SHAPE THE FUTURE OF ENERGY

Backcast of the University of California-Irvine Campus Energy Efficiency Upgrade: The Opportunity for Population NMEC

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I. Introduction / Key Findings and Recommendations

This report contains results and recommendations from the backcast of the University of California-Irvine (UCI) campus energy efficiency upgrades that took place from 2017 - 2019. These projects were completed in partnership with Southern California Edison as part of the UC/CSU Statewide Energy Efficiency Partnership Program. Projects focused on seven buildings that received a wide range of upgrades.

In this backcast Recurve evaluated the viability of the population-level NMEC[1] approach for the UC system by analyzing the meter-based performance of the UCI projects. Based on the definitions provided by the CPUC, population-level NMEC is appropriate when savings claims are made for a portfolio of projects using fixed, standardized, verifiable measurement methods that are established before the program starts and are uniformly applied to all sites in the group.[2] All NMEC approaches are based on pre- and post-intervention energy consumption data observed at the meter. Eligibility criteria are based in part on model fit (gauged by the coefficient of variation of the root-mean squared error or CVRMSE) and portfolio fractional savings uncertainty (FSU)[3]. Recurve tracked savings for all projects from their inception through March 2020. At that point projects had delivered a total of 9,407 MWh of savings across 12 electric meters with an FSU of 16.87%. Putting the savings value on an annual, normal-weather year[4] basis, Recurve calculates savings of 4,086 MWh for the 12 electric meters. Recurve observed that the energy usage pattern of the Sprague Hall cold water system in the reporting period was not captured by a limited baseline period and resulted in a savings outlier. This meter is not included in the backcast analysis.

With daily CalTRACK methods Recurve found the baseline-period coefficient of variation of the root-mean-squared error (CVRMSE; a standard measure for model fit) to range from .04 to .34, well under the 0.75 upper limit often applied within population NMEC programs. However, only four electric meters passed CalTRACK data sufficiency requirements. This appears to be due to UC Irvine initiating data collection in 2016 under the UC/CSU Partnership's Monitoring-Based Commissioning (MBCx) Program with a shorter baseline data collection requirement, leaving a number of meters without the full year of baseline (pre-intervention) data needed to specify a predictive model per CalTRACK requirements. Going forward this should not be an issue due to subsequent data collection for UC buildings given updated program baseline data requirements and the availability of other sources of consumption data such as utility smart meter data.

Based on these findings, the UC system is a promising candidate for NMEC evaluation, but it will be imperative that sufficient data be available for target sites prior to project implementation.

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

[2] CPUC's full definition: "Population-level NMEC is an energy savings calculation approach in which results are based on pre- and post-intervention energy usage data observed at the meter and calculated across a group of sites, rather than a modeled engineering forecast or deemed value (or a Site-level metered savings calculation). For Population-level NMEC, measurement methods are fixed before the program starts and apply to all sites in the group in a uniform fashion, as opposed to Site-level NMEC measurement methods which may differ on a site-by-site basis." Rulebook p. 24

[3] https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442463694

[4] Savings projected onto a TMY3 (standardized) weather year

II. Methods and Data/Results Summary

Recurve utilized the CalTRACK 2.0 Daily and Hourly methods and the OpenEEmeter open-source Python code-base to conduct all savings calculations presented in this backcast.[5] The CalTRACK Daily methods describe a set of linear regression models with variable balance point temperature. The CalTRACK Hourly model is a Time-of-Week and Temperature (TOWT) model and operates using a temperature-binning scheme of up to seven distinct bins. The model is piecewise linear across the bins. The model is also weather normalized and toggles between occupancy states depending on hourly usage patterns. All CalTRACK methods are described in full detail at www.caltrack.org and the hourly methods are summarized in a recent article on Recurve's website.

In measuring savings, Recurve first establishes a model based on pre-program consumption data. This time period is known as the "baseline" and the model as the "baseline" model. CalTRACK calls for a minimum of 328 days of data to construct a baseline model but this requirement can be relaxed for the analytical purposes of this study. Recurve then projects this model into the 365-day period following program participation (the "reporting period"), applying the temperature data of the reporting period. This model projection, known as the "counterfactual," represents the estimation of energy usage that *would have* occurred in the absence of program intervention. The difference between this counterfactual and actual consumption is taken as the savings attributable to the program. This process is completed for each meter and results are aggregated as needed to analyze different segments of the population.

