ASSESSMENT OF THE WHOLE BUILDING SAVINGS VERIFICATION APPROACH IN THE UNIVERSITY OF CALIFORNIA MONITORING-BASED COMMISSIONING PROGRAM

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TABLE OF CONTENTS

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1. EXECUTIVE SUMMARY

The University of California (University) has been very actively participating in Monitoring Based Commissioning (MBCx) for ten years as part of the UC/CSU/IOU Statewide Partnership Program. Recently, in support of the University's Presidential Initiative to achieve carbon neutrality by 2025, there has been strong interest to leverage this MBCx experience and methodology to utilize a whole building approach in order to accurately and comprehensively quantify energy savings that translate to associated carbon reductions. In addition, the University recognizes significant value in the whole building approach's potential to: ensure long term persistence of energy efficiency investments, better manage its buildings, enable more opportunity for demand response program participation, and to track energy reduction for California Air Resources Board regulatory reporting.

Pacific Gas & Electric Company (PG&E) as administrator of public goods funding for energy efficiency has responsibility to develop cost-effective and integrated programs that deliver savings. As programs mature, opportunities to harvest "low hanging fruit" such as compact fluorescent lighting diminish and new initiatives to achieve deep and long lasting savings must be developed. To this end, PG&E recognizes the MBCx program's whole building approach as a model for energy efficiency programs to achieve deep, cost effective, integrated, and long lasting savings in its service territory.

In order to move forward, the University and PG&E needed to determine how well suited were the UC buildings for this whole building approach, were they reasonably predictable and did they generate savings estimations within reasonable tolerances.

The study addressed these questions with positive results and concluded that that the whole building approach was viable for all buildings and building types reviewed. The investigation also identified several opportunities to improve the current MBCx process and support a more robust whole building approach.

Specifically, this study reviewed several projects in the UC/CSU/IOU Partnership Program to identify its current progress in applying whole building measurement and verification (M&V) and to provide recommendations for improvement. Four areas of investigation were pursued:

1) A literature review was conducted to understand California's energy efficiency policies and strategic plans related to whole building approaches and how the MBCx program's whole building M&V method can inform them. Program M&V guidance documentation, published papers and reports, industry standard M&V guidelines, and recent evaluation reports were also reviewed.
2) Whole building data from twenty buildings at UC Berkeley and UC Davis were collected and analyzed.
3) Monitoring-Based Commissioning (MBCx) project reports and documentation were collected and reviewed to understand how campuses were implementing the M&V guidance, and what results were obtained.
4) Campus MBCx program managers were interviewed to understand how meter data was captured, and plans for how the data and analysis were used in ongoing energy management practices.

We found that baseline models developed using an advanced regression algorithm using time and temperature as independent variables and using three months of data provided robust models with goodness-of-fit metric CV well within program M&V guidelines. While the models did not consistently generate R^2 values above the program's criterion, we note that this factor has less relevance in determining model or savings accuracy.

We examined the limited data set to determine whether there were more predictable buildings included. It is important to note that all building types examined provided sufficient results to effectively utilize the whole building approach, some types performed better than others Based on our limited data, laboratories were more predictable as a group, followed by mixed use buildings. Buildings with high EUIs also tended to be more predictable. This information is useful when planning whole building M&V projects.

We found that the project's calculated savings uncertainties were predominately under 10%, with a large number under 5%. From a technical point of view, we find these values acceptable, however stakeholders must evaluate the risks these uncertainties represent and establish a suitable acceptance criterion. We note that estimations of savings uncertainties are not standard practice under California's ratepayer funded energy efficiency programs.

