project, including project pre-screening, savings determination, and reporting.

This M&V plan will apply to a variety of building NMEC projects, each of which addresses different equipment, operating schedules, changes impacting energy use, metering and data resources, and levels of savings. For consistency among savings calculations and incentive payments, PG&E will employ the same meter-based savings analysis methodology and procedures to calculate claimable and payable savings across all projects. Implementers are welcome to use their own methods in their interactions with customers, however incentives will be based on PG&E's analysis. Implementers are welcome to use PG&E's methods as well. As we gain more experience with specific customers, modeling methods, and premise types, we expect to expand specific methodologies beyond current requirements.

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[1] International Performance Measurement and Verification Protocol (IPMVP), Efficiency Valuation Organization, www.evo-world.org.

[2] Rulebook for Programs and Projects Based on Normalized Metered Energy Consumption, version 2.0, January 7, 2020, available at https://www.cpuc.ca.gov/General.aspx?id=6442456320.

1.2. Background Information

The site-level NMEC methodology has long been established in two well-known industry guidelines: IPVMP (Option C) and ASHRAE Guideline 14.[3] The IPMVP describes best practices for different savings verification approaches while the ASHRAE Guideline 14 provides more detailed technical requirements. With the widespread availability of electric and natural gas energy use data measured in short-time intervals (e.g., sub-hourly, hourly, and daily) from advanced metering infrastructure (AMI) in the PG&E territory, and development of more accurate energy modeling algorithms,[4] meter-based approaches have been employed in efficiency projects with great accuracy and success. The AMI data and advanced modeling algorithms have enabled more timely feedback on a building's energy use and savings achievements and have provided insight on the identification and treatment of non-routine events (NREs). The NMEC Savings Procedures Manual[5] describes the fundamental process and requirements in each site-level NMEC project phase, incorporating the well-established guidance of the IPMVP and ASHRAE documents, and updated with more recent developments in energy modeling.

The approach detailed in this plan was developed based on guidance provided by LBNL to the CPUC[6] and requirements set forth in CPUC Proceeding A.17-01-013 for measure cost-effectiveness, measure EUL, and behavioral, retro-commissioning, and operational (BRO) measure requirements. Implementers are strongly encouraged to familiarize themselves with the approaches, methods, and data requirements described in this M&V Plan and review the guidance documents provided by PG&E in its Platform Rulebook[7] and by the CPUC Rulebook 2.0 to gain a full understanding of the fundamental requirements of site-level NMEC offerings.

2. Project Approach and Process

This document describes how individual projects will be accepted into the Public Sector NMEC and CWB program offerings, how project-level M&V will be carried out, how CPUC requirements will be fulfilled, and

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[3] American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) Guideline 14-2014 Measurement of Energy and Demand Savings. Available from www.ashrae.org.

[4] Webster, L., et. al., 2020, "IPMVP's Snapshot on Advanced Measurement and Verification." Available from http://evo-world.org/images/corporate_documents/NRE-NRA_White_Paper_Final_2701.pdf.

[5] Normalized Metered Energy Consumption Savings Procedures Manual. SCE Emerging Technology Project ET15SCE1130, available at: https://www.etcc-ca.com/reports/normalized-metered-energy-consumption-savings-procedures-manual.

[6] Site-Level NMEC Technical Guidance: Program M&V Plans Utilizing Normalized Metered Energy Consumption Savings Estimation, Version 2.0, December 15, 2019, available at: https://www.cpuc.ca.gov/General.aspx?id=6442456320 .

[7] PG&E Resource Savings Rulebook version 1.0, 3/27/2020, available at: https://www.pge.com/pge_global/common/pdfs/for-our-business-partners/energy-efficiency-solicitations/PGE%20Platform%20Rulebook%20V1.0%20Final_PC2%20(2).pdf

what information must be provided in each project-level M&V plan and savings report. This section first describes the site-level NMEC M&V project procedures and documentation requirements, then addresses the broader program-level requirements.

There are three periods of activity in each project: the baseline, installation, and performance periods. Pre-screening and project development take place in the baseline period, EEMs are installed and verified in the installation period, and savings are determined and documented in the performance period. These M&V activities are illustrated within the three periods in Figure 1. For more information for how these activities fit in the overall program process please refer to the program offering manual.

1. **Baseline Period:**

    a. **Pre-screening.** Each potential project is pre-screened for eligibility. The facility's condition is assessed to make sure it is not in need of major repairs and upgrades. Potential efficiency measures are identified and their potential for deep savings assessed (high level assessment, no detailed calculations). An energy model is developed from a year of energy use and temperature data and an assessment of building predictability is made. The potential for non-routine events is assessed. The customer's desire to participate in a pay for performance approach is documented. PG&E decides whether the project is a good candidate for the NMEC platform.

    b. **Feasibility Study and M&V Plan Development.** Implementers develop the project by identifying specific EEMs and estimating their savings. A feasibility study is completed to describe the facility, its equipment and operations, recommended savings measures, their savings-weighted useful life, and how the program influenced the customer. The required program information and data is collected. A project-level M&V plan is developed that documents specifically how data will be collected and how savings will be quantified for the project based on program requirements, including how risks will be managed.

2. **Installation Period.** Following acceptance of the project by PG&E, the customer installs the EEMs. A post-installation report is completed to document the as-installed EEMs and updates to the weighted useful life. Partial payments of incentives are made.

3. **Performance Period.** During the performance period, energy data is collected, achieved savings are determined, normalized savings are reported, and incentives are paid.

Figure 1 illustrates what activities take place in the baseline, installation, and performance periods of the individual projects. A project's baseline model is developed using energy use and ambient temperature data from a baseline period of one year. This model is used to determine what energy use would have been in the performance period absent the intervention (called adjusted baseline energy use) as represented by the black line. The difference between the adjusted baseline use and the energy use as observed at the meter during the performance period is the savings expressed as avoided energy use. At the end of the 12-month performance period, the normalized savings is determined. This requires development of a model based on performance period data, so that both baseline and performance period energy may be normalized to long term weather conditions as required by CPUC (referred to as CALEE 2018 weather data).[8] Incentives are based on the normalized savings.

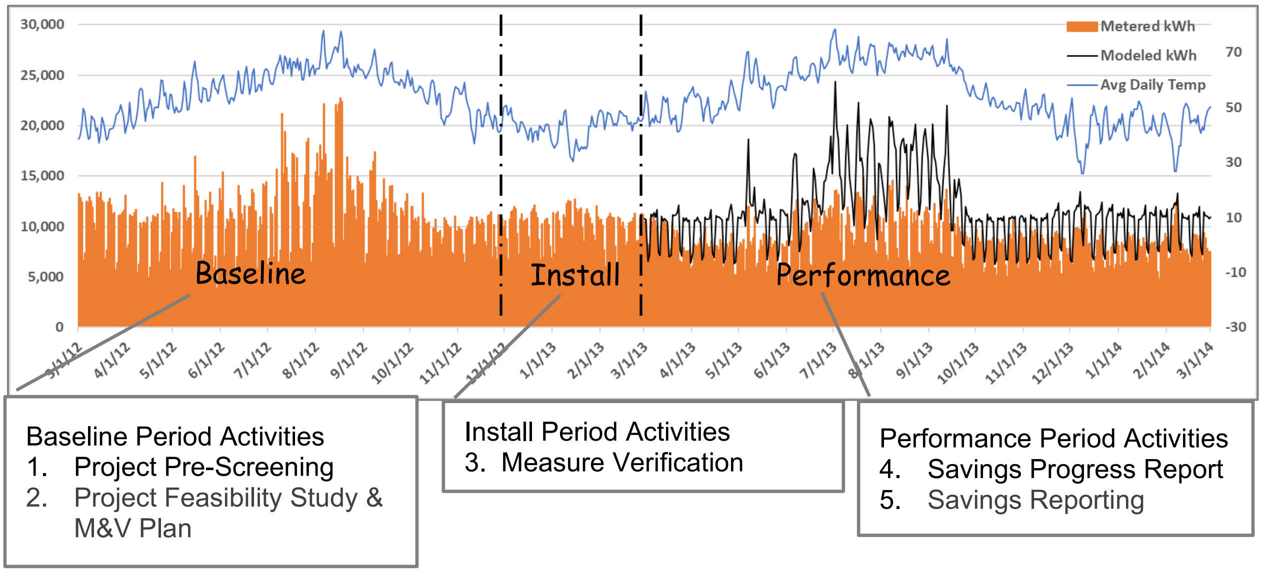

Figure 1. NMEC Project Process

2.1. Baseline Period

Project Predictability Report. As described in the Program Manual, each potential project is pre-screened for eligibility. The principal M&V activity is to assure the meter-based M&V approach can accurately account for the project's savings. The building's 'predictability' is determined by collecting a year of energy use, weather, and other potentially influential variable data, which is then analyzed to determine whether an acceptable energy model may be developed that meets the eligibility requirements. These modeling criteria are:[9]

- Coefficient of Variation of the Root Mean Squared Error: $CV(RMSE) < 25\%$
- Net Mean Bias Error: $-0.5 < NMBE < 0.5\%$

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[8] CPUC's NMEC Rulebook 2.0 requires CALEE2018 weather data for normalization and is available at: http://www.calmac.org/weather.asp.

[9] Descriptions and recommended values of the modeling goodness-of-fit metrics are recommended in "Site-Level NMEC Technical Guidance: Program M&V Plans Utilizing Normalized Metered Energy Consumption Savings Estimation, Version 2.0, December 15, 2019" provided to CPUC by LBNL. CV(RMSE) is a measure of model random error, NMBE is a measure of model bias error, and R^2 is an indication of how well the independent variables 'explain' the dependent variable. This document is available at: https://www.cpuc.ca.gov/General.aspx?id=6442456320 .

- Coefficient of Determination: $R^2 > 0.7$ (recommendation only, not a criterion[10])

The year of data shall also be analyzed to determine the presence of unusual energy use patterns that may be caused by NREs. All suspected NREs should be confirmed with the participant and confirmed baseline period NREs must be documented in the predictability report, with a description of how their impacts may be addressed should the project be accepted into the program. Section 3.10 describes some methods and external resources for NRE detection and savings adjustments.

A predictability report template is provided in Appendix 2.

Project Feasibility Study. The Program Manual describes the project feasibility study, which provides a more in-depth assessment of potential energy efficiency measures and provides information to meet the requirements set forth by the CPUC. This study includes an energy audit to identify and assess the cost-effectiveness and feasibility of EEMs.

The annual expected total savings for the recommended measures and the annual baseline period energy use for both electric and natural gas is reported in the feasibility study. To assure savings are detectable above model noise, the program targets 10% savings of baseline year electric and natural gas consumption. If lower than 10% savings for each energy commodity are anticipated, the feasibility study should describe how the meter-based analysis may be used to quantify the savings at an acceptable certainty level.

A feasibility report template is provided with the Program Manual.

Project-Level M&V Plan. A project-level M&V Plan shall be delivered with each project feasibility study and follow CPUC Rulebook guidance. This M&V Plan shall describe:

- A data collection plan documenting where data is collected from and how it is prepared for analysis
- The building's utility meters or participant-owned submeters, including electric, natural gas, or energy delivered from a central plant (chilled or hot water and steam).
    - Utility meter ID numbers
    - Sub-meter calibration requirements and recent calibration documentation
    - Description of systems and equipment served by each meter and submeter
- Documentation of how EEMs will be verified as installed and operating
- Description of the modeling algorithms, and software used to develop the building's baseline energy models (see Modeling Methods).
- The baseline energy model's goodness-of-fit and accuracy metrics, showing how they meet the offering's criteria
- Assessment of expected savings uncertainty and how savings will be detectable at an acceptable level of certainty

[10] Why r2 Doesn't Matter, M Stetz P.E., CMVP, M&V Focus, EVO's Measurement & Verification Magazine, October 2019. https://evo-world.org/en/news-media/m-v-focus/868-m-v-focus-issue-5/1164-why-r2-doesn-t-matter

- Documentation of how baseline period NREs were identified and how they were analyzed for the baseline period models
- Documentation of static factors and they will be tracked to identify potential NREs, and how anticipated NREs occurring in the installation and performance periods will be identified and impacts removed from the final savings estimation (see Section 3.10)
- How savings will be documented and reported after twelve months of the performance period
- How all data and savings calculations used to determine the meter-based savings estimations will be made available.
- How often savings progress reports will be documented and provided to the participant and to PG&E

An M&V Plan Template is provided in Appendix 3.

2.2. Installation Period

Post-Installation Report. The duration of the installation period will be limited to 18 months, per CPUC requirement. The participant must inform PG&E when the EEMs have been installed. The participant or implementer is responsible for verifying each installed measure and completing a post-installation report. The post-installation report describes the EEMs that were installed and updates the individual EEM energy savings estimates if the EEMs were installed differently than originally planned. It describes why some EEMs were not installed. It provides descriptions of how the EEMs were verified as performing efficiently. It provides full measure installation and project cost information for the installed EEMs, supported by receipts, contractor invoices, installed meter costs, and the customer's own labor and materials spent on the project. Costs must be associated with each measure. It provides an updated savings weighted EUL calculation. Incentives may be calculated and included in the post-installation report.