Table 1.1 gives meter counts for the groupings of projects that Recurve investigated as part of this backcast. The initial UCI dataset contained 20 meters for 7 different project sites; 13 of these were electric and 7 were gas. All meters had acceptable CVRMSE for the CalTRACK daily model. In the first grouping, Recurve is not applying data sufficiency filters that would typically be required in a population NMEC program. In the second and third groupings Recurve removed meters with less than 328 days of data in either the baseline or reporting periods.

The first grouping represents the best estimate of weather-normalized changes in consumption after program participation. To calculate this value Recurve has not applied data sufficiency filters or adjusted for exogenous factors and non-routine events including the energy impacts of COVID-19. However, in assessing the viability of population NMEC, it is important to investigate cases in which data sufficiency criteria are applied and where impacts are expected to be due predominantly to the program. Therefore, in the second grouping Recurve has examined project impacts isolated to the pre-COVID period (ending March 1st 2020). In this group, only projects that have sufficient data for a full analysis of annual savings that occurred entirely in the pre-COVID period are analyzed.

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[5] The CalTRACK methods are based on industry guidelines established by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Guideline 14) and the Uniform Methods Project (Chapter 8 - Whole Building Methods). The CalTRACK methods meet all International Performance Measurement and Verification Protocol (IPMVP Option C) requirements. CalTRACK represents the most detailed public specification of IPMVP Option C and includes rigorous steps for data cleaning and organization, weather station selection and weather normalization, and selection of specific model parameters for best fit to the raw consumption data.

Finally, COVID-19 itself presents an opportunity to gauge the feasibility of population NMEC because the pandemic can be expected to alter energy consumption patterns in a similar way that efficiency upgrades might. Therefore, the third grouping represents a separate measurement focused on COVID impacts. The baseline period was defined as the year leading up to March 1st 2020 and the performance period as the beginning of lockdown measures until present day. This measurement can serve as an additional feasibility check for population NMEC by testing models on a known variable impact.[6]

Table 1.1 Observed savings and FSU for different portfolio groups

	Group 1 (pre-COVID no restrictions)	Group 2 (pre-COVID, with sufficient data)	Group 3 (COVID Impacts, post March 2020)
Reporting Period	Dec 2017 to Feb 2020	Dec 2017 to Feb 2020	Mar 2020 to Feb 2021
Electric Meters	12	4	11
Gas Meters	7	4	6
Savings (total)	32,740 MMBTU	8,701 MMBTU	2,965 MMBTU
Savings (elec)	9,407 MWh	2,621 MWh	898.4 MWh
Normal Year Savings (elec)	4,086 MWh/yr	1,068 MWh/yr	NA
Percent Savings (total)	16.75%	15.2%	2.8%
Percent Savings (elec)	19.13%	19.3%	3.1%
FSU* (total)	16.71%	31.1%	122%
FSU* (elec)	16.87%	30.0%	108.9%

*Fractional Savings Uncertainty at the 90% confidence level

In establishing rules to guide population NMEC programs, the CPUC has set an upper limit of 25% FSU at the 90% confidence level. The FSU for group 1 is within this range, however the FSUs for the pre-COVID and COVID portfolios are higher. The pre-COVID portfolio FSU of 31.1% is close to the 25% threshold and with more projects it is likely the FSU would drop. A population NMEC portfolio should generally have significantly more than 4 meters. The FSU for the COVID impacts portfolio reflects that FSU is also a function of depth of savings, with very low savings producing very high FSU values. The usage change

[6] In order to fully isolate and remove COVID impacts from program impacts a comparison group analysis should be undertaken. Recurve recently developed open source methods and code (the GRIDmeter) to automate comparison group selection and analysis. See: https://groups.recurve.com/methods.html

from COVID for these laboratories was mixed (more ventilation but less occupancy) resulting in high uncertainty in the impact estimate.