In addition, based on the literature review, analysis results, project report reviews, and interviews with campus managers, several recommendations for improvement were made for the current MBCx process, and to support a more robust whole building approach:

- Upgrade the MBCx program whole building M&V requirements to require or prefer one standard regression-based whole building methodology for all MBCx projects, narrow the criteria for CV(RMSE) from 20% to 15% or 10%, and introduce ASHRAE's method for predicting savings uncertainty based on CV(RMSE), amount of savings, and planned post-installation measurement duration.
- Program stakeholders should examine past results and set a criterion for acceptable uncertainty in savings estimations, enabling campuses to determine whether the whole building approach should be pursued, or whether to pursue a retrofit isolation method based on system sub metering.
- Increase reporting requirements to clearly report the important parameters used to determine savings, including start and end dates of data used, quality assurance steps, identification and treatment of non-routine events, values model goodness-of-fit metrics, modeling method used, and savings. Savings should be reported with its associated uncertainty.
- Split the responsibility for savings quantification from savings opportunity identification. Require campuses to collect and analyze building data, set baselines, and quantify savings according to program requirements. This transfers the monitoring and tracking of building energy performance and savings from service providers to campuses, with the added benefit that campus personnel incorporate the data and analysis into ongoing practices. Campus personnel could engage with a larger pool of service providers, including commissioning agents, and HVAC and controls contractors to identify and correct operational deficiencies under the MBCx program. Deficiencies may be corrected when they occur rather than after reports are generated.
- Provide software tools for the whole building M&V analysis or assist campuses in programming the method in their energy information systems. Service providers may use software tools for

analysis, and upon project completion, deliver the data and analysis in software tool form directly to those responsible for maintaining use over time.

- Include fault detection and diagnostic algorithms in software tools. Establish the key diagnostics determined in individual building projects as a resource for addressing on-going maintenance of energy performance.

The next research steps were identified. These were (1) expand the study to determine application of the whole building approach in different climate zones and more building types, including smaller buildings and residence halls which typically receive less attention due to the low cost-effectiveness of the MBCx process in these buildings, (2) develop an acceptance criteria for the whole building approach based on building predictability, savings uncertainty, and financial risk, and (3) develop a top-down M&V protocol starting with whole building then system-level approaches that are integrated with campus resources so that persistence strategies may be pursued. Conduct case studies documenting application of the protocol.

The MBCx program is uniquely positioned to demonstrate how a whole building approach can address several barriers that prevent buildings from achieving deep and long-lasting savings. It can demonstrate the value of high frequency data made available from smart meters. It can demonstrate the effectiveness of new empirical modeling methods in M&V applications. Its M&V guidance can serve as a model for other non-public sector programs, through software applications in individual tools or programmed into enterprise-wide energy information systems. It can standardize the M&V process, which has benefits in streamlining technical review and evaluation. Its data and analysis methodologies may also be integrated into building management practices, which serve to maintain and continue achievement of gains in energy efficiency over longer terms. These are the key steps to success identified in California’s energy efficiency policies and strategic plans.

2. INTRODUCTION

The University of California, California State University, and Investor Owned Utility (UC/CSU/IOU) Partnership's Monitoring Based Commissioning (MBCx) Program has reached a ten-year milestone. This innovative program has progressed from a pilot in 2004 to a mature program in 2014 that pays its incentives based on verified savings.

A key element of the program is its emphasis on monitoring—particularly the installation of energy meters to provide measurements of whole building energy use in short time increments such as 5 or 15 minutes. This data is used to develop a rigorous analysis of each project's savings, enable a more informed building energy management strategy, and ultimately lead to deeper savings and longer savings persistence. To meet these objectives, the program emphasizes a whole building measurement and verification (M&V) approach and requires training for campus operations personnel on commissioning and energy management practices.

Concurrently in the last ten years, several developments in energy metering, network communication and data management, and analytic capabilities have enabled advancements in building energy management. For example, remote building monitoring and electronic dashboard systems provide actionable information to help manage building operations and energy use. The rise of demand response applications to help mitigate a customer's peak power expenses has yielded analysis techniques that generate more accurate predictions of building energy use patterns on an hourly basis.