Measure verification requirements may vary depending on the type of measure. For example, lighting (only lighting fixtures on the DLC OR eligible through the calculated or deemed programs are eligible) fixture upgrades may be verified by a count of replaced fixtures and recording the new fixture types and wattages. Control sequences may be verified with the use of building control system trended data, or from data collected by data loggers. Trend data provides the most direct evidence of the EEM's improvement of systems and equipment energy performance. Photographs, contractor invoices, and other cost information should also be collected. Over time, these techniques for documenting measure performance may be used by building operators to demonstrate measure persistence.

A post-installation report is required. PG&E reserves the right to inspect and verify all information claimed in the post-installation report and send a representative to perform a site inspection.

Large projects (projects that are expected to receive over $50,000 in incentives) are required to document that savings are accruing. For large projects, the achieved savings at three months shall be determined with an avoided energy use calculation and compared with the expected savings at three months based on the installed EEMs and their revised savings calculations. Section 3.7 describes the avoided energy use analysis and savings progress report.

A post-install report template is available with the Program Manual.

2.3. Performance Period

Savings Report. A savings report shall be provided after twelve months of the performance period has elapsed. This report shall document the data collected and analysis used to estimate the normalized savings achieved by the project.

The savings report must contain a narrative description of the models used, meter calibration requirements and documentation for data from any sub meters used, identify the baseline period, document the actual measures installed and their expected savings, and document the modeling algorithms used, model goodness of fit metrics, and energy savings analysis. Any NREs identified and treated as part of the analysis must be documented. Savings must be reported as normalized savings using CALEE2018 weather data. This means a model based on post-installation period energy use and conditions must also be developed and documented. Normalized savings are described in Section 3.6.

Demand savings must also be determined using the most recent California statewide guidance DEER peak demand definition, and documentation included in the final savings report. Any deviations from planned M&V activities must be clearly identified and explained. Savings reports must also report project costs per the requirements described in the next section. Estimated incentives must be reported in savings reports according to the requirements in the Program Manual. All data and information, spreadsheets or analysis code used to determine savings must be provided for technical review and program evaluation. Calculations must be live, based on the data provided, and calculation methods must be transparent from raw data through final savings results. All documentation, data, and calculation tools must be provided with the savings report.

The contents of the savings report is specified in the M&V Plan and a savings report template is available in Appendix 5.

3. Additional M&V Requirements

The following sections provide additional detail on the considerations and requirements to complete the M&V activities described in the baseline and performance periods.

3.1. Data Collection and Preparation

The project-level M&V Plans must include a section on data collection and preparation that describes:

1. The baseline period duration that must be at least 12 months. Longer durations are acceptable for the purposes of increasing modeling accuracy or replacing significant missing or removed data in cases of poor data quality or occurrence of non-routine events.

2. The meters serving the project measurement boundary must be clearly identified and labeled. The measurement boundary should include all the equipment to be improved in the project.

    a. Data from multiple meters serving equipment that is affected by the EEMs should be combined in the savings analysis.

b. If some meters serve equipment that will not be affected by the installation of EEMs and the equipment does not serve the same space as the affected equipment, their meters may be excluded from the project.

c. The site-Level NMEC project may include additional buildings, such as a central heating and cooling plant that serves multiple buildings. For example, a chilled water system may be upgraded in the central plant while control strategies are implemented in the buildings air handlers. Data from the central plant and building electricity meters should be included in the M&V plans for these buildings. This will capture the interactive effects between the electricity use in the buildings as well as the central plant. Note that 10% savings should still be targeted for each meter in the project.

d. In the case where on-site generation is present and serves the facility, the generation data should be collected and combined with the building energy use data to assure that all energy used by the building is used in the analysis. In addition, projects where non-IOU is present are required to follow the savings claim methodology at the analysis intervals stated in the non-IOU fuel source guidance document.[11]

3. The source of both dependent and independent variable data to be used throughout the project duration, how data will be collected from each source, and how often.

   a. Utility data must be indicated by meter identification or service agreement identification number and sources named, such as utility account representative or via green button connect.

      i. How the meters used in the analysis will be mapped to the customer accounts, premises, and measurement boundaries of the loads affected by the EEMs.

   b. Data from participant-owned meters must be identified and their accuracy specifications documented. Recent calibration documentation must be provided for meters that require periodic calibration. Minimum accuracy requirements must adhere to CPUC specifications, which are shown in Table 4 of the Program Manual. Meters undergoing in-situ calibration must describe the process and equipment used to calibrate the meter and how results were used to update meter readings.

   c. Weather station sources must be named and their distances from the project site listed. When alternate weather station data is used, a justification must be provided. When weather services are used, the name of the service and a description of how that service generates weather data for the building site must be included.

[11] California Public Utilities Commission, Energy Division, November 6, 2015, Guidance Document: Energy Efficiency Savings at Sites with Non-IOU Fuel Sources.

   d. Sources for other data (e.g. restaurant meals served data, key card swipes, water usage data, WiFi network usage levels, on-site generation, etc.) must be named and a discussion of the reliability of the data provided.

4. How the implementer, PG&E, and participant will work together to ensure data is available throughout the project duration.

5. How often energy use and independent variable data will be collected and prepared for analysis.

6. What data quality issues were identified and how they were treated. Data quality issues include missing data – in small or large quantities, erroneous or outlier data, and repeated data values. The M&V Plan should have a clear description of how the raw data was prepared for analysis.

3.2. Model Development

Energy model development may be an iterative process. The goal is to develop the most accurate and reliable energy model for the duration of the project. Several factors must be considered to achieve an acceptable energy model, and include:

- Selection of an appropriate baseline period to include conditions expected in the post-installation period. The CPUC Rulebook 2.0 allows no more than 18 months from the end of the baseline period to the beginning of the performance period.

- Influence on energy use of factors other than ambient temperature and availability of their data throughout the baseline, installation, and performance periods.

- Presence of non-routine events and influences and methods to remove their impacts from the savings analysis.

- Choice of modeling algorithm, number of independent variables, and time interval of data (hourly, daily, monthly billing period).

- Model compliance with goodness of fit criteria.

- Adherence of energy model to assumptions of regression modeling.

These considerations should be evaluated in the development of the baseline energy models. For consistency, the performance period energy model should use the same modeling algorithm, independent variables, time interval of data, and other considerations used to develop the baseline energy model.

3.3. Modeling Algorithms and Strategies

The savings analysis process begins with the development of a baseline period energy use model. Because the main influences on energy use in commercial and public sector buildings are ambient temperature, building operation schedule, and sometimes on occupancy load, preferred modeling algorithms will be capable of including multiple independent variables. Two common public domain modeling algorithms are described below.

- The time-of-week and temperature modeling algorithm (TOWT), which develops coefficients for each time-of-week and piecewise linear temperature segments specified in the model. TOWT accounts for the influence on energy use from the time-of-week as well as the ambient temperature. It may be applied using hourly of daily time interval data. This modeling algorithm was originally developed by Lawrence Berkeley National Laboratory.[12] and has been modified and updated to include additional independent variables. A full description may be found in Appendix 1.

- Modeling algorithms described in ASHRAE Guideline 14-2014, Table 5-1, which include the collection of temperature-dependent change-point models from ASHRAE Research Project 1050's inverse modeling toolkit (IMT).[13] These algorithms may be applied with average temperatures or with heating or cooling degree days as the independent variable and may be applied with daily data.

Other modeling algorithms may be used to determine normalized savings. The site-level M&V plan must include a complete description of the algorithm, citing references as necessary, provide live calculation files that develop the energy models, and calculate their goodness of fit metrics (described below).

Different modeling strategies may be used to develop the energy models. One strategy is to use one modeling algorithm for the entire 12-month period but add additional independent variables. Additional independent variables may be continuous variables with values of the same time interval as the energy use (hourly, daily, or monthly billing period) or indicator variables which have values of 0 or 1 and are used for periods of time when buildings are in different operation modes, or for non-routine events (NREs). Additional independent variables may be used to explain the low-occupancy period of the COVID-19 pandemic shutdown, or other non-routine events in the building. They may be used if they are demonstrated to have statistical significance in explaining the energy use and their data is reliable and available throughout the NMEC project engagement.

Another common modeling strategy is to filter the energy data by distinct building operation modes and develop separate energy models for each mode, with the final baseline model comprising of all the models for each operation mode in the year. An example of an operation mode may be occupied hours and unoccupied hours, weekdays, weekends, holidays, and vacation periods. Operation modes may define when building HVAC operations operate differently than normal, such as a chiller being down for

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[12] Mathieu, et. at. 2011. "Quantifying Changes in Building Electricity Use, with Application to Demand Response," LBNL report LBNL-49944E, April 2011.

[13] Kissock, J. K., J. S. Haberl and D.E. Claridge, "Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models," ASHRAE Research Project 1050, final report November 1, 2002. Available at www.ashrae.org.

maintenance. The operation modes must be present in the performance period so that the proper baseline operation mode may be applied when determining the adjusted baseline use.

Each accepted energy model must pass the model acceptance criteria described below. The M&V plan shall document the modeling algorithm chosen, the modeling strategy employed, and describe how the model predictions will be made in the performance period, and how NREs will be identified and adjustments made to remove their impacts from the savings analysis. NREs are discussed in Section 3.10.

3.4. Model Goodness-of-Fit

Baseline and performance period models shall be fit using a least-squares regression method. The model must meet the following acceptance criteria, as required by the CPUC:

- The net mean bias error (NMBE) must be greater than -0.5% and less than 0.5%. NMBE is calculated using Equation 1.

Equation 1.
$$NMBE = \frac{\frac{1}{n}\sum_i^n (E_i - \hat{E}_i)}{\bar{E}_i} \times 100$$

- The coefficient of variation of the root mean square error CV(RSME) shall be less than or equal to 25%. CV(RMSE) is calculated using Equation 2.

Equation 2.
$$CV(RMSE) = \frac{\left(\frac{\sum_{i=1}^n (E_i - \hat{E}_i)^2}{(n-p)}\right)^{1/2}}{\bar{E}}$$

- The Coefficient of Determination, R^2, should be checked to inform how well the dependent variable (temperature) explains the variation in the dependent variable (energy use), but it should not be used as an acceptance criterion.[10]

Equation 3.
$$R^2 = 1 - \frac{\frac{1}{n}\sum_i^n (E_i - \hat{E}_i)^2}{\sigma_E^2}$$

- Savings Uncertainty for models with autocorrelation (models based on hourly and daily data) should be less than 50% at the 90% confidence level. The calculation should be made using the total expected savings from the feasibility study, or by assuming a minimum 10% savings would be achieved. Savings Uncertainty is expressed as a fraction of actual savings using the formulation in Equation 4[14] from ASHRAE Guideline 14 for weather-dependent models with correlated residuals.

Equation 4. $$U = \frac{\Delta E_{save,m}}{E_{save,m}} = \frac{\alpha \cdot t}{m\bar{E}_{base,n}}\left[MSE'\left(1+\frac{2}{n\prime}\right)m\right]^{0.5}$$

Where $$MSE' = \frac{1}{n'-p}\sum_{i=1}^{n}\left(E_i - \hat{E}_i\right)^2$$

E_i is the measured energy use in any time interval, in energy units (kWh, therms, BTUs, etc.)

$\hat{E}_i$ is the model's predicted energy use in any time interval, in energy units

$\bar{E}$ is the average energy use over all the time intervals, in energy units

E is the total energy use over the training time period, in energy units

$E_{save,m}$is the estimated energy savings over m time periods, in energy units

n is the number of data points in the training period*p* is the number of parameters in the model

x_i is the value of the independent variable in any time interval

σ_E is the standard deviation of the distribution of energy use values

$\Delta E_{save,m}$is the absolute precision of the savings estimate over m time periods, in energy units

t is student's t-statistic for the specified confidence level and n-p degrees of freedom

α is an equation depending on the analysis time interval:

α = 1.26 for hourly interval data

α = -0.00024M^2 + 0.03535M + 1.00286 for daily interval data

α = -0.00022M^2 + 0.03306M + 0.94054 for monthly interval data

M is the number of months of reporting period data

n' is the number of data points in the model training period, corrected for autocorrelation

[14] Uncertainty formula taken ASHRAE Guideline 14-2014, equation B-31, p. 91. For monthly data with uncorrelated residuals, equation B-28 on p. 89 may be used.

$$n' = n\frac{(1-\rho)}{(1+\rho)}$$

ρ is the autocorrelation coefficient at lag 1, which is the correlation of the model residuals $E_i - \hat{E}_i$ at time stamp *i* with their values at the previous time stamp, *i* – 1.

m is the number of data points in the performance period

MSE' is the mean squared error based on the degrees of freedom *n'* – *p*, modified for autocorrelation

F is the expected savings, expressed as a fraction of baseline energy use

Baseline model residuals shall be checked for normality of residuals, heteroskedasticity, kurtosis and skewness. Plots of model residuals such as those shown in Figure 2 are useful for this purpose. Unacceptable amounts of these effects shall be removed from the model.