Table 2: Data sufficiency steps and project counts

Meters	W/ baseline model	W/ sufficient baseline	W/ baseline & CVRMSE
21	20	8	8

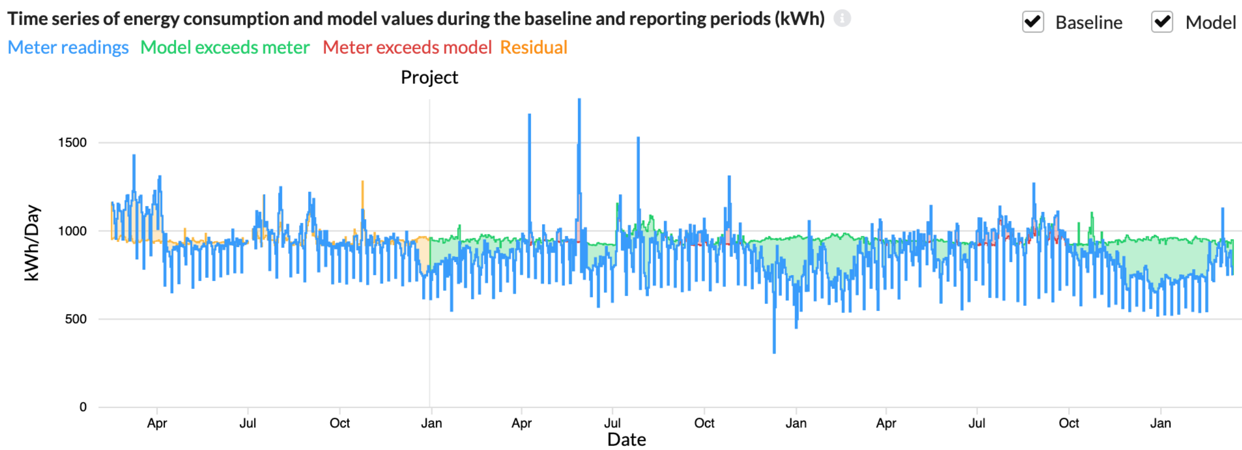
Historically, Monitoring Based Commissioning (MBCx) required only 90 days of pre-project data. It is therefore unsurprising that the UCI buildings did not always have a full year of pre-program data to specify a baseline model. With a longer baseline period and more data, stronger temperature correlation and corresponding seasonal dependence can be established resulting in better model fits and reliable counterfactuals. Using a year of baseline data delivers fully-specified models that represent a building's pre-intervention energy. Fortunately, many UCI buildings did have sufficient data, and for most far more than 90 days of baseline data existed.

III. Additional Results and Discussion

A. Project Examples

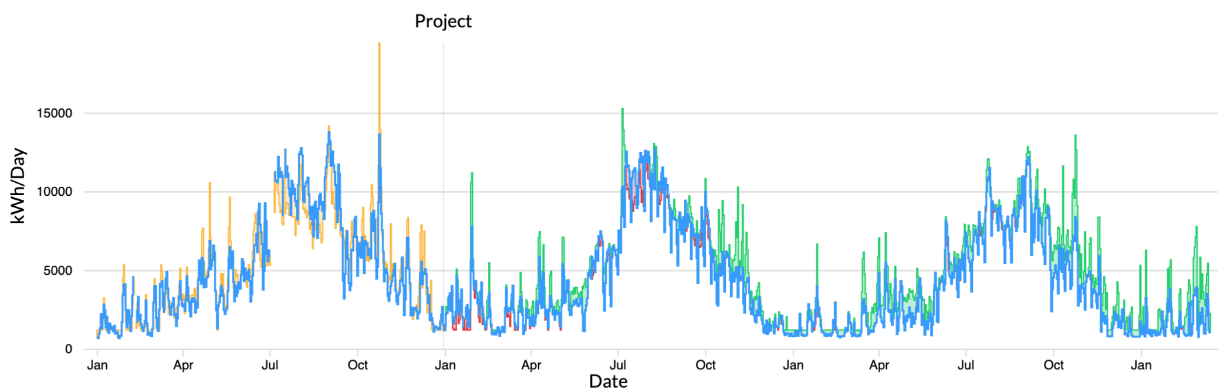
The Engineering Hall houses the department of Electrical Engineering and Computer Science, along with multiple labs, offices, and lecture rooms. Figure 1.1 shows the Engineering Hall's daily observed electricity usage (blue) along with the baseline model and counterfactual. Model residuals are shown in orange during the baseline period. The period following the project shows the savings (positive in green, negative in red). The total savings for this project was 85,280 kWh. Recurve observes a relatively high savings depth of 11.2% (savings as a percentage of usage). The combination of good model fit and high savings depth indicate that population NMEC can be a valid option for portfolios of similar projects within the UC system. The FSU for this project alone was 25.6%.