Recent studies have advanced the practical application of whole building M&V methods. Granderson and Price (LBNL, 2012) demonstrate the accuracy of different whole building methods over and above linear and mean week methods. Another recent study has yielded a methodology to evaluate the accuracy of energy models used in whole building M&V (PG&E, 2013). These algorithms are finding widespread use in quantifying savings from energy management programs. Much of this development can be traced to innovative programs such as the partnership's MBCx program.

Recently, in support of the University of California's Presidential Initiative to achieve carbon neutrality by 2025, there has been strong interest to leverage this whole building approach in order to accurately quantify energy savings that translate to associated carbon reductions. In addition, the University recognizes significant value in the approach's potential to: ensure long term persistence of energy efficiency investments, to enable more opportunity for demand response program participation, and to track energy reduction for California Air Resources Board regulatory reporting.

Pacific Gas & Electric Company (PG&E) as administrator of public goods funding for energy efficiency has responsibility to develop cost-effective and integrated programs that deliver savings. As programs mature, opportunities to harvest "low hanging fruit" such as compact fluorescent lighting diminish and new initiatives to achieve deep and long lasting savings must be developed. To this end, PG&E recognizes the MBCx program's whole building approach as a model for energy efficiency programs to achieve deep, cost effective, integrated, and long lasting savings in its service territory.

In light of the MBCx program history and recent program evaluation, and in an effort to improve procedures to achieve its objectives of deeper and more long lasting savings and cost effectiveness, PG&E and the University of California initiated the study detailed in this report to evaluate the application of whole building M&V in MBCx projects and to identify areas for improvement to better meet these program goals.

This study was undertaken in four parts:

1) A literature review to provide context and identify areas for improvement this study may address;
2) An in-depth analysis of whole building data and reports from 20 buildings selected from two UC campuses
3) A review of Monitoring-Based Commissioning (MBCx) project reports; and
4) An informal interview of campus MBCx program managers.

The literature review was conducted to identify critical issues regarding the application of whole building M&V and summarized as part of the research plan for this project. The plan identified several research questions and a methodology to address them.

The primary research questions were:

1) How well suited are UC buildings for the whole building M&V approach?
2) How well is the current whole building M&V guidance followed?
3) What guidance in terms of data and model development is needed to assure savings are estimated within reasonable tolerances?
4) Can a more standard M&V procedure be prescribed?
5) In what ways can whole building data be used to monitor and track energy use and persistence of savings?

Additional questions that were addressed as part of this study included:

1) How can unexpected energy use behaviors be treated, measured, or documented, in order to maintain accurate savings estimations?
2) What energy efficient measure based verification activities can be included to meet the regulatory requirements of savings attribution? And
3) How may MBCx program approaches and best practices be used to help California toward its strategic goals of deep and long energy efficiency?

The draft research plan was circulated among MBCx program stakeholders, and their feedback was used to update the research plan, which is included as **Appendix A** of this report.

This report describes the research methodology used to evaluate application of whole building M&V in 20 UC Buildings at two UC campuses. It provides a review of implemented whole building M&V for selected MBCx projects and feedback from an informal interview of campus MBCx program managers. Analysis of findings from these investigations are discussed and used to inform recommendations for program improvement.

3. METHODOLOGY

3.1 BUILDING SELECTION

Twenty buildings that have implemented MBCx measures or installed retrofits were selected for this study, ten from UC Davis and ten from UC Berkeley (Table 3-1, next page). We sought projects that were implemented in the most recent program cycles, with installation completion dates within the last three years. Buildings were selected based on the following general criteria:

1. The selected projects had a high level of savings, generally greater than 10% of annual use;
2. The quality of whole building energy use data was high (e.g. minimal gaps in data) and buildings with many unexpected changes in use patterns were avoided;
3. There were at least six months of baseline period data;
4. There were at least six months of data between consecutive projects (e.g. MBCx and retrofit projects).