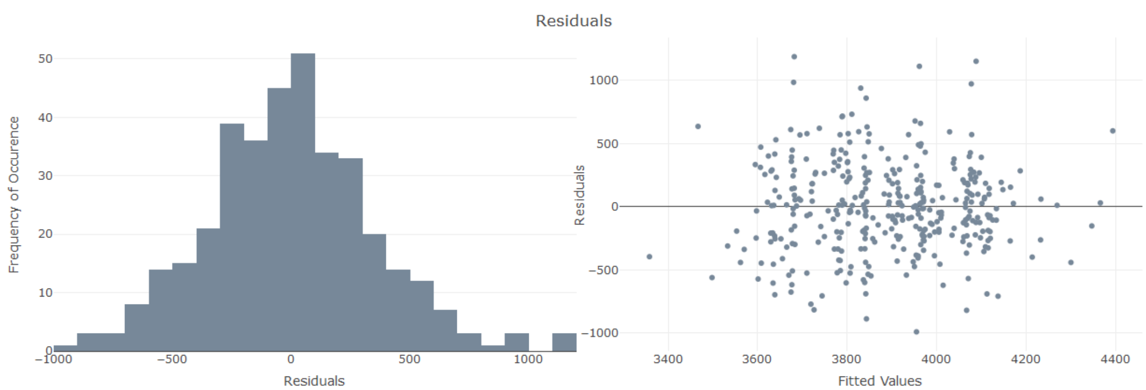

Figure 2. Residual Frequency and Scatter Plots

Should the fitted model fail to meet the goodness of fit criteria, additional independent variables representing other key drivers of energy usage in the building may be added to improve model fit, or the modeling strategy may be adapted to model different operation modes separately. If the revised model fails to meet the GOF criteria, alternative modeling algorithms may be used. If all attempts fail, the energy commodity (electricity or natural gas) or the entire project may be excluded from participation in the NMEC program offering.

3.5. Assessing Predictability

Assessing the predictability of a building's energy use simply means determining whether an energy model that meets the required goodness-of-fit criteria may be developed from the energy use and independent variable data. A 12-month period of energy use and independent variable data is required. The data is collected and prepared, though not necessarily as rigorously as it would be for documenting in the M&V Plan as this is just a pre-screening exercise. A modeling algorithm and strategy are selected, a model developed, and the goodness of fit metrics are calculated. While pre-screening buildings, actual savings estimates may not yet be available. In such cases a 10% savings over baseline year may be assumed to estimate the savings uncertainty.

Unusual energy use patterns occurring in the data may indicate the presence of an NRE. Information to explain what happened in the building during these unusual energy performance periods should be collected from the participant. This helps the assessment of how identified NREs will be treated throughout the project. There are various methods that may be used, as documented in Section 3.10.

A predictability report template is provided in Appendix 2.

3.6. Normalized Energy Savings

In PG&E's NMEC programs, savings are determined under normalized conditions, which is defined by CALEE 2018 typical weather year data for the climate zone the building is located in. These weather files were updated in 2018 and may be found at www.calmac.org/weather.asp. Normalized savings are the difference between the baseline period energy use and the performance period energy use after they have been normalized to the CALEE 2018 weather conditions.

Normalized savings are reported after 12-months of reporting period data have been collected. A model based on performance period data must be developed so that performance period energy use under normalized conditions may be determined. Performance period models should use the same modeling algorithm and strategies as were used for the baseline model development.

All data and analysis activities must be reported in a savings report. A savings report template may be found in Appendix 5.

3.7 Avoided Energy Use

Avoided energy use is determined by inputting the performance period temperatures (and other independent variable values, if used) into the baseline energy model. This produces the adjusted baseline energy use. The avoided energy use is the sum of the adjusted baseline predictions less the sum of the performance period energy use to that point in time. Results may be tabulated or charted with time series charts of the adjusted baseline and performance period usage data, or with a cumulative sum of savings chart.

Various factors dictate how often if at all a savings progress report should be made. While savings progress analysis and reporting should not take long, if the project is not expected to produce large savings, only one progress report may be provided. If the project is large or there is a significant potential for NREs occurring, more frequent progress reports should be provided. The M&V Plan should document how often savings progress reports must be provided.

For projects anticipated to receive over $50,000 in incentives based on annual normalized savings, a savings progress report based on the avoided energy use achieved at 3 months is required.

A savings progress report template is provided in Appendix 4.

3.8. Demand Savings

Demand savings will be determined by the DEER Peak Permanent Peak Demand Reduction calculation procedure, as documented in the 2021 IOU Statewide Customized Offering Procedures Manual for Business.[15] This procedure determines the average peak demand reduction from 4pm to 9pm over the three DEER peak period days defined for each climate zone. This calculation procedure may be completed with hourly baseline and performance period models. The models must meet the NMEC goodness of fit requirements, which include the CV(RMSE) and NMBE metrics described earlier. The savings uncertainty formula from ASHRAE is unreliable for models based on hourly data and should not be used. This is due to severe autocorrelation in the data.

When hourly models fail the goodness of fit criteria, alternate calculations, such as engineering calculations of the individual energy and demand savings of individual EEMs may be used, subject to the requirement that they are thoroughly documented in the savings report, and the data and live calculations are provided.

3.9. Approach to Ensure Adequate Monitoring in Reporting Period

Each M&V Plan is required to describe how often energy use and independent variable data in the performance period will be collected and avoided energy use calculated. This activity is critical for three reasons:

1. To assure a participant's sub meters continue to record data as expected. This is important for projects where a participant's own energy metering systems are used. It is sometimes the case that these systems fail or encounter issues with data collection and archiving.

2. To assure savings are accumulating as expected, and

3. To periodically check for the presence of NREs, work with participants to determine their cause, and determine how to remove their impacts from the final savings analysis.

For each project, these factors are considered when determining the frequency of the savings progress reports. For example, projects with predictable buildings using reliable utility meter data may require savings progress to be checked only once or twice in the performance period. Projects with customer-owned meters, potential NREs, and uncertain upfront savings estimates may need to check savings progress each month.

Monitoring shall include the collection of data for each dependent variable (energy use in kWh, therms, chilled and hot water BTUs, etc.) and independent variable (weather data, production rates, etc.) used in the baseline model. Implementers must request the data from the utility or the participant according to a schedule developed in the project-level M&V Plan.

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[15] https://www.pge.com/pge_global/common/pdfs/save-energy-money/facility-improvements/custom-retrofit/Statewide-Customized-Offering-Procedures-Manual-for-Business-2021.pdf

3.10. Identifying, Documenting and Adjusting for Non-Routine Events

Non-routine events are significant changes to the building or its operations that are unrelated to the EEMs. They can be short term, long term, or permanent changes in building energy use. They may be additions or removal of constant or variable loads. The IPMVP defines NREs as changes to a building's prevailing conditions, or static factors. These conditions may be building and equipment operating conditions, added or removed energy consuming (or generating) equipment, reduced occupancy, major building additions or renovations. Major occupancy changes, HVAC equipment maintenance, and addition of new equipment are typical examples of NREs. Useful methods such as those described in the IPMVP Application Guide on Non-Routine Events & Adjustments.[16] may be used to address NREs in NMEC projects.

Using various techniques, NREs occurring in the baseline period may be accounted for when developing the baseline model. Because they may occur at any time without the participant's or implementer's knowledge, NREs occurring in the post-installation period present risks to the final savings estimation, and if not sufficiently documented will bias the energy savings calculation.

The project-level M&V plan should describe any NREs that occurred in the baseline period along with how they were treated, and any NREs anticipated during the performance period. Information on anticipated performance period NREs should be based on discussions with a knowledgeable representative of the participant, including type of NRE, its significance, anticipated time of occurrence, and duration. The project-level M&V Plan should describe how the NRE impacts will be quantified. The possibility of adding meters to help quantify NRE impacts should be considered.

During the performance period, the most common method to identify NREs is through visual inspection of the metered energy use data. Time-series charts of energy use data may be used to identify shifts in energy use patterns that may be caused by NREs. When a significant amount of performance period energy use data is available, an energy model may be developed. When the energy use data begins trending significantly outside expected values as determined by the model, an NRE may be present. Many other NRE detection algorithms may be used, as documented in the NRE Application Guide described above. Other methods that may be employed are provided by BPA[17] and LBNL.[18] NRE detection and impact quantification algorithms are the subject of ongoing research.

Each NRE and adjustment method should be described in the Energy Savings Reports.

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[16] IPMVP Application Guide on Non-Routine Events & Adjustments, October 2020, available from www.evo-world.org.

[17] SBW Consulting, April 30, 2018, Potential Analytics for Non-Routine Adjustments. Prepared for Bonneville Power Administration

[18] https://github.com/LBNL-ETA/nre

Accounting for Savings from Non-Program EEMs

To the extent possible, customers should be discouraged from implementing EEMs incented under other programs, ineligible EEMS (such as purely normal replacement measures), or other changes to the building that affect its energy use for the duration of participation in PG&E's Site-Level NMEC programs: Commercial Whole Building or Public Sector. In the event that such EEMs are installed, their impacts must be removed from the normalized savings analysis in a similar way as described above for non-routine adjustments. At a minimum, their installation start and completion dates must be identified, and the method used to remove their impacts from the normalized savings must be described in the savings reports. The reports must provide the data and the analysis files used to adjust the normalized savings.

Addressing COVID Impacts

Literature has recently emerged to describe methodologies to assess the low-occupancy impacts on energy use and savings in meter-based projects due to the shutdown caused by the COVID pandemic.[19] Many of the methods describe applications of techniques in the IPMVP NRE Application Guide. Following are short descriptions of methods implementers may use to assess the low occupancy impacts and account for them in baseline models and the savings analysis. These descriptions are not comprehensive. More appropriate and applicable methods that address each project's circumstances may be found in the IPMVP NRE Application Guide.

Assessing Low-Occupancy Impacts

Not all buildings are affected the same way. The deepest reductions in energy use are evident in commercial office buildings and hotels, while hospitals and grocery stores continue to operate normally or have increased use. One method to assess the impacts of the low-occupancy period is to collect energy and independent variable data (usually temperature) for the calendar years of 2019 and 2020. Develop a regression model based on the 2019 data and use the 2020 independent variable data to determine the predictions from the 2019 model in 2020. Assuming there were no other changes to the building in 2020, the difference between the predictions and the actual data provide an indication of the impact of the pandemic on energy use in 2020.

Baseline Models with Occupancy Data

For projects with baseline periods that include 2020 and the low-occupancy periods, if possible, identify a source of data that may serve as a proxy to occupancy. Such sources may include key card swipes tracked by the security system, connections to building IT networks, air handler fan motor variable speed drive speed signals, or other sources. The data must have the same time interval of analysis as the energy use data. It should have a significant amount of variance throughout the baseline period corresponding to the shutdown period, as it will be tested for significance in explaining the energy use. The data source must be available throughout the baseline and performance periods. If the proxy

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[19] See EVO's M&V Focus magazine, March 2021 for three related articles: https://evo-world.org/en/news-media/m-v-focus/884-m-v-focus-march-2021-issue-8.

occupancy variable is significant, the model will account for the impact of occupancy automatically and provide reliable estimates of savings.

Baseline Models without Occupancy Data

For projects where a source of occupancy data cannot be found, consider recommending establishing an occupancy data source for the performance period, establishing a maximum correction factor based on the assessment described above, and using the proxy variable to diminish the correction factor throughout the performance period as the building increases occupancy. Savings would be based on a model developed from data from the pre-COVID shutdown period. Its predictions would be adjusted by a correction factor that is adjusted from its maximum value as the building re-occupies. This correction factor adjustment would be based on the new occupancy variable.

In each case, the M&V plan and savings report must provide a description of why the occupancy variable was selected, its data source and reliability, and its significance in the energy models.

3.11. Determining Project Influence

Project influence documentation should be consistent with other custom program requirements, which are described below.

> A narrative and supporting evidence must be provided to document the actions performed by the program that induced the customer to implement the energy efficiency project. The narrative should include the project developer's engagement and communications with the customer, the customer's decision-making criteria, and the project timeline, and should describe how the project was initiated, how the measure was identified, the alternative viable options that also meet the customer's needs, and the energy and non- energy benefits. Supporting evidence with time stamps must be provided to support the narrative. The supporting evidence may include one or more of the following:
>
> - Marketing materials, including website links, or other communication about program details. Marketing materials provide program details and allow program staff to intervene and upsell EE measures.
> - Audits or site visit results where EE opportunities are assessed. Site visits can illuminate additional EE opportunities and validate/quantify known opportunities.
> - Energy savings and/or financial calculations for EE measures. Showing the value of EE savings and effects of incentives can motivate a customer to pursue a project they otherwise would not have in absence of program intervention.
> - Email correspondence or meeting minutes with timestamps that discuss any of the above or that support the narrative.
> - Customer decision-making policies such as corporate sustainability policy or investment criteria.

- Internal customer communications or communications with design team that discuss design alternatives, cost estimates, or the customer's decision making process.

Effective Date: Program inception

Rule Source: R.09-11-014 EE Policy Manual v5

The Public Sector and CWB offerings will apply the net-to-gross (NTG) ratio of 0.95 per CPUC Resolution E-4952.

3.12. Rationale for Confidence in Savings when Less than 10% of Baseline Consumption

Predictability analysis will assess the project's ability to detect a minimum 10% savings based on ASHRAE's fractional savings uncertainty formula, provided in Section 3.4. This formulation uses the baseline model MSE, the savings expressed as a fraction of baseline energy use (assumed to be 10%), the t-statistic for a confidence level of 90% (1.65), and the number of points in the baseline and performance periods respectively. An adjustment to the number of points n is made for lag-1 autocorrelation, n', when modeling with hourly or daily time interval data.