Figure 1.1: Baseline and reporting period usage (blue), baseline model (orange) and counterfactual (green/red) for the Engineering hall main site from February 2017 to March 2020.



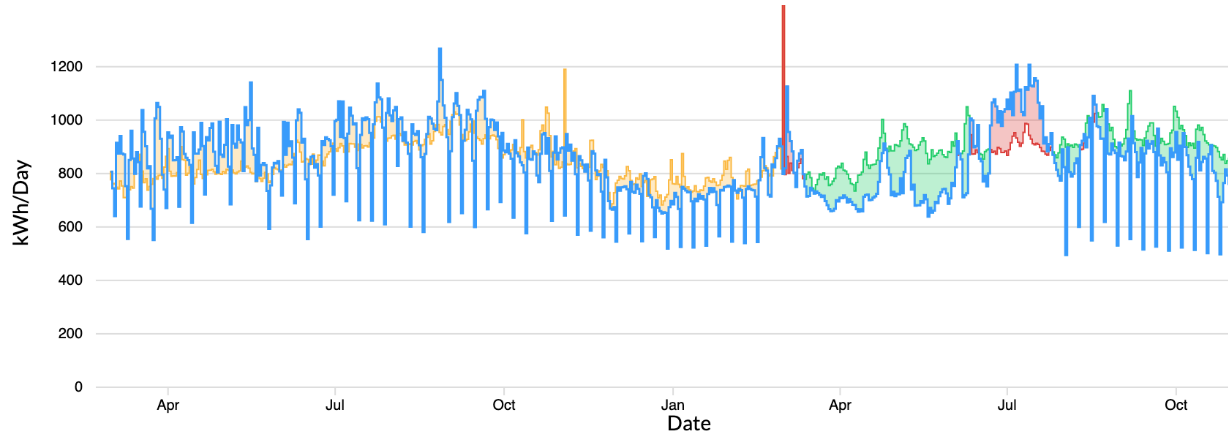
The Engineering Hall has a separate meter for the cold water space cooling system and CalTRACK modeling could therefore be performed independently for this meter. Results are shown in Figure 1.2. The savings for this system was 582,000 kWh with a 15% savings depth and an FSU of 36.18%.

Figure 1.2: Engineering hall cold water



The changes in building energy consumption on account of COVID provide another feasibility check on the ability of CalTRACK to model load impacts. In Section V we will discuss strategies and recommendations to isolate and remove COVID impacts from program savings via comparison groups. Figure 2 shows the impact of covid on engineering hall operations. The savings immediately after march 14th demonstrate the campus shut down due to COVID. The abrupt change in consumption patterns observed in March is clearly attributable to COVID and it appears that normal operations returned around August for this building.