Building projects with high savings were desired because savings could be attributed to the efficiency projects (MBCx or retrofit) with greater accuracy. Savings would be more difficult to distinguish when they were low relative to the building's total usage or if there were building operation or occupancy changes occurring in the same time period as an installed measure. In some cases the projects did not meet these criteria, and a few building projects with low savings were selected.

In addition to the whole building data, we obtained project documentation, including MBCx project reports, system operations data, spreadsheet analysis files, and completed program forms. A summary report from the program administrator's project database yielded the best available installation dates for projects. This report revealed that multiple projects were installed in the selected buildings, with retrofit project installations often following MBCx projects some months after their completion.

We compiled building sizes in square feet, space use type, and annual energy use from these documents. The buildings selected represented a wide range of buildings typically found on UC campuses, but they should not be considered a representative sample as no sampling strategy was employed in selecting them.

TABLE 3-1
Selected Buildings for Whole Building Study

	Building Name	EUI	Use	Project Type	
				MBCx	Retrofit
UC Davis	Wellman	1.39	Classrooms		2*
UC Davis	Olson	4.05	Classroom	1	1
UC Davis	Shields	7.72	Library		2
UC Davis	King	9.85	Classrooms		1
UC Davis	Tercero	9.87	Residential - Dorm	1	1
UC Davis	Mrak	17.3	Office		2
UC Davis	Hutchison	23.6	Laboratory	1	2*
UC Davis	Academic Surge	24.8	Laboratory	1	1
UC Davis	Plant and Environmental Sciences	30.0	Laboratory	1	
UC Davis	Tupper	32.1	Laboratory		1
UC Berkeley	Bechtel	7.34	Mixed	1	
UC Berkeley	Doe	8.38	Library	1	1
UC Berkeley	Gardner	14.4	Library	1	1
UC Berkeley	Haas	18.1	Mixed	1	1
UC Berkeley	Donner	22.2	Laboratory		1
UC Berkeley	Hearst Mining	32.4	Mixed		1
UC Berkeley	Hildebrand	34.6	Mixed	1	
UC Berkeley	LSA	36.8	Laboratory	1	
UC Berkeley	Tan	37.0	Mixed		1
UC Berkeley	Cory	63.8	Laboratory	1	

* Due to the close install dates of these projects, they were modeled as one project with a longer install period.

3.2 DATA COLLECTION

Hourly outside air temperature (OAT) data was acquired from the airport nearest to the University. For UC Davis, OAT data was from Sacramento International Airport (SMF) and for UC Berkeley, OAT data was collected from Oakland International Airport (OAK). (Both campuses had on-site weather stations, however because we could not collect a weather dataset that spanned the entire date range of interest for either campus from these sources, we used data from the local airports.)

Whole building electric data was acquired for each building for the time period from when the meter was installed and calibrated through fall 2014. UC Davis whole building data was provided by its campus utilities department. UC Berkeley data was made available for downloading directly through a website.

All MBCx reports and associated retrofit documentation for each building were provided by PG&E through its program administrative group, Newcomb Anderson McCormick. The documents contained detailed project information such as the list of measures, dates for measure installations, description of M&V approach, and data and analysis files.

Bad data was often evident in the whole building datasets. Bad data included noise or gaps where no data was recorded. The presence of bad data could be due to meter or sensor errors, or errors in transmission or recording. If the dataset contained too much noise or a large number of gaps, we excluded the building from the study. When there were a few bad data points, the values were deleted from the dataset, and the remaining building data was used.

Baseline models were established using three and six months of consecutive data. Typically, the last day of the baseline period was aligned with the start date of the install period. In some cases, non-routine (NR) events occurring around the install period were avoided and the baseline period was adjusted to an earlier time period.

Buildings with multiple projects (MBCx or retrofit) were selected if their installation periods were at least six months apart. This allowed enough time to monitor a full range of building operation between projects. Savings were then calculated for the first set of measures. For buildings with a second set of measures, the same baseline model was used to estimate the cumulative savings of both projects. This approach was useful for examining the cumulative effects of savings from multiple projects.