After measures have been identified and their expected savings quantified, the uncertainty for the expected savings may be determined using the same formula.

To be detectable, the maximum allowable savings cannot be more than 50% at the 90% confidence level.

Use of interval data and advanced modeling methods means that even if fewer EEMs are installed or if they are not functioning as intended, savings down to levels of 4 – 5 % may still be determined with reasonable accuracy and confidence.

3.13. Documentation of Costs, Energy Savings, and Expected Useful Life

Each site-level NMEC project requires a list of EEMs with their estimated savings, measure costs, and EUL. This is for the purposes of informing the participant of the costs and benefits of different EEM options. The customer selects the measures from this list, with the requirement to achieve 10% of baseline use or more in savings after implementation. Because all savings are quantified from the existing conditions baseline, the individual EEM savings estimates need not quantify to-standard practice and above-code portions of savings. Deemed savings estimates for specific EEMs may be used if their gross savings from existing conditions baselines are available. For each EEM, its full measure cost must be estimated and its EUL must be determined. A weighted average EUL for the entire list of recommended EEMs must be determined. The weighted average EUL is calculated by adding together the product of each EEM's EUL multiplied by its expected savings and dividing by the total expected savings. This information must be documented in the feasibility study report.

After the implementation period, a list of installed EEMs with their expected savings, costs, and EULs will be documented. This may be a shorter list than that documented in the feasibility study. Individual EEM savings estimates must be updated if the EEMs were not installed as assumed in the original savings estimations, and a new weighted EUL calculated. At the end of the twelve-month performance period, the final savings will be apportioned to each individual EEM, and a final weighted average EUL determined.

3.14. Project Level EUL Calculation

A weighted average EUL will be estimated for each installed and verified measure based on the measure's original expected savings estimate and the measure's EUL as determined above. The weighted average for all recommended EEMs will be reported in the feasibility study report, and the updated weighted average EUL for the EEMs actually installed and verified will be included in the post-installation report.

3.15. Accounting for On-Site Generation or Other Fuel Sources

Energy savings claims should only support impacts to energy supplied by PG&E. If a facility generates electricity and exports it to the grid, then the energy savings must be limited to the amount delivered from the grid for each hour of each day in the reporting period. On-site generation may include solar photovoltaic panels and other renewable energy sources, cogeneration equipment, or other equipment.

NMEC projects at customer sites must include a description of the non-IOU fuel source, data collected and analyzed, and how savings will be capped to limit savings to the amount of delivered energy from the grid, according to the governing non-IOU policy.[20]

3.16. Case When One Energy Model Fails Acceptance Criteria

Some projects pursuing site-level NMEC may encounter a situation where one energy use model (usually electricity) passes while another energy use model (usually natural gas) fails the model acceptance criteria. In these cases, additional effort should be made to enable the energy model to pass. Recommendations to improve the model include:

1. Extending the baseline data from 12 months (program minimum requirement) to 24 months,
2. Developing weekly/monthly models instead of daily,
3. Using a different modeling algorithm,
4. Adding additional independent variables, such as occupancy loads.

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[20] Energy Efficiency Savings Eligibility at Sites with non-IOU Supplied Energy Sources – Guidance document. Version 1.1.
file:///K:/Jobs/PG&E/2018%20TechAssist%20for%20Eval%20of%20NMEC/2.%20Regulatory%20Support/M&V%20Plan%20and%20Prog%20Man%202021/Savings%20at%20Sites%20with%20non-IOU%20Fuel%20Sources%20-%20Guidance%20Doc.pdf

If none of these options yields a model that meets the goodness of fit criteria, then the measures providing direct savings (see Definitions) for the energy use with the failed models may be incented under the Custom project ruleset.

3.17. Negative Savings

As described in the California Energy Efficiency Policy Manual Version 6 (April 2020),[21] projects resulting in negative savings will be claimed by PG&E, but Customers are not penalized for negative indirect savings. However negative direct savings are accounted for and reduce the incentive.

Clearly, negative direct savings results should be avoided by assuring that the EEM will result in lowered energy use. In situations where all EEMs save electricity, but may result in negative indirect natural gas savings, the negative indirect savings must be reported.

4. Definitions

Advanced Metering Infrastructure (AMI): An integrated system of smart meters (AMI meters), communication networks, and data management systems that enables two-way communication between utilities and customers. Among other capabilities, AMI meters enable measurement of energy use in short time intervals, such as 15 minutes, hourly, or daily, providing better insights into building operations, compared to monthly billing data.

AMI Data: Data produced by AMI meters.

Autocorrelation: Also known as serial correlation; the correlation between the elements of a series and others from the same series separated from them by a given interval. Error terms that are correlated over time are said to be autocorrelated. Informally, it is the similarity between observations as a function of the time lag between them.

Avoided Energy Use: Reduction in energy use or demand that occurs in the reporting period, relative to the baseline period, as adjusted by routine and non-routine adjustments, for the reporting period conditions.

Baseline Training Period: Period of time chosen to represent the operation of the facility before the implementation of an energy efficiency measure.

Categorical Variable: Variables used in empirical modeling that have discrete values and are not continuous. They may represent different operation periods in a building, such as occupied and non-occupied periods.

Coefficient of Determination R^2: The coefficient of determination (R^2) is the measure of how well future outcomes are likely to be predicted by the model. It illustrates how well the independent variables explain

[21] https://www.cpuc.ca.gov/energyefficiency/

variation in the dependent variable. R^2 values range from 0 (indicating none of the variation in the dependent variable is associated with variation in any of the independent variables) to 1 (indicating all of the variation in the dependent variable is associated with variation in the independent variables, a "perfect fit" of the regression model to the data).

Coefficient of Variation of the Root Mean Squared Error CV(RMSE): The coefficient of variation of the root mean squared error (CV(RMSE) is the RMSE expressed as a fraction or percentage of the mean of the actual data.

CZ2020 Weather Data: CZ2010 Weather Data is long term average weather data published by the California Energy Commission.

Dependent Variable: A variable whose value depends on values of one or more other variables. In this document, the dependent variable is the energy use measured at the energy meter, such as electric, natural gas, chilled or hot water, and steam.

Direct Savings: Direct energy savings occur as the primary source of the EEM, for example the lower energy a newly installed lighting fixture uses over that from the inefficient lighting fixture it replaced represents direct energy savings. See also Indirect Savings.

Feasibility Study: A document that includes a description of the building, its equipment, and operations, annual energy use, recommended EEMS with individual energy (kWh and therms) and demand savings information, costs and cost-effectiveness metrics for each measure, individual measure estimated useful life (EUL) and weighted EUL calculations, documentation of program influence, and the project M&V Plan. Additional relevant information as described in this document should also be included.

Implementer. An Implementer is an entity that has technical expertise in building energy systems, conducting energy audits and recommending efficiency measures, verifying savings, and related reporting. Implementers may include trade professionals, engineering service providers, or customers themselves.

Independent Variable: A parameter that is expected to change regularly and has a measurable effect on the energy use of a building. Independent variables may be continuously changing, such as ambient dry-bulb temperature, humidity, and production rate, or may represent operation modes of a building (categorical), such as occupied and unoccupied periods, school in-session or out-of-session periods, etc.

Indirect Savings: Indirect energy savings or savings from interactive effects are savings that occur from other than the primary purpose of the EEM. For example, a lighting retrofit lowers the energy use of the replaced fixtures and lowers the energy required for cooling in the building. The lowered energy of the cooling system is indirect energy savings or savings from interactive effects.

M&V: Measurement and Verification (M&V) is the process of using measurement to reliably determine actual savings created within an individual facility by an energy efficiency intervention. Savings cannot be directly measured, since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions.

M&V Plan: The project-level M&V plan is a document describing the energy efficiency measures, data collection activities, data analysis methods and reporting activities for a prospective NMEC project. The preparation of a project-level M&V Plan is a required part of project approval. Advance planning ensures that all data needed for savings determination will be available after implementation of the energy efficiency measures.

Non-Routine Event: Changes that occur in a building that are not related to energy efficiency measures, but that affect the energy use in the baseline and/or the reporting period, that must be accounted for in savings estimations.

Normalized Mean Bias Error NMBE. NMBE refers to normalized mean bias error, which is the total error in the model expressed as a fraction of the total energy use, adjusted for the number of parameters in the model.

Normalized Metered Energy Consumption (NMEC): Energy use in a baseline and/or a reporting period is adjusted to a common, or normal, set of conditions. Savings based on NMEC is what the savings would be under a normal set of conditions, which usually includes long-term average weather for building climate zones.

Normalized Savings: Reduction in energy consumption or demand that occurs in the reporting period, relative to the baseline period, after both have been adjusted to a common set of conditions.

Performance Period: Period of time chosen for the purposes of verifying savings after implementation of energy efficiency measures (also known as reporting period).

Project Measurement Boundary: The Project Measurement Boundary refers to the portion of the building or facility included in the energy savings model. In the context of Option C (whole building) analysis, the measurement boundary encompasses the whole facility. For M&V plans that utilize submetering, or selection of a subset of meters serving the building, the project measurement boundary is the portion of the building served by the selected meters or submeters.

Residual: The residual is the difference between the predicted and actual value of the dependent variable in an energy consumption model.

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

Weather Coverage Factor: Weather coverage factor may be expressed as the range of weather parameter (e.g. dry-bulb temperature, wet-bulb temperature, etc.) extended by at most 10% that includes (or ‘covers’) the range of weather data used to normalize the baseline or post-installation energy use. It may also be expressed as the amount of time represented by the normal conditions data that is covered by the extended range of the training period weather data. Modeling best practices require that an empirical model not be used to extrapolate far beyond the range of data from which it was developed.

Appendix 1: Description of the LBNL Temperature and Time-of-Week Modeling Algorithm

The following description includes descriptions of the time-of-week model and temperature (TOWT model) adapted from its original authors, along with descriptions of adaptations that have been added to improve model fit. For a more comprehensive description of the original modeling algorithm, please consult the publication by Matthieu, et. al.[22]

- A building's energy use (natural gas use, hot water, steam, or chilled water, as well as electricity) is generally a function of ambient temperature and the time of week. In some cases, additional parameters influence energy use in buildings, such as humidity and a production variable. The TOWT model may include independent variables in addition to the time-of-week and temperature, if their data are provided in concurrent time intervals (such as hourly or daily time intervals). As the dominant influencing parameters for building energy use is the schedule of operation and ambient temperature, this model description focuses on the use of these parameters. The following discussion uses electric kWh as the energy data, however it applies equally well for other energy sources.

- The time-of-week parameter is modeled as an indicator variable. This allows some flexibility to define this parameter according to the time-interval of the data. Electric energy use data (kWh) from advanced metering systems is typically available in 15-minute intervals, ambient temperature data from weather stations are typically available in hourly intervals. Natural gas energy use data (therms) from advanced metering systems is also available in hourly or daily time intervals. The following description assumes hourly time intervals, but also applies for daily time intervals.

- Each week is divided into hourly intervals (indexed by i), with the first interval from midnight to 1 am Monday morning, the second from 1 am to 2 am, and so on for the 168 hours each week (7 for daily time intervals). A different regression coefficient for each time of week indicator variable, α_i, allows each time-of-week to have a different predicted load.

- Energy response to temperature in a building is non-linear but may be modeled as continuous and piecewise linear. At low temperatures, electric energy use may increase as temperatures lower due to more use of heating system equipment such as pumps, fans, and electric heating elements. In moderate temperatures, the building does not require heating and cooling and therefore energy use is not sensitive to temperature. At warm temperatures, energy use increases with increasing temperature due to use of cooling system equipment. At the highest temperatures, energy use may again be insensitive to temperature as cooling equipment has reached its maximum load. There may be multiple regimes of energy response to temperature.

[22] Matthieu, J.L., P.N. Price, S. Kiliccote, and M.A. Piette, "Quantifying Changes in Building Electricity Use, With Application to Demand Response," IEEE Transactions on Smart Grid, 2:507-518, 2011.

- For natural gas use in multi-family buildings, we expect high gas use at low ambient temperatures, with use decreasing as temperature warm. At some point, space heating is no longer required, and the only use for gas is for water heating, which is expected to have a milder relationship with ambient temperature. We therefore also expect multiple regimes for natural gas use, though they are likely fewer than for electric use.

- Boundary temperature values of the piecewise linear temperature segments may be chosen in two ways:

    - Specified by the user

    - Specified to have equal length line segments

    - Specified to have an equal number of data points to define each line segment.

  Boundary temperature values specified by the user is appropriate when the energy use behavior is known in the different temperature regimes. Some care should be taken to assure there are a significant number of data points that define the line segments at the high and low ends of the range. When the temperature response of the building is unknown, a good practice is to define the line segments throughout the temperature range by specifying that each line segment shall have the same number of points. This assures that the highest and lowest line segments are well-defined and avoids potential extrapolation errors when making model predictions for temperature conditions outside the range used to develop the model.