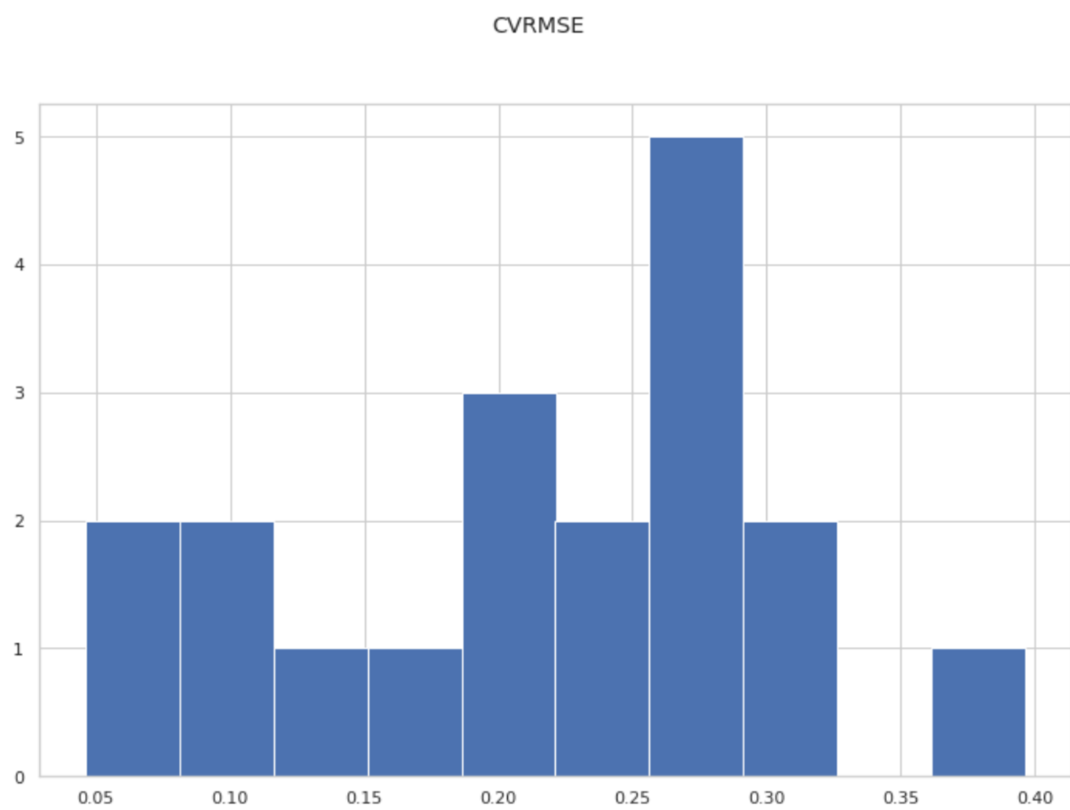
Figure 2: Covid Impacts on the Engineering hall. The baseline period is from March 14th 2019- March 2020



B. Model Fit

A common measure of model fit is the coefficient of variation of the root mean squared error or CVRMSE. CVRMSE values above 0.75 can be considered poor while values between 0.25 and 0.5 considered reasonable and values below 0.25 considered good or excellent. The CVRMSE is a reflection of the ability of a model to form an accurate prediction of energy consumption in the absence of a program. The CVRMSE of the models fell well within the bounds accepted by the NMEC process. Figure 3 shows the distribution of CVRMSE values of all the baseline models.

Figure 3: Histogram of Baseline CVRMSE for all meters



IV. Comparison to Predicted Savings

The UC system provided normal year savings estimates for the subject buildings as a comparison point for Recurve's results. There were 7 meters that met CalTRACK data sufficiency requirements and we focus on those here. The results are given in table 3.1. While individually the realization rates vary dramatically, Recurve found a realization rate (Recurve Savings est./ UC savings est.) of 140% for electric meters and 34% for gas meters. Gas meter savings was particularly shallow leading to higher variance in the comparison. The complexity of the building did not have a significant impact on model fit, implying that all buildings will make good candidates for NMEC provided that there is sufficient data and effective savings measures.

Table 3.1: Normal Year Savings for data sufficient projects

Site	Meter Name	UC Savings Estimate	Recurve Savings Estimate	Realization Rate	CVRMSE
Engineering Hall	CHW (kWh)	42,329	135,053	319%	0.24

	HTW (Therms)	9,735	4,197	43%	0.17
GNRF	CHW (kWh)	18,622	42,762	230%	0.27
	HTW (Therms)	372	-168	-45%	0.25
McGaughHall	HTW (Therms)	6,333	1,572	25%	0.27
NATSCI	CHW (kWh)	700,476	890,359	127%	0.34
	HTW (Therms)	2,800	962	34%	0.19
TOTAL Gas	(Therms)	**19,240**	**6,563**	**34%**	**NA**
TOTAL Elec	(kWh)	**761,427**	**106,8173**	**140%**	**NA**

V. Recommendations

A. Data Sufficiency

While the UC system backcast provides an excellent statistical assessment of the viability of population NMEC for UC programs, the backcast process also reveals several important logistical elements that the UC system should incorporate into program planning. Given the findings on data sufficiency, Recurve recommends screening projects to ensure that associated meters meet CalTRACK data requirements. To prepare for a program in the upcoming year, the UC system may wish to ensure that meter data is being collected (either by the campus or by the utility) and will be available where projects are anticipated.