3.3 ANALYSIS PROCEDURE

For whole building M&V, industry-standard guidelines (EVO, 2012, ASHRAE 2002) required that an empirical relationship between baseline energy use and independent variables be developed. This was necessary to enable baseline use to be adjusted to post-installation or other conditions when calculating savings. This was an important step in the savings estimation process and was echoed in the MBCx program's M&V guidelines. There were several ways this statistical relationship may be developed. To reduce variability in modeling approaches, we applied one consistent methodology and modeling algorithm consistently in the development of baseline energy models and estimation of savings.

Baseline models were developed using an advanced regression-based energy modeling algorithm originally developed for demand response applications by Lawrence Berkeley National Laboratory (Mathieu, et. al., 2011). This algorithm included time of week and ambient temperature as independent variables[1] and has been shown to be more accurate than models using ambient temperature alone (PG&E, 2013). We used hourly analysis time intervals, meaning that energy use was summed to totals each hour, ambient temperatures were averaged over each hour, and an hour-of-week indicator was used to account for time effects. We did not separate the data into occupied/unoccupied or weekday/weekend/holiday periods for separate baseline model development, as the time-of-week and temperature algorithm was sufficiently accurate for this study's purposes, and the effort to account for these operation periods of the different building space use types had uncertain value. The only data filtering used was to eliminate bad data and erroneous values that were due to errors in measurement and recordings. Non-routine events were also filtered, as described previously.

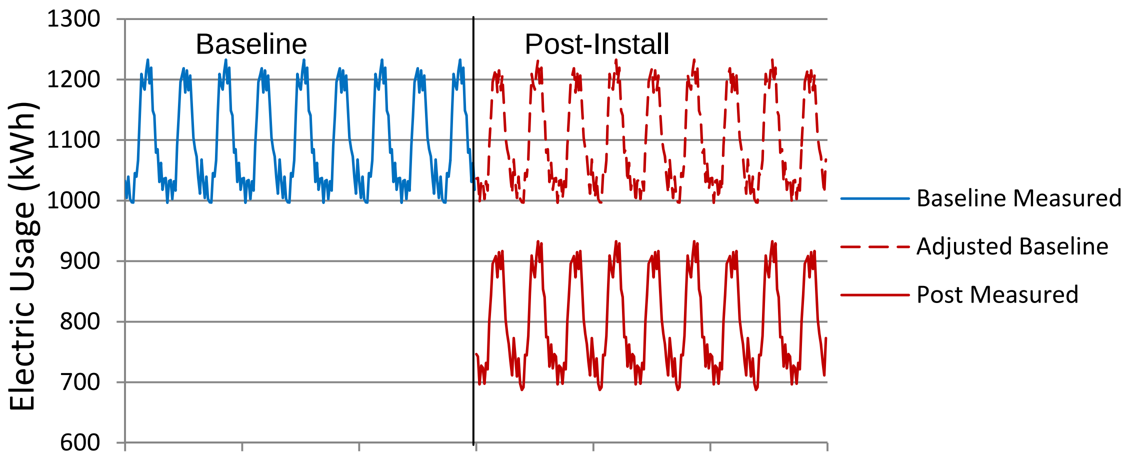
The baseline energy use models were created with the measurement and verification analysis module within PG&E's Universal Translator, version 3 software. This software tool was developed with funding from the California Energy Commission's Public Interest Energy Research Program (Haves, et. al., 2015). This M&V module used the time and temperature algorithm described above to capture baseline energy use behavior with time of week and ambient temperature, and to estimate savings. The module

[1] The algorithm is not limited to time-of-week and ambient temperature, it may include other independent variables such as humidity, occupancy variables, and other influencing factors.

determines the goodness-of-fit metrics: coefficient of variation of the root-mean squared error (CV(RMSE), or CV) and coefficient of determination (R^2) for baseline and post-installation models it develops. The software allows the user to create different analysis bins and models for different periods of operation; however we did not use this feature in order to maintain a consistent modeling procedure across all projects.