- The piecewise linear and continuous temperature at time t, $T(t_i)$ (which occurs at time of week interval i) is broken down into a number of component temperatures, $T_{c.j}(t_i)$, with j = 1 to n_s (n_s being the number of line segments, usually no more than 10 to avoid overfitting, often 6 is enough). Each $T_{c.j}(t_i)$ is multiplied by β_j and then summed to determine the temperature dependent load. Boundary temperature values of the temperature segments are defined by B_k (k = 1…n_s-1). And component temperatures are determined with the following algorithm (assuming n_s = 6):

    - If $T(t_i) > B_1$, then $T_{c,1}(t_i) = B_1$. Otherwise, $T_{c,1}(t_i) = T(t_i)$ and $T_{c,m}(t_i) = 0$ for m = 2 … 6 and algorithm is ended.

    - For n = 2 … 4, if $T(t_i) > B_n$, then $T_{c,n}(t_i) = B_n - B_{n-1}$. Otherwise, $T_{c,n}(t_i) = T(t_i) - B_{n-1}$ and $T_{c,m}(t_i)$ = 0 for m = (n + 1) … 6 and algorithm is ended.

    - If $T(t_i) > B_5$, then $T_{c,5}(t_i) = B_5 - B_4$ and $T_{c,6}(t_i) = T(t_i) - B_5$.

  For example, if the boundary temperatures were specified as B_1 = 30, B_2 = 40, B_3 = 50, B_4 = 60, and B_5 = 70 °F, the temperatures T would be sorted into the $T_{c,i}(t_i)$ matrix as shown Figure A-1 below.

T	$T_{c,1}$	$T_{c,2}$	$T_{c,3}$	$T_{c,4}$	$T_{c,5}$	$T_{c,6}$
28	28	0	0	0	0	0
35	30	5	0	0	0	0
56	30	10	10	6	0	0
64	30	10	10	10	4	0
72	30	10	10	10	10	2

Figure A-1. Example component temperature computation.

- The building is anticipated to have a different response to temperature in occupied periods versus unoccupied periods. The TOWT algorithm uses a very simple method to separate occupied from unoccupied time periods. It develops a simple linear regression with all the baseline energy and temperature data to determine occupied versus unoccupied time periods. It defines occupied times as those times of week where the differences between the data and simple linear model prediction are positive 65% of the time or more. For hourly data, unoccupied periods tend to be nights, weekends, and holidays. For daily data, unoccupied periods tend to be weekends and holidays.

- The occupied load is expected to have a time component, a temperature component (T), and potential dependence on other independent variables (OV). It is estimated using the following equation:

$$\hat{E}_{o,b}(t_i, T(t_i), OV(t_i)) = \alpha_i + \sum_{j=1}^{n_s} \beta_j T_{c,j}(t_i) + \sum_{k=1}^{n_{OV}} \gamma_k OV(t_i)$$

  Where $\hat{E}_{o,b}$ is the predicted occupied energy use in the baseline period. A similar expression is used for the performance period model occupied period.

- Unoccupied loads are expected to have similar dependence as occupied loads, but potentially less dependence on temperature, since the building is expected to operate without sensitivity to temperature when systems are off during these periods. Unoccupied load is modeled with the following equation:

$$\hat{E}_{u,b}(t_i, T(t_i), OV(t_i)) = \delta_i + \sum_{j=1}^{m_s} \theta_j T_{c,j}(t_i) + \sum_{k=1}^{m_{OV}} \mu_k OV(t_i)$$

  Where $\hat{E}_{u,b}$ is the predicted unoccupied energy use in the baseline period. A similar expression is used for the performance period model unoccupied period.

- The parameters α_i, for i = 1 to 168, β_j for j = 1 to n_s line segments, and γ_k for the number of independent variables n_{OV}, are estimated using the data from the occupied period with ordinary least squares regression. The parameters δ_i for i = 1 to 168, θ_j for j = 1 to m_s line segments, and μ_k for the number of independent variables m_{OV}, are estimated using the data from the unoccupied period with ordinary least squares regression.

- Based on discussions with one of the TOWT algorithm's authors,[23] additional independent variables may be added to a TOWT model as it is fundamentally an ordinary least squares regression. Other independent variables may be continuous, such as a production rate, or categorical, such as a school operating schedule. Each additional independent variable should be significant, as demonstrated by its p-value or t-statistic. Note that additional independent variables are not included in LBNL's RMV2.0 R code.

- The total energy use estimated by the model is the sum of the occupied and unoccupied terms for each time interval.

$$\hat{E}_b = \sum_{i=1}^{n} \left(\hat{E}_{o,b} + \hat{E}_{u,b} \right)$$

- The model produces residuals that are autocorrelated and heteroscedastic, and the regression parameters α_i and β_j, and δ_i and θ_j are correlated. This means that the standard errors associated with each regression parameter underestimates their level of uncertainty. However, uncertainty on the load predictions can be approximated with the standard error, which can be computed at each interval *i*.

- There are multiple tools that implement the TOWT algorithm, although there are differences among them.

    - LBNL's RMV2.0 is open source public domain R code available from LBNL's GitHub public repository RMV2.0. It is part of an R code package that develops baseline models and calculates avoided energy use (given the required baseline and performance period data). It does not have inputs for additional independent variables, however they may be included through additional programming. RMV2.0 was originally developed to estimate demand savings for demand response events. It includes a weighting function that weights the most recent data points in the model in order to improves its predictions during demand response events.

    - kW Engineering's nmecr is open source public domain R code available from kW Engineering's GitHub public repository nmecr. It's TOWT algorithm was developed from RMV2.0, however the weighting function was made optional. It is an R code package that develops baseline and post-installation models, calculates avoided energy use and normalized savings, outputs goodness of fit metrics, model and savings uncertainties based on ASHRAE Guideline 14 formulations, and independent variable coefficients and statistics, and includes other independent variables. It includes vignettes in the R markdown, pdf, and .docx formats. It provides a code base with version control and invites collaborators to add

[23] Phillip Price Ph.D.

functionality, such as improved uncertainty calculations and quantification of non-routine event impacts.

- Universal Translator version 3 (UT3) M&V Analysis module. Funded under the California Energy Commission's Public Interest Energy Research program and completed in 2014, this analysis module in PG&E's free UT3 desktop software enables users to manually upload data, develop baseline and performance period energy models, and calculate avoided energy use and normalized savings. It has many features that allow users flexibility in modeling approaches in order to develop the best fitting baseline and performance period energy models. Modeling algorithms include: LBNL's TOWT algorithm, selected change-point models, and simple linear regressions. Users may filter the data and develop models for different operation periods, which the module will put together.

Appendix 2: Predictability Report Template

Commercial Whole Building Program Model Predictability & NRE Assessment Report

Project Name

Customer

Customer Contact

Date

Site Name or Address:

Area (square feet):

Annual Usage

Electricity

Natural Gas

Predictability Analysis

Predictability Analysis Purpose and Summary of Findings

The purpose of the predictability analysis is to determine whether the building's energy use can be reliably predicted over the duration of the project. Using empirical models,[24] a building is considered predictable if:

- a model can be developed that meets certain goodness of fit and accuracy metrics as defined in this report, and

[24] Empirical models are simple linear regression or more advanced models, not building simulation models.

- the risk of non-routine events is limited or non-existent.[25]

The purpose of this report is to document the findings of the predictability analysis of the project as a criterion for participation in the PG&E Commercial Whole Building Program. This report documents the energy and weather data received, summary descriptions of the models developed, and provides a summary table of the key model goodness of fit and accuracy metrics for each model.

We received data for two energy use commodities: electricity and natural gas. This data was provided by _____. The data were in ___ time intervals, the energy unit for each commodity was ___, and the data spanned the time period from MM/DD/YYYY hh:mm through MM/DD/YYYY hh:mm – a full year.

For each meter, we developed an energy model based on daily data. Below, we summarize the data received, the modeling algorithms used, and the results of the predictability analysis.

[25] Non-routine events (NREs) are changes to building energy use due to changes in occupancy, additions of loads, equipment maintenance periods, and so on. Significant changes to building energy use not caused by installed measures are considered to be caused by NREs.

Electricity

Summary of Data Received

Energy Data		Weather Data	
Utility	Data from ___	Weather Station	(list location)
Commodity	Electricity	Approx. Distance to Site	xx mi
Received Date		Downloaded Date	
Data Interval	xx-min	Data Interval	xx min
# Missing Data Points		# Missing Data Points	##
File format	(.csv, xlsx, txt file?)	TMY or CZ2010 or CALEE2018 data available?	
Start - End Date	MM/DD/YY – MM/DD/YY		

Models

Model #	Energy Type	Modeling Algorithm	Model Training Period	Analysis Time Interval	Independent variables	Modeling Notes
1	Electric		11/6/17-11/7/18	Daily	Daily Avg. OAT	No Schedules Incl.

Model Goodness-of-Fit Metrics* (red does not meet the criteria)

Model #	CV(RMSE) %	NDBE %	R^2	U (90% CI**, 10% savings)	Savings Required for U @ 90% CI (10%)	Minimum Savings Required (U = 50% @ 90% CI
Passing Criteria	*Below 25%*	*Below 0.005 %*	*NA*	*Below 50%*	*NA*	*NA*
1						

*Equations for these metrics are provided below.
**CI is confidence interval. Uncertainties must be stated with a precision (in energy units or as a percent of savings) and a confidence level (%). Note a higher CI (90%) is used whereas a lower level (68%) was described in the approved CRR advice filing. Also note: work by LBNL showed uncertainty estimates for hourly models were unreliable due to the presence of autocorrelation in the data.

Natural Gas

Summary of Data Received

Energy Data		Weather Data	
Utility	Data from ___	Weather Station	(list location)
Commodity	Electricity	Approx. Distance to Site	xx mi
Received Date		Downloaded Date	
Data Interval	xx-min	Data Interval	xx min
# Missing Data Points		# Missing Data Points	##
File format	(.csv, xlsx, txt file?)	CZ2010 or CALEE2018 data available?	
Start - End Date	MM/DD/YY – MM/DD/YY		

Models

Model #	Energy Type	Modeling Algorithm	Model Training Period	Analysis Time Interval	Independent variables	Modeling Notes
1	Electric		11/6/17-11/7/18	Daily	Daily Avg. OAT	No Schedules Incl.

Model Goodness-of-Fit Metrics* (red does not meet the criteria)

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Passing Criteria	*Below 25%*	*Below 0.005 %*	*NA*	*Below 50%*	*NA*	*NA*
1						

*Equations for these metrics are provided below.
**CI is confidence interval. Uncertainties must be stated with a precision (in energy units or as a percent of savings) and a confidence level (%). Note a higher CI (90%) is used whereas a lower level (68%) was described in the approved CRR advice filing. Also note: work by LBNL showed uncertainty estimates for hourly models were unreliable due to the presence of autocorrelation in the data.

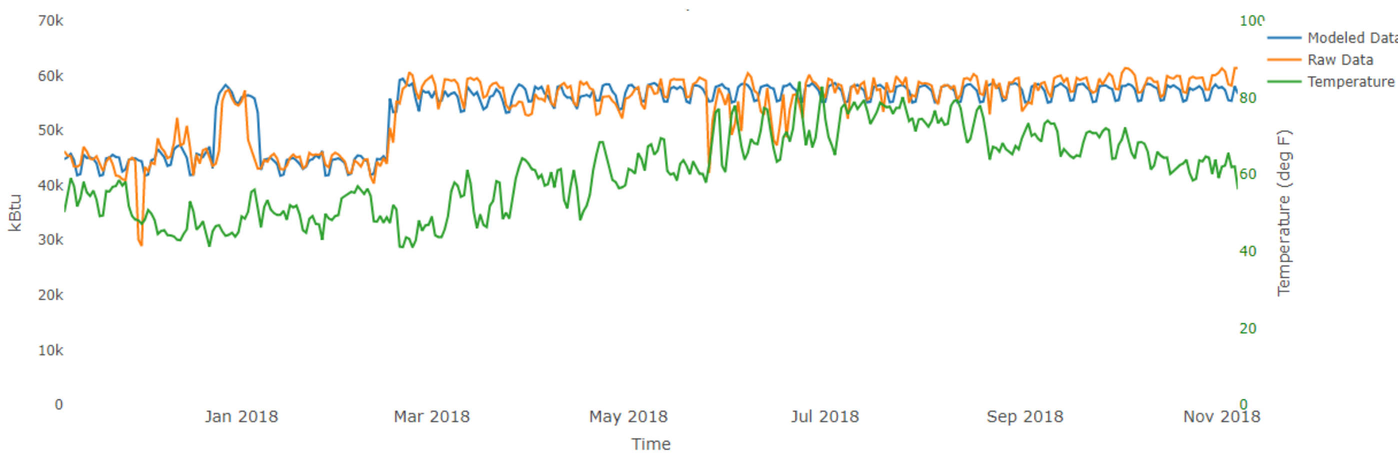
Assessment of NREs

[Example] While the goodness of fit and accuracy metrics are within the program criteria as shown above, review of the energy use patterns in the charts (next page), shows two periods that must be investigated:

- An upward shift in the energy use patterns starting in March 2018.
- A small and short duration period of higher energy use is seen in January 2018.

The cause of these changes in energy use should be investigated. Understanding their cause will help identify it as a non-routine event, improve the model fit, and determine how to address them when estimating savings.

The time-series chart of temperature, energy use, and modeled energy use data below show the energy use patterns over the model training period (separate charts for electricity and natural gas).