B. FSU

The UC system must manage fractional savings uncertainty in order to manage risk in a successful population NMEC program. In addition the UC system should plan for active management of its population NMEC program based on ongoing M&V results.

Fractional savings uncertainty depends on the number of projects in a portfolio, the depth of savings of individual projects, and the model fit. All of these factors are under the UC system's control. The UC system should plan to have a high number of projects, which would help ensure that FSU can be managed and that no one project would be likely to have an outsized impact on the portfolio.

The UC system should also plan on projects that offer a high depth of savings. This means prioritizing projects such as deeper retrofits and HVAC upgrades over "light touch" projects with shallow savings. Recurve found that the UCI energy savings upgrade generally consisted of projects with deep savings.

C. Model Fit

Though no issues were found here related to poor model fit, it is still important in the pre-screening process to measure baseline CVRMSE to ensure that enrolled meters are modeled reasonably well by CalTRACK. Though certainly not required, if the UC system continues to monitor separate streams of discretionary, heating, and cooling load, Recurve anticipates that model fit should continue to be strong.

Recurve recommends that the UC system prescreen projects to ensure they qualify based on a predetermined CVRMSE threshold prior to implementation. Recurve recommends this threshold be set at .5 with case by case exceptions possible up to .75.

D. Active Management

Active management of an NMEC program allows for ongoing compliance and greatly increases the program's chance of success. NMEC projects should be screened for known major load changes unrelated to the program such as addition of solar PV or EV charging, or a large expansion of building square footage in the baseline or post-implementation measurement period. If such major projects are undertaken, submetering can be installed to monitor the usage of such systems and adjustments made accordingly. Recurve recommends that the UC system track projects in real time and to take action if FSU remains high for the portofolio after 3 - 6 months of full participation. Recurve also recommends using the CVRMSE of the reporting period model in order to screen for Non-Routine Events (NREs). Adopting a baseline and reporting reporting period CVRMSE threshold of 0.5 for automatic NRE review would help ensure that highly variable usage patterns that are not well captured by CalTRACK do not cause undue risk within the program. If CVRMSE is greater than 0.5 in a given period, it may be a signal of erratic behavior characteristic of one or more NREs.

E. Comparison Groups

Comparison groups are critical to eliminating exogenous error and should be included in future UC system NMEC. To address the impacts of COVID on energy efficiency projects, Recurve partnered with the DOE to produce an open source method for the selection and implementation of comparison groups for NMEC[7]. A comparison group is selected that shares important demographic and consumption features as the treatment population. Both groups are fit with the CalTRACK model. The participant group savings is adjusted by the observed changes in consumption over the same time period within the comparison group of similar but non-participating customers. This adjustment can be considered the exogenous error in the model. In the case of COVID, this means removing the impact of closures and reopenings from the savings estimate. The need for a comparison group can be easily seen by examining the COVID portfolio in Figure 2. Recurve recommends the UC system consider using one or two campuses as a comparison group.

VI. Conclusions

The UC system is a strong candidate for NMEC enrollments based on the result of the backcast of the University of California-Irvine Campus Energy Efficiency Upgrade. UCI buildings had strong model fits

[7]https://grid.recurve.com/uploads/8/6/5/0/8650231/recurve_comparison_group_methods_final_report_2.pdf

across the board. None had a higher baseline CVRMSE than .34. The energy efficiency projects resulted in high savings for electric sites, creating a strong portfolio signal. The FSU was acceptable according to CalTRACK criteria, with only a fraction of the normal amount of projects. In a full scale program the number of projects will dramatically increase, resulting in even better FSU. With strong model fits and effective energy efficiency measures, the UC system should be confident in its ability to qualify for, and successfully execute a CalTRACK NMEC program.

Appendix A: Fractional Savings Uncertainty (FSU)

Program Design Criteria

The UC Irvine impacts analysis has been designed to meet the CPUC criteria for population-level NMEC programs. It has a population of 7 buildings, an average savings of 6113 MMBTU, and a fractional savings uncertainty of 19.37% at the 90% confidence level. It has been calculated using ASHRAE methods at the daily level, described in the following section.