Savings were calculated in the M&V analysis module using two approaches: "Avoided Energy Use" and "Normalized Savings." The Avoided Energy Use method estimates savings by subtracting the measured post-installation energy use from the adjusted baseline use, as predicted by the baseline model under post-installation time-of-week and temperature conditions (Figure 3-1). Avoided Energy Use can only calculate annual savings when there is a full year of post installation data. For cases when the post installation period was between six and twelve months, we used the normalized savings method to estimate annual savings. This required a post-installation model also be developed. We used typical meteorological year 3 (TMY3) ambient temperature data in each climate zone as the conditions to which we adjusted baseline and post-installation energy use. The adjusted post installation model usage was subtracted from the adjusted baseline model usage to determine normalized annual savings under TMY3 conditions.

Figure 3-1. In the avoided energy use method, savings are calculated by subtracting the post measured data from the adjusted baseline.



Goodness-of-fit and uncertainty metrics were calculated for each model to track how well the models reproduced energy use data and to track the accuracy of the savings estimates. These metrics included the CV (Equation 1), R^2 (Equation 2), and the fractional savings uncertainty (Equation 3). The fractional savings uncertainty (FSU) is the industry-standard metric described in ASHRAE Guideline 14 (ASHRAE 2002) to estimate savings uncertainty in regression-based M&V analysis, including whole building M&V. The FSU could be estimated in the baseline period to assess the quality of the baseline model relative to the expected amount of savings and monitoring period durations. The FSU could be recalculated after post-installation monitoring was complete and savings were estimated.

QuEST

$$R^2 = \frac{\sum_{i=1}^{n}(E_i - \bar{E})^2 - \sum_{i=1}^{n}(E_i - \hat{E}_i)^2}{\sum_{i=1}^{n}(E_i - \bar{E})^2} \quad (1)$$

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(E_i - \hat{E}_i)^2}{n}}}{\bar{E}} \quad (2)$$

$$FSU = t \cdot \frac{1.26 \cdot CV(RMSE) \cdot \sqrt{\frac{n}{n'}\left(1 + \frac{2}{n'}\right)\frac{1}{m}}}{F} \quad (3)$$

where:

E_i = measured data during the period i

$\hat{E}_i$ = modeled data during the period i

$\bar{E}$ = average of measured data

n = number of data points in baseline period

n' = number of statistically independent data points in baseline period

m = number of data points in post-install period

F = fraction of savings to annual use (estimated in baseline period or realized in post-install period)

t = t-statistic for desired confidence interval

For each building, avoided energy use and normalized savings estimates and their uncertainties for each project based on three and six month baseline periods were recorded. For each baseline period the goodness-of-fit metrics and estimate of uncertainty were calculated and recorded. We also estimated annual energy use from the data and captured savings estimates, floor area, and building type from project documentation. This information was analyzed to help address the research questions posed at the outset of this project.

3.4 REVIEW OF PROJECT DOCUMENTATION

The MBCx project documentation was reviewed to determine how each campus estimated savings for each project, what information was reported, and whether the M&V approach was aligned with program guidelines. We developed a series of questions to address as we reviewed each MBCx project. For the twenty buildings in the study, we determined whether the whole building approach was employed, and how well it was followed by noting which of the baseline model goodness-of-fit metrics were reported. If an alternate M&V approach was followed, we listed its description from the report. This was not an evaluation of the report or methods used, only an informational exercise to understand current practices.

3.5 INTERVIEW CAMPUS OPERATORS

Campus program managers from UC Berkeley and UC Davis were informally interviewed to determine to what extent whole building data was captured, stored, and used at each campus, how they were addressing data quality, and what plans were there for how the data could be used to maintain savings. The survey questions fell into three broad categories: accuracy of building data, management of building data, and lessons learned.