Goodness of Fit Metrics

Coefficient of Variation of the root mean squared error, $CV(RMSE) = \frac{\left(\frac{\sum_{i=1}^{n}(E_i - \hat{E}_i)^2}{(n-p)}\right)^{1/2}}{\bar{E}}$

CV(RMSE) is a measure of how much random error there is between a model's predictions and the dependent variable data it is based on. Generally, we want to minimize this error as much as possible.

Net Determination Bias Error, $NDBE = \sum_{i=1}^{n}\left(E_i - \hat{E}_i\right)/E$

NDBE is a measure of how the model's predictions of training period total energy use is different than the actual energy use. this error should be very very low.

Coefficient of Determination, $R^2 = 1 - \frac{\frac{1}{n}\sum_{i}^{n}(E_i - \hat{E}_i)^2}{\sigma_E^2}$

The coefficient of determination describes how well the independent variable explains the variations in the dependent (energy) variable. Higher R^2 means the independent variables have more explanatory power. This is an informative metric only, not a criterion, because while the energy use may not have high variation, an independent variable may adequately 'explain' the existing variation in the energy use, despite a low R^2.

Mean Bias Error, $MBE = \sum_{i=1}^{n}\left(E_i - \hat{E}_i\right)/n$

The MBE is a similar metric to the NDBE but has units of energy.

ASHRAE Guideline 14-2002 provided these formulas to determine the 'fractional savings uncertainty' as a means to estimate the uncertainty of the savings estimated with this modeling approach. The formulation also enables one to estimate how well we will know savings based only on the baseline model's goodness of fit metric CV(RMSE), the number of points in the baseline and post-installation period, the amount of savings, the level of confidence at which we estimate the uncertainty and including a correction for autocorrelation. Using this formula, we can estimate what the savings uncertainty would be to achieve 10% savings, at 90% confidence, for a year of post-installation period monitoring, for a baseline model with a year of data and its CV(RMSE) value. We want the uncertainty to be low, but the minimum level of uncertainty cannot be greater than ± 50% at the 90% confidence level. Note the percentage refers to the amount of savings, not to the baseline energy use.

Additional research by LBNL showed that ASHRAE's formula for uncertainty was invalid when used on hourly models, due to the high degree of autocorrelation in the data.

Savings Uncertainty, models with autocorrelation (hourly or daily), $U = \frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{a \cdot CV \cdot \left[\frac{n}{n'}\left(1 + \frac{2}{n'}\right)\frac{1}{m}\right]^{\frac{1}{2}}}{F}$

Savings Uncertainty, models without autocorrelation (monthly), $U = \frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{a \cdot CV \cdot \left[\left(1+\frac{2}{n}\right)\frac{1}{m}\right]^{\frac{1}{2}}}{F}$

Therm Savings Required for Uncertainty @ 90% Confidence Interval (10%) = 0.1*E_i

Minimum Therm Savings for 50% Uncertainty @ 90% Confidence Interval,

$E_i * t \cdot \frac{a \cdot CV \cdot \left[\frac{n}{n'}\left(1+\frac{2}{n'}\right)\frac{1}{m}\right]^{\frac{1}{2}}}{U}$

Where:

E_i is the measured energy use in any time interval, in energy units

$\hat{E}_i$ is the model's predicted energy use in any time interval, in energy units

$\bar{E}$ is the average energy use over all the time intervals, in energy units

E is the total energy use over the training time period

$E_{save,m}$is the estimated energy savings over m time periods, in energy units

n is the number of data points in the training period

p is the number of parameters in the model

x_i is the value of the independent variable in any time interval

σ_E is the standard deviation of the distribution of energy use values

$\Delta E_{save,m}$is the absolute precision of the savings estimate over m time periods, in energy units

t is student's t-statistic for the specified confidence level and n-p degrees of freedom

α is an equation depending on the analysis time interval:

α = 1.26 for hourly interval data

α = -0.00024M^2 + 0.03535M + 1.00286 for daily interval data

α = -0.00022M^2 + 0.03306M + 0.94054 for monthly interval data

M is the number of months of reporting period data

CV is the coefficient of variation of the root mean squared error, defined above

n' is the number of data points in the model training period, corrected for autocorrelation

$$n' = n\frac{(1-\rho)}{(1+\rho)}$$

ρ is the autocorrelation coefficient at lag 1, which is the correlation of the model residuals $E_i - \hat{E}_i$ at time stamp *i* with their values at the previous time stamp, *i* – 1.

m is the number of data points in the proposed post-installation period

F is the expected savings, expressed as a fraction of training period energy use

Appendix 3: Measurement and Verification Plan Template

Measurement and Verification Plan Template

Prepared for: [program name]

Prepared by: [implementer name/firm]

Project Name:

Date:

CUSTOMER INFORMATION	
Customer Name	**PG&E Service Account No.** Electric: Gas:
Customer Contact	**Customer Address**
Telephone	**E-Mail**

PROJECT INFORMATION		
Site Name		
Project Site Address	**City**	**State Zip**

PROGRAM CONTACTS			
PG&E Program Manager	**PG&E Engineer**	**Implementer**	**NMEC Program Consultant**
Telephone	**Telephone**	**Telephone**	**Telephone**
E-Mail:	**E-Mail:**	**E-Mail:**	**E-Mail:**

Contents

Introduction

This Measurement and Verification (M&V) plan describes in detail how normalized energy savings will be quantified for the (site or project name) NMEC project. The M&V plan presented here adheres to the PG&E M&V Requirements for Site-Level NMEC manual. This approach is consistent with the requirements set forth by the AB 802 legislation and the California Public Utilities Commission's (CPUC) NMEC Rulebook 2.0.

Energy savings represent the absence of energy use and cannot be directly measured. M&V involves the process of using measurements to reliably quantify actual gross energy savings from an energy savings project within a facility, a process, a building, or a building subsystem. It is used to verify that an energy efficiency project is achieving its intended savings, using measurements of energy use before and after implementation of an energy or water savings project, with appropriate adjustments made for changes in conditions. Such adjustments may be routine and expected, while others are non-routine and due to factors unrelated to the project.

This M&V Plan describes the assessment of energy models to be used in the savings analysis. It describes the baseline and reporting periods, the data collection and analysis activities to be carried out throughout each period and describes how and when normalized savings will be reported for the (site or project name). This M&V plan describes the independent variables, the analysis time intervals, and the modeling algorithms that will be used to develop baseline and reporting period energy models. It describes how non-routine events will be identified and treated in the baseline, implementation, and reporting periods.

The M&V Plan is required prior to project installation to document and describe the approach to quantifying savings, the key measurements required and computation methods, the timing of these activities, roles and responsibilities of involved parties, and the quality assurance requirements associated with the process. The main body of this M&V Plan provides a narrative description of the process and requirements. Individual project information for is provided in an Attachment to this M&V Plan. The Attachment provides:

1. The energy conservation measures and their expected savings

2. Energy meter ID, the model training period, and annual energy use

3. Independent variables used in the model training period and their data sources

4. Non-routine events identified during the model training period, if any

5. Charts of the meter, fitted model, and temperature data for the model training period

6. Tables of the fitted model's goodness of fit metrics and coverage factor, with comparison to program requirements.

Terminology

Baseline Model: A mathematical model, developed using empirical modeling methods (such as regression analysis), using energy use and independent variable data collected during the baseline period.

Adjusted Baseline Energy Use: Energy use that would have occurred in the reporting period had no measures been installed. The adjusted baseline use is determined by inputting independent variable data collected during the reporting period into the baseline model.

Avoided Energy Use: Reduction in energy use relative to the baseline period, as adjusted for the reporting period conditions. Avoided Energy Use is calculated as difference between the baseline energy use and the adjusted baseline energy use.

Model Training Period: A period of time prior to the measure installation period that represents typical building energy use behavior. Its duration should be one year unless otherwise noted. The model training period is used to assess how accurately a baseline energy use model may be developed, and to observe the presence of any non-routine events. Baseline models are generally developed from a one-year period immediately prior to the start of the measure installation period but may be developed from the model training period data under certain circumstances.

Normal Conditions: A non-extreme set of conditions that is representative of conditions typically expected for the building and its operations. Savings estimated under normal conditions are expected to represent typical savings for the project and are not over- or under-estimated due to extreme conditions that may occur in the given reporting period.

Normalized Savings: Savings based on the overall reduction in normalized metered energy consumption. Savings from a project that are based on 'normal conditions' as agreed upon by project stakeholders. Normalized savings may require that both baseline and reporting period energy use be adjusted to a common set of normal conditions.

Non-Routine Event: An event within the building, occurring outside of the project's installed energy efficiency measures' scope, that affects the energy use measured at the meter. Non-routine events may include equipment shut down for maintenance, added building load due to a data center, or sudden change in occupancy such as when building tenants move in or out.

Non-Routine Adjustment: Adjustments to baseline energy use made necessary by the occurrence of non-routine events. Such adjustments are necessary so that the resulting computed normalized savings are due to the project's installed energy efficiency measures, and not due to other events that affect the energy use at the meter.

Project Description

2.1 Site Description

- *Facility description*
- *Description and summary of audit(s) or scoping site visit(s) including involved parties and date(s)*

- *Can reference/attach external audit*

2.2 Energy Efficiency Measures

A list of the proposed energy conservation measures with their individual savings estimates are provided in Attachment 1 of this M&V Plan. The measures were developed and documented in the project feasibility study.

Measurement and Verification Procedures

4.1. Verification of Measure Installation

Example text below.

(Customer name) will monitor each the project's start and end of the measure installation period and notify PG&E so that the baseline period and the reporting period start and end dates may be specified. (customer name) will monitor the installation of energy conservation measures and verify that the measures are installed and operating correctly. It is recommended that (customer name) collect photos, make measurements, conduct functional testing or trend analysis of operational data (trended by the energy management system) to verify that the installed measures are performing as per expectation. (Customer name) will provide a post-installation report upon completion to PG&E. This report will include measure installation completion dates for use in the M&V analysis.

4.2. Measurement Boundary and Energy Meters

Measurement Boundary

All ECMs must be installed within the measurement boundary, which includes all the systems served by the (site or project name) electric utility meters.

Energy Meters

This project concerns electric and natural savings; therefore, data from the utility electric and natural gas energy meters will be used. The (site or project name)'s meters have been identified and documented in Attachment 1.

4.3. Baseline Model Development

Energy Use (Dependent) Variables

Describe the Energy (dependent variables) – example text provided below.

Electric and natural gas energy use (kWh) are the dependent variables and data from the (project name)'s meters will be used in the M&V analysis described herein. All energy use data has been inspected for missing or erroneous values (if any). Data preparation procedures for the project are described in Attachment 1. The energy use readings have been added up to daily time intervals. The selected modeling algorithm (described below) used daily time intervals. Figure 1 in Attachment 1 shows the daily energy use along with the modeled energy use and daily average temperature the over the model training period.

Independent Variables

Describe the independent variable(s) – example text provided below.

Independent variables included ambient temperature, averaged to a daily time interval, and school operating schedule, as represented by indicator variables. Indicator variables are used to show holidays, in-session and out-of-session periods and are derived from information for individual schools. Weather data was obtained from (name of weather source). The weather data source, data period used, and other descriptive information for the temperature data are in the Attachment. The weather data received by (implementer, M&V analyst) were inspected and (description of issues found). Indicator variables for the school operating schedules can be found in Attachment 1.

Independent Variables Not Included in the Analysis

Example text below.

No other independent variables were considered in the analysis. Variables such as building occupancy may have had an impact on the energy use, but no data on the number of occupants were available.

Normalized Conditions

Per CPUC Policy, the normalized conditions are represented by the CALEE 2018 dataset for this location's climate zone, which is Climate Zone X. The Attachment describes the Normalized Conditions weather file for this climate zone.

Model Training Period

Example text below.

The model training period represented one year of energy use data, as per NMEC requirements. Energy use models were developed using this data to assess whether an accurate baseline model could be developed and used for estimating savings with reasonable confidence. Note that the model training period does not necessarily represent the baseline period, as the baseline period may be updated based on the first measure installation date. A new baseline model may be developed for the Savings Reports for each school, should the installation period exceed 18 months, per CPUC requirement.

The Attachment describes the model training period used for assessing each model's accuracy for the savings expected from each project.

Baseline Period Non-Routine Adjustments

Example text below.

Non-routine events (NREs) are events that occur in buildings that affect energy use and are unrelated to the efficiency measures. Impacts of NREs must be accounted for in the baseline and reporting periods. The Attachment describes whether NREs were identified during the model training period and how they were treated for this project.

Modeling Algorithm

Example text below (for TOWT model). Note other models may be used.

The electric energy use was modeled using a variation of Lawrence Berkley National Lab's (LBNL) time-of-week and temperature (TOWT) model in the R programming language. This modeling algorithm uses indicator variables for each time-of-week (168 for hourly, 7 for daily) to group together similar operating periods during each week. It also segments the range of temperatures into 6 lines, assuring the same number of points define each line segment. Because a building's operating schedule and the ambient temperature are major drivers of energy use, the TOWT model was selected for this project.

The TOWT modeling algorithm allows additional independent variables to be used, including indicator variables. We've added indicator variables to define different operating modes for (the school).