Fractional Savings Uncertainty

Calculation of Fractional Savings Uncertainty used in this plan complies with industry best practice and specifically reflects Section 4.3 of the CalTRACK methods. The two key metrics for uncertainty are the Coefficient of Variation of the Root Mean Square Error (CVRMSE) and Fractional Savings Uncertainty (FSU). The FSU depends on a number of interactive factors, several of which have non-linear dependencies. In general, driving deeper savings, recruiting buildings with good model fit, and serving a large number of customers will improve FSU at a given confidence interval. FSU at an individual site level is defined by the following equation:

$$FSU_i = \frac{\Delta U_{save,Qi}}{U_{save,Qi}} = \frac{t(aM^2 + bM + d)CV(RMSE) * \sqrt{\frac{P}{P'}(1 + \frac{2}{P'})\frac{1}{Q})}}{F}$$

where

t is the t-statistic and a, b, and d are empirical coefficients described further in the online CalTRACK documentation

M is the number of months in the reporting period

Q is the number of periods in the reporting period (days or billing periods for example)

F is the savings fraction defined as the savings divided by the counterfactual baseline usage

CVRMSE is the coefficient of variation of the root-mean-squared error and provides a measurement of the quality of model fit (lower CVRMSE equates to better model fit) and is defined as follows:

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{p=1}^{P}(U_p - \hat{U}_p)^2}{P-c}}}{\overline{U}}$$

where

U_P is the total energy use during period P

Uhat is the predicted energy use during period p

Ubar is the mean energy use during the baseline period

P is the total number of periods

c is the number of explanatory variables in the model

Fractional savings uncertainty at an aggregated (portfolio) level is calculated via the following equation:

$$FSU_{portfolio} = \frac{\sqrt{\sum_{i=1}^{N}(\Delta U_{save,Qi})^2}}{\sum_{i=1}^{N} U_{save,Qi}}$$

For UC Irvine the CalTRACK methods described above were applied to each of the 7 sites. The CalTRACK methods model each site individually before aggregating to the portfolio level with savings uncertainty reported as a first-class output. Savings uncertainty as opposed to savings depth is the ultimate parameter of concern (e.g. savings of 4+/-1% may be acceptable, but savings of 10+/-3% may be unacceptable). Aggregating results to a portfolio mitigates issues related to model noise and increases confidence in savings estimates. An extensive discussion of model uncertainty is included in CalTRACK documentation and was leveraged for this analysis.[8]

Appendix B: Additional Results

[8] See CalTRACK issue: https://github.com/energy-market-methods/caltrack/issues/71.

Individual models were created for every meter. Here are a few more examples of the model fits and savings estimates.

Figure 3.1 Bio Sci CHW:

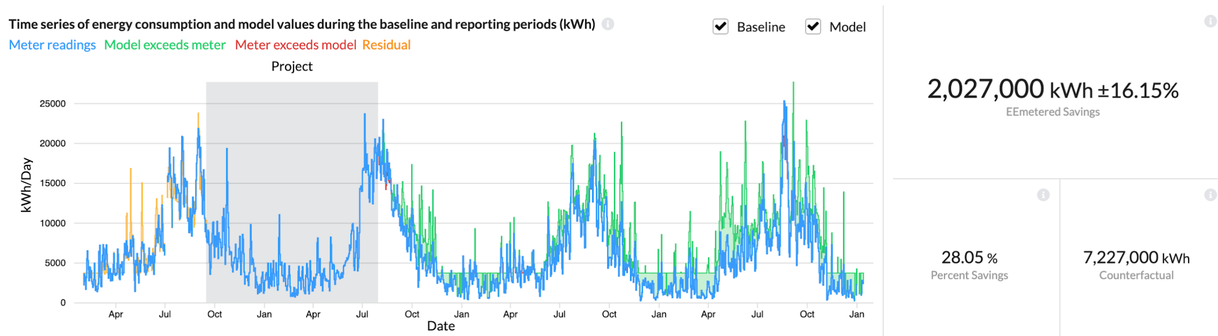


Figure 3.2 McGaugh Hall CHW Showing Monitoring of FSU and Percent Savings

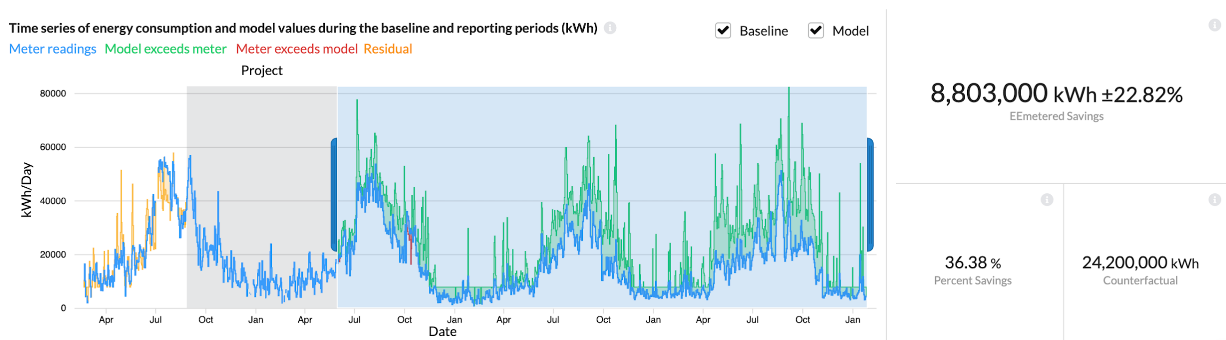


Figure 3.3: McGaugh Hall Elec Showing Monitoring of FSU and Percent Savings

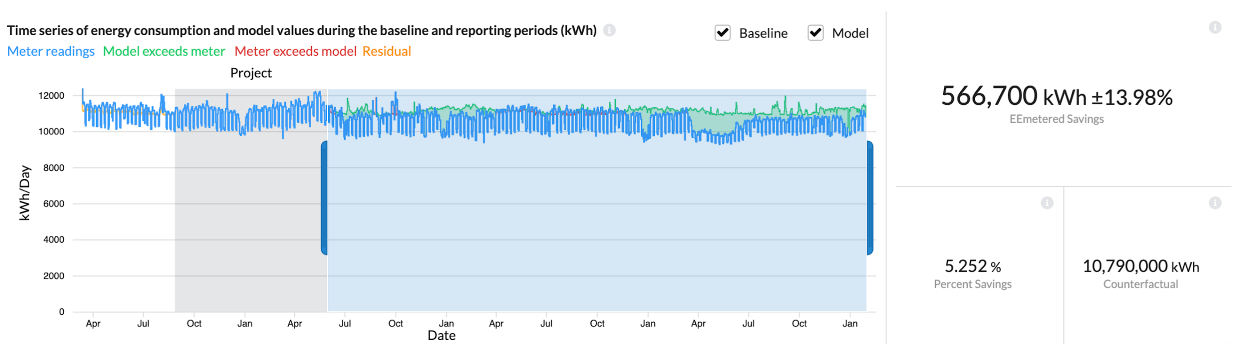


Table 3.2: Realization Rates for Electric Meters (Normal Year). Outliers removed. Note that these numbers should be considered abstractions because data sufficiency requirements were not met.

Site	Meter Name	UC Savings Estimate (kWh)	Recurve Savings Estimate (kWh)	Realization Rate	CVRMSE
Bio Sci	CHW	584,125	575,994	99%	0.23
	ELEC	659,633	163,992	25%	0.08
Engineering Hall	CHW	42,329	135,053	319%	0.24
	ELEC	35,912	33,192	92%	0.13
GNRF	CHW	18,622	42,762	230%	0.27
Gross Hall1	CHW	40,922	38,546	94%	0.2
	ELEC	33,419	112,162	336%	0.1
McGaugh Hall	CHW	2,103,767	1,800,798	86%	0.28
	ELEC	332,069	174,367	53%	0.04
Natural Science	CHW	700,476	890,359	127%	0.34
Sprague Hall	ELEC	147,695	120,368	81%	0.04
Total		**4,698,969**	**4,087,593**	**87%**	**NA**