The model's algorithm was modified to ensure all datapoints are weighed equally in the analysis. The data was summed to a daily data interval to minimize variability within the data and achieve acceptable model goodness of fit criteria. Average daily temperature and indicator variables representing different operation periods were used as the independent variables. Charts of the daily metered and modeled energy use with daily average ambient temperatures for each school are provided in the Attachment.

Coverage Factors

Example text below.

Good modeling practice requires that models be developed from a dataset that includes the maximum range of energy and independent variable values. In addition, good practice requires that models not be extrapolated more than 10% beyond the maximum and minimum of the independent variable data in the training period. In this project, baseline energy use will be estimated under the normalized conditions defined by the California CALEE 2018 Climate Zone X weather data. The coverage factor shows how much of training period range of weather used on model development covers the range of the normalized conditions weather.

The NMEC program requires that a full year of baseline period data be used to develop the baseline model for both energy and demand savings (demand savings described below). The Attachment shows that the extended model training period, developed for the daily data interval, captures 100% of the temperatures of the normal conditions data set and 100% of the total days of the normalized conditions year. The extended model training period for the hourly model, captures 89.7% of the temperatures of the normal conditions data set and 99.8% of the total hours, leaving 18 hours outside this range. The hourly models will only be used for peak demand reduction estimation and since the peak hours, as defined by DEER, are within the normalized conditions data set already, the uncovered 18 hours are not expected to have any negative effects on the models' prediction accuracy. The comparison of daily and hourly temperature distributions with normal conditions have been plotted in the Attachment.

Baseline Model Accuracy Metrics

Example text below.

The acceptance criteria for the baseline models' accuracy metrics are:

1. CV(RMSE) – Less than 25%
2. NMBE – Less than 0.5%
3. Savings Uncertainty – Less than 50% at a 90% confidence level, for 10% savings at a minimum

The coefficient of determination (R2) was also calculated for the model. The model was developed for the model training period using the LBNL TOWT modeling algorithm with data in daily time intervals The model accuracy metrics are shown for each (project name) in the Attachment. The models met the accuracy criteria.

4.4. Reporting Period

Reporting Period Data Collection

Example text below.

Data will be continuously collected throughout the baseline, installation, and reporting periods. The planned reporting period's data collection will be for a period of one year. The data to be collected and their sources are the same as used in the baseline period: electric and natural gas energy use, ambient temperature, and (building) operation periods.

On-Site Generation

Example text below.

The (project name) may have plans to install photovoltaic (PV) systems. For the installed PV system, system size and the date it becomes operational will be obtained, and electric generation data collected. PG&E may switch to a net meter, in which case data for the energy delivered and received from the grid will be obtained. Reporting period models will be based on the electric energy that the building consumes, which is the energy delivered from the grid plus the PV generation energy less the energy sent back to the grid. Per CPUC requirements, a non-IOU analysis will be performed, as described in Section 4.6.

Updated Baseline Model Development

Example text below.

IN case of delays and in order to adhere to the 18 month limit for installation, the baseline period may be updated to the 12-month period immediately preceding the date of the first measure installation. A baseline model will be developed using the baseline period energy use, ambient temperature, and other independent variable data, using the same modeling algorithm. Its goodness of fit and accuracy metrics must also meet the NMEC requirements and will be updated.

Reporting Period

Example text below.

The planned reporting period start date is recommended to immediately follow the ECM implementation period. However, the actual start date will be jointly decided by the (customer name) and PG&E.

Reporting Period Modeling Algorithm

Example text below.

The reporting period will use the same modeling algorithm as the baseline period for the (project name) electric and natural gas use data. The daily time interval will be used to minimize variability in data and match the modeling setup for the baseline period.

Indicator variables will be used to identify the same operating periods in the post-installation period as were used in the baseline period, such as holidays, in-session and out-of-session periods. The indicator variables will be used to assure the correct adjustments are made to both baseline and reporting period models when estimating normalized savings.

Reporting Period Model Accuracy Metrics

Example text below.

The reporting period model's accuracy metrics, including NMBE and CV(RMSE) are the same as for the baseline period. This section will include graphs of the reporting period models once the post-implementation data has been collected.

The acceptance criteria for the reporting period model accuracy metrics are as follows:

1. CV(RMSE) – Less than 25%

2. NMBE – Less than 0.5%

4.5. Non-Routine Adjustments

Example text below.

Non-routine events will be identified by a significant increase or decrease in energy usage that cannot be fully explained or predicted by the reporting period model. The NRE will be identified using data visualizations or an owner report. This requires frequent contact with the (customer), data collection, and analysis throughout the reporting period.

Once a possible NRE is detected, it will be assessed to determine if its impact merits a detailed analysis. If so, we will assess whether:

- the NRE is temporary or permanent?
- is a constant or variable load?
- is an added or removed load?

Based on these considerations, we will assess impact of the NRE using at least one of the following methods:

- Analysis of before/after NRE using metered data
- Engineering calculations and assumptions
- Engineering calculations and logged data

Savings will be adjusted accordingly. All calculation data and files will be provided for review.

Accounting for Energy Consumption Changes due to Participation in Other Programs

Example text below.

Should the (customer) participate in other energy efficiency programs, incentives for measures installed under other programs are ineligible under the PG&E NMEC program. As the energy data is collected for each Savings Report (at 12-months), information regarding installation of 'other program' measures will be collected, including live calculation savings estimates of those measures. Should other program measures be installed, their savings will be normalized to the CALEE 2018 weather data for the (project's) climate zone and subtracted from the final normalized savings as described in Section 4.6.

4.6. Normalized Savings Determination

Normalized Savings

Example text below.

Normalized savings are the reductions in energy use that would occur, had the facility operated under a normal set of conditions. In the NMEC program per CPUC rules, normal conditions are defined with California Climate Zone CALEE 2018.26 Such long-term typical weather data is used so that savings are not estimated with excessively warm or cool weather years, yielding an estimate of typical savings. Normalized savings are defined as the normalized baseline energy use minus the normalized reporting-period energy use.

Normalized energy use will be determined for both the baseline period and the reporting period using models implemented with the same normal conditions weather data. Their predicted energy use (kWh

[26] http://www.calmac.org/weather.asp

usage) under normal conditions will then be compared against each other. This approach reduces the risk of extreme weather years and is required by the HOPPs program.

Peak Savings and Demand Models

Example text below.

The demand savings calculation will follow the DEER Peak Demand Reduction Calculations as described in the Statewide Customized Calculated Savings Guidelines. This requires any grid demand reduction to occur during the three consecutive hottest days, during 4:00 pm to 9:00 pm, for the respective California climate zone. The (customer) is located in California Climate Zone X, which has a DEER Peak Period of <date> through <date>. If the peak period falls on a weekend, the following three weekdays are to be used.

Demand savings are based on energy models constructed using hourly time intervals. Since demand savings are expected from the reduction of the building's electric energy use, electric data were used to develop hourly energy models. Their goodness of fit metrics are shown in the Attachment. (in cases where the model fails, traditional engineering calculations will be used or demand savings incentives will not be determined.)

Normalized Savings Uncertainty

Example text below.

The resulting estimated savings uncertainty, using the ASHRAE Guideline 14 method for the anticipated project savings, will reflect assumption errors; measurement errors in both the independent and dependent variables; random and systematic measurement errors; and errors in the regression model, which include predictive and normalization errors.

Non-IOU Fuel Analysis

Example text below.

For schools where PV systems (or other on-site generation) are installed, a non-IOU analysis is required. A non-IOU analysis assures that incentives for savings are capped based on what is delivered from the grid through PG&E's electric meter. For electricity, this analysis is performed on an hourly basis. The non-IOU fuel analysis procedure will follow that described in (PG&E non-IOU analysis reference).

Savings Tracking Frequency

Example text below.

Savings progress reports are short memoranda showing the avoided energy use (savings to date) achieved at specified intervals during the performance period. Savings progress reports will be provided at (3 and 6 months). The 12-month normalized energy savings report will be provided after 12 months of performance period data has been collected. The data to be provided along with these reports will include raw, cleaned, and analyzed data. Normalized savings will be reported using graphs and/or other means of data visualization.

Responsibilities

Table 1: M&V Roles and Responsibilities

Role	Responsibility	Contact
Owner / Facility management	**Monitor project and keep parties informed. Collect utility bills, provide to M&V agent. Provide access to utility and non-utility meter data to M&V Agent.** **Provide any independent variable data to M&V Agent.** **Work with customer to verify installation and proper functioning of measures. Assist with identification of NREs.**	**Name** **Title** **Company** **Phone** **email**
M&V Agent	**Collect and verify energy use and weather data. Perform all M&V tasks. Document savings reports.**	
Program Administrator, Quality Assurance Provider, Financial Stakeholder	**Review M&V activities, data, and analysis, work with M&V agent to ensure results accurate and reliable.** **Provide input to Owner/ Facility Management regarding M&V-related issues to be resolved, and their resolution.**	

Energy Savings Report Contents

Example Text Below.

Contents of the 12-month Savings Report will be the same as required in the PG&E NMEC M&V Procedures Manual. It will follow the provided Savings Report Template.

Appendix A: Goodness-of-Fit Metrics

Coefficient of Variation of the root mean squared error, CV(RMSE)

$$CV(RMSE) = \frac{\left(\frac{\sum_{i=1}^{n}(E_i - \hat{E_i})^2}{n-p}\right)^{1/2}}{\bar{E}}$$

CV(RMSE) is a measure of random error between a model's predictions and the actual data. Generally, we want to minimize this error as much as possible.

Net Mean Bias Error (NMBE)

$$NMBE = \frac{\sum_{i=1}^{n}(E_i - \hat{E_i})}{(n-p) \cdot \bar{E}}$$

NMBE is a measure of the difference between the model's predictions of training period total energy use and the actual energy use. This error should be very low.

Coefficient of Determination, R^2

$$R^2 = \left(\frac{1}{n}\sum_{i=1}^{n}\frac{(x_i - \bar{x})(E_i - \bar{E_i})}{\sigma_x * \sigma_E}\right)^2$$

The coefficient of determination describes how well the independent variables explain the variations in the dependent (energy) variable. Higher R2 means the independent variables have more explanatory power. This is an informative metric only, not a criterion, because while the energy use sometimes may not have high variation, an independent variable may adequately 'explain' the existing variation in the energy use, despite a low R2.

Fractional Savings Uncertainty

ASHRAE Guideline 14-2014 provided the following 'fractional savings uncertainty' formulas as a means to estimate the uncertainty of the savings estimated with this modeling approach. The formulas also enable the estimation of how well we will know savings based only on the baseline model's goodness of fit, the number of points in the baseline and post-installation periods, the amount of savings, and the level of confidence at which we estimate the uncertainty. For daily or hourly models, they include a correction for autocorrelation. Using these formulas, we can estimate what the savings uncertainty, at 90% confidence, would be for a project that yields 10% savings, with a year of post-installation period monitoring, using a baseline model with its MSE or MSE' value and a year of baseline data. We want the uncertainty to be low, but the minimum level of uncertainty cannot be greater than +/- 50% at the 90% confidence level. Note the percentage refers to the amount of savings, not to the baseline energy use.

Additional research by LBNL showed that ASHRAE's formula underestimated uncertainty when used on hourly models, due to the high degree of autocorrelation in the data. This is why uncertainty in hourly models is not reported in the predictability report.

Savings Uncertainty, models with autocorrelation (hourly or daily):

$$U = \frac{\Delta E_{save,m}}{E_{save,m}} = \frac{\alpha * t_{(1-\alpha)/2,n\prime-p}}{m * \bar{E}_{base,n} * F} [MSE'(1 + 2/n') * m]^{1/2}$$

$$MSE = \frac{1}{n' - p} \sum_{i}^{n} (Y_i - \hat{Y}_i)^2$$

Savings Uncertainty, models without autocorrelation (monthly):

$$U = \frac{\Delta E_{save,m}}{E_{save,m}} = \frac{\alpha * t_{(1-\alpha)/2,n-p}}{m * \bar{E}_{base,n} * F} [MSE(1 + 2/n) * m]^{1/2}$$

Energy Savings Required for Uncertainty @ 90% Confidence Interval (10%) = 0.1*E

Where:

E_i is the measured energy use in any time interval, in energy units

$\hat{E}_i$ is the model's predicted energy use in any time interval, in energy units

$\bar{E}$ is the average energy use over all the time intervals, in energy units

E is the total energy use over the training time period

$E_{save,m}$ is the estimated energy savings over m time periods, in energy units

n is the number of data points in the training period

p is the number of parameters in the model

x_i is the value of the independent variable in any time interval

σ_x is the standard deviation of the distribution of dependent variable values

σ_E is the standard deviation of the distribution of energy use values

$\Delta E_{save,m}$ is the absolute precision of the savings estimate over m time periods, in energy units

t is student's t-statistic for the specified confidence level and n-p degrees of freedom

$alpha$ is an equation depending on the analysis time interval:

$\alpha = 1.26$ for hourly interval data

$\alpha = -0.00024M^2 + 0.03535M + 1.00286$ for daily interval data

$\alpha = -0.00022M^2 + 0.03606M + 1.94054$ for monthly interval data

M is the number of months in the reporting period

n' is the number of data points in the model training period, corrected for autocorrelation

m is the number of data points in the proposed post-installation period

F is the expected savings, expressed as a fraction of training period energy use

Attachment 1: M&V Data and Modeling Information

Energy Conservation Measures

Table 1: Energy Efficiency Measures' Summary

#	Measure	Measure Description	Electricity Savings (kWh/yr)	Electric Demand Reduction (kW)
1	Exterior Fixture Retrofit – HID, CFL, or Incandescent to LED	It is recommended to replace 61 metal halide, 14 high pressure sodium, nine (9) incandescent fixtures with LED fixtures, relamp 50 2-lamp T8 fixtures with TLED lamps, and relamp one (1) incandescent fixture with an LED lamp.	39,302	0.00
2	Interior Linear Fluorescent Relamping – T5 relamp to reduced wattage	It is recommended to relamp 36 4-Lamp T5 fixtures with reduced wattage T5 lamps	713	0.01
3	Lighting- Retrofit Interior Lamps to LED – T12 or T8 relamp to TLED	It is recommended to relamp ten (10) 1-lamp T8 fixtures, 171 2-lamp T8 fixtures, eight (8) 2-Lamp T12 fixtures, and 446 4-lamp T8 fixtures with TLED lamps.	45,178	0.52
4	Lighting- Interior Fixture Retrofit – Incandescent or CFL fixture retrofit to LED	It is recommended to replace six (6) circline fluorescent fixtures with LED fixtures.	407	0.01
5	Lighting- Retrofit Interior Lamps to LED – Incandescent or CFL relamp to LED	It is recommended to relamp 52 incandescent fixtures with LED lamps.	4,488	0.06
6	Lighting- LED Exit Signs – Incandescent or CFL exit sign fixture retrofit to LED	Replace two (2) incandescent exit signs with LED exit signs.	666	0.00
7	Lighting Controls – Interior and Exterior Controls	It is recommended to install Interior and Exterior Controls to reduce unnecesary run hours	12,670	0.00
		Total	**103,423**	**0.60**

Energy Service Accounts and Model Training Period

Table 2: Meter List

Service Account #	Energy Source (elec., gas, etc.)	Model Training Period		Annual Energy Use (kWh)
		Start	End	

Energy Use (Dependent) Variables

Table 1: Data Preparation

Variable	Issue	Number Points Affected	Action Taken	Basis for Action Taken
kWh (dependent)	None	0 (out of 8,760) ~ 0.0%	None	NA

Independent Variables

Table 4: Weather Data

Variable	Issue	Number Points Affected	Action Taken	Basis for Action Taken
Temperature (independent)	Missing Data Points	Date: # points	Removed	Removed entire day if missing data was greater or equal to 4 hours.

Table 5: Operation Periods

Operation Period	Start and Finish Dates
School Holidays (end date inclusive)	1/1/18 -1/5/18, 1/15/18, 2/16/18, 2/19/18, 3/30/18, 4/2/18 – 4/6/18, 5/28/18, 9/3/18, 10/22/18 – 10/26/18, 11/22/18 – 11/23/18, 12/24/18 – 12/31/18
Summer School	6/19/18 – 7/13/18
Maintenance	6/14/18 – 6/18/18; 7/14/18 – 8/4/18
Pre-class Ramp Up	8/5/18 – 8/22/18

Model Training Period Non-Routine Adjustments

Baseline Model Accuracy Metrics

The model accuracy metrics are shown in the below table. R2, CV(RMSE), NDBE, and the uncertainty associated with achieving an assumed 10% savings from the installed measures were calculated in the R programming software. The uncertainty was determined at the 90% confidence level.

Model	Meter	Analysis Time interval	Baseline Period	R2	CV(RMSE)	NDBE	U (for at least 10% savings, 90% CI)
Electric	YYYYYY	Daily	(04/01/2019 to 03/31/2020)	0.58	9.28%	0.000%	6.3% (31,650 kWh)

Coverage Factors

Model	Baseline Period		Extended Baseline Period		Temperature Coverage Factor	Days Coverage Factor	Days 'Uncovered'
	Min Temp °F	Max Temp °F	Min Temp °F	Max Temp °F			
Electric, kWh							

Appendix 4: Savings Progress Report Template

Savings Progress Report

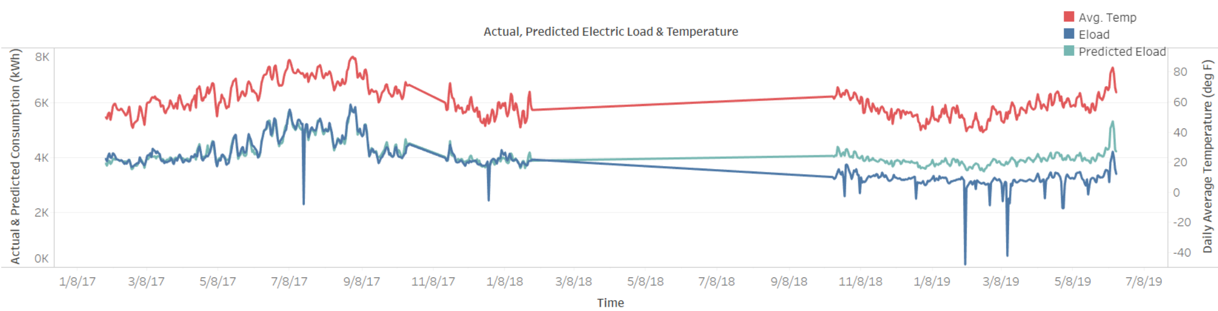
Prepared for: [program name]

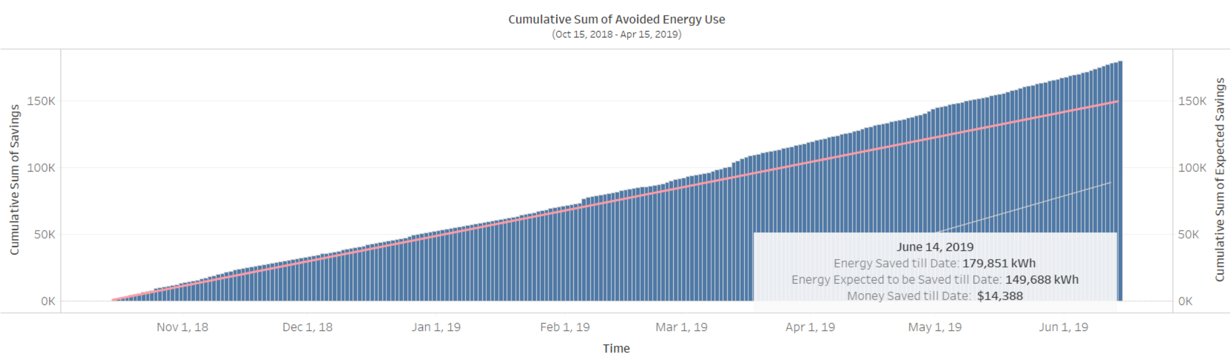
Prepared by: [implementer name/firm]

Project Name:

Date

Energy Savings Progress





The upper chart shows the time-series data: the ambient dry-bulb temperature (red), the building's meter data (blue), and the baseline model's predictions (green). The lower chart is a cumulative summation (CuSum) chart showing the achieved savings in the period from October 15, 2018 – June 14, 2019. The CuSum Chart also shows a red line which is the estimated savings expected in this performance period.

The baseline model was developed and documented in the M&V Plan for this project, submitted previously.

No non-routine events were detected in the baseline period (2/1/2017 – 1/31/2018) or the performance period (10/15/2018 – 6/15/2019).

The estimated savings was taken from a list of efficiency measures from the feasibility study and are summarized in the table below. After six months, the expected and actual savings are tracking closely.

Appendix 5: Savings Report Template

Normalized Metered Energy Consumption Savings Report

Prepared for: [program name]

Prepared by: [implementer name/firm]

Project Name:

Date

CUSTOMER INFORMATION	
Customer Name	**PG&E Service Account No.** Electric: Gas:
Customer Contact	**Customer Address**
Telephone	**E-Mail**

PROJECT INFORMATION		
Project Name		
Project Site Address	**City**	**State Zip**

PROGRAM CONTACTS			
PG&E Program Manager	**PG&E Engineer**	**Implementer**	**NMEC Program Consultant**

Telephone	**Telephone**	**Telephone**	**Telephone**
E-Mail:	**E-Mail:**	**E-Mail:**	**E-Mail:**

Savings Summary and Incentives

This Energy Savings Report provides a summary of the annual normalized energy savings, calculated using the performance period (from start date through end date), in the xxx Building

Table S-1: Annual Normalized Energy Savings

Building	Electric Savings (kWh)	Electric Savings (kW)	Gas Savings (Therms)
xxx	yyy	zzz	www

Incentives for the xxx Program for the 12-month performance period are summarized below.

Table S-2: Combined SCE and SoCal Gas Incentives

	PG&E Incentives ($)
Total	**$xxx**

Table of Contents

1. Introduction

2. Terminology

Baseline Period Model: A mathematical model, developed using empirical modeling methods (such as regression analysis), using energy use and independent variable data collected during the baseline period.

Performance Period Model: A mathematical model, developed using empirical modeling methods (such as regression analysis), using energy use and independent variable data collected during the reporting period.

Adjusted Baseline Energy Use: Energy use that would have occurred in the reporting period had no measures been installed. The adjusted baseline use is determined by inputting independent variable data collected during the reporting period into the baseline model.

Normalized Savings: Savings based on the overall reduction in normalized metered energy consumption. Savings from a project that are based on 'normal conditions' as agreed upon by project stakeholders. Normalized savings require that both baseline and reporting period energy use be adjusted to a common set of normal conditions.

Normal Conditions: A non-extreme set of conditions that is representative of conditions typically expected for the building and it operations. Savings estimated under normal conditions are expected to represent typical savings for the project and are not over- or under-estimated due to more extreme conditions that may occur in any given reporting period.

Non-Routine Event: An event occurring within the building that affects the energy use measured at the meter that is not due to the project's installed energy efficiency measures. Non-routine events may include equipment shut down for maintenance, added building load due to a data center, or sudden change in occupancy such as when building tenants move in or out.

Non-Routine Adjustment: Adjustments to baseline energy use made necessary by the occurrence of non-routine events. Such adjustments are necessary so that the resulting normalized savings are due to the project's installed the energy efficiency measures, and not due to other events that affect the energy use at the meter.

3. Project Description

3.1. Energy Conservation Measures

Table 3-2 summarizes the energy savings measures recommended for the xxx Building.

Table 3-2: Energy Conservation Measures' Summary

4. Deviations from Planned M&V Activities

4.1. Baseline Training Period

The baseline training periods, originally used for the M&V plan, were as follows:

Table 4-1: Original Baseline Training Periods

Building	Energy Source	Baseline Training Period	
		Start	End
xxx	Electric (kWh)		
xxx	Natural Gas (therms)		

4.2. Dependent Variables

4.3. Independent Variables

4.4. Programming Environment

4.5. Modeling Algorithm

4.5. Baseline Model Accuracy Metrics

Table 4-2: Updated Baseline Models' Accuracy Metrics

Wing	Energy Source	Analysis Time Interval	R^2 [27]	CV(RMSE)[28]	NDBE[29]	Uncertainty (for 10% savings at 90% CL)
Passing Criteria				*Must be less than 25%*	*Must be less than 0.005%*	*Must be less than 50%*
Chemistry	Electric (kWh)	Daily				
Chemistry	Natural Gas (therms)	Daily				

4.6. Baseline Model Coverage Factor

4.7. Baseline Period Non-Routine Events and Adjustments

5. Verification of Measure Installation

[27] Coefficient of Determination: $R^2 = 1 - \frac{\frac{1}{n}\sum_i^n (E_i - \hat{E}_i)^2}{\sigma_E^2}$

[28] Coefficient of Variation of Root Mean Squared Error: $CV(RMSE) = \frac{\left(\frac{\sum_{i=1}^n (E_i - \hat{E}_i)^2}{(n-p)}\right)^{1/2}}{\bar{E}}$

[29] Net Determination Bias Error: $NDBE = \sum_{i=1}^n (E_i - \hat{E}_i)/E$

6. Performance Period Model Development

6.1. Performance Period

6.2. Independent Variables

Table 6-1: Independent Variables

Variable	Source of Data	Distance to Site	Type	Time Interval
Ambient Dry-Bulb Temperature				

6.3. Independent Variables Not Included in the Analysis

6.4. Modeling Algorithm

6.5. Reporting Period Model Accuracy Metrics

The acceptance criteria for the reporting period model accuracy metrics are as follows:

1. CV(RMSE) – Less than 25%
2. NDBE – Less than 0.005%

As shown in **Table** , each model met these requirements:

Table 6-2: Reporting Period Model Accuracy Metrics

Building	Energy Source	Analysis Time Interval	R^2	CV(RMSE)	NMBE
	Electric (kWh)	Daily			
	Natural Gas (therms)	Daily			

6.6. Reporting Period Model Coverage Factor

7. Performance and Savings

7.1 Energy Performance Tracking

7.2 Reporting Period Non-Routine Events (NREs)

7.3 Normalized Savings and Uncertainty

8. Incentives

9. Quality Control Activities

Appendix A: Data and Electronic Files

Appendix B Measure Verification Report

Appendix C. Project Cost