In regard to data accuracy, campus program managers were asked about practices used to assure the quality of the data, and if there was a process for managing bad data. For example, we asked whether periodic meter calibrations were carried out, or if reasonableness checks of data were conducted, or whether other processes were employed. We also asked about NR events that we observed in the whole building data, and how they were alerted to anomalous energy behavior.

We also probed the campuses to understand how the data was used in building energy management practices. We asked if the whole building data was used to maintain savings from retrofit or MBCx projects, and if not, what would be most useful for this purpose. We asked whether campuses were using dashboards, websites, desktop tools, or third-party vendor software, and what features were found to be useful. We inquired about existing or developing energy management policies, and training requirements.

Questions were also asked about lessons they learned in collecting and managing the data through the MBCx program, and what recommendations they had for improving the program or other aspects of it. We collected any additional comments and recommendations they had that were not addressed in the survey.

4. RESULTS/FINDINGS

4.1 DATA QUALITY

An ongoing challenge during the study was the management of bad data. The most common source of bad data was either gaps where no data was collected, or periods of erroneous values, where data was obviously incorrect. Data gaps were infrequent in all of the reviewed data, however data from UC Davis had significantly more data gaps and erroneous values than UC Berkeley data. This issue was addressed in the interview with UC Davis. The cause was revealed to be a connectivity issue. The installed meters had the capability to store monitored data, but when the network connection failed for period of time, not all data was restored upon re-establishment of the connection. In addition, the campus reported that the data was not checked unless someone is reviewing it for specific purposes, such as an MBCx or retrofit project, or other purpose.

The whole building meters were installed as part of the UC/CSU/IOU program, and in most cases they were installed over 5 years ago. At the time of their installation, there was no infrastructure in place to maintain the building meters. While each campus was initiating data quality control systems, in general data quality issues were not corrected unless the problem was noticed during a review of the data for project purposes.

During the interviews, we found that there was no campus protocol to assure meters were calibrated. A similar finding was reported in the evaluation report WO 033 Appendix G (Itron, 2014).

4.2 ANALYSIS RESULTS

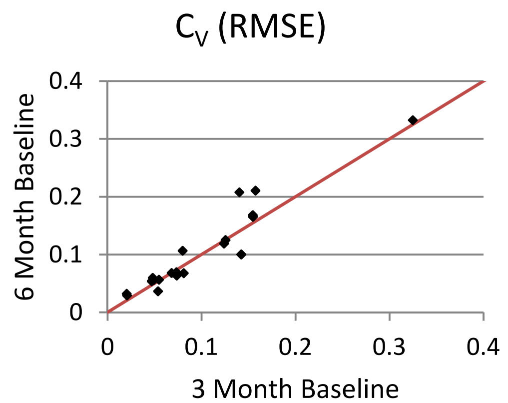
4.2.1 Building Predictability and Baseline Duration

A critical factor of interest in savings estimations produced by whole building M&V was the accuracy in predicting what energy use would have been under future conditions after efficiency measures had been installed. A building energy model's accuracy in predicting energy use relied on several factors, among them the modeling algorithm employed, the number of independent variables included, the amount and range of data used to develop the model, and the 'predictability' of a building's energy use. Used here, building predictability referred to how well a building's energy use patterns lends themselves to be mathematically modeled by the algorithm, variables, and data. Good indicators of predictability included the model's goodness-of-fit metrics and the absence of significant NR events. The coefficient of variation of the root mean squared error, CV, provided a measure of the variability between the model and the data it was developed from; the higher the CV, the less well the model predicted building energy use. Price (PG&E, 2013) used a similar metric, the monthly mean absolute percent error (monthly MAPE) to explain how well a model predicted energy use each month.

Having fixed the modeling algorithm and number of independent variables, and having removed obvious NR events from the baseline periods, we examined the CV and R^2 to understand differences in building predictability when developing models from three or six months of data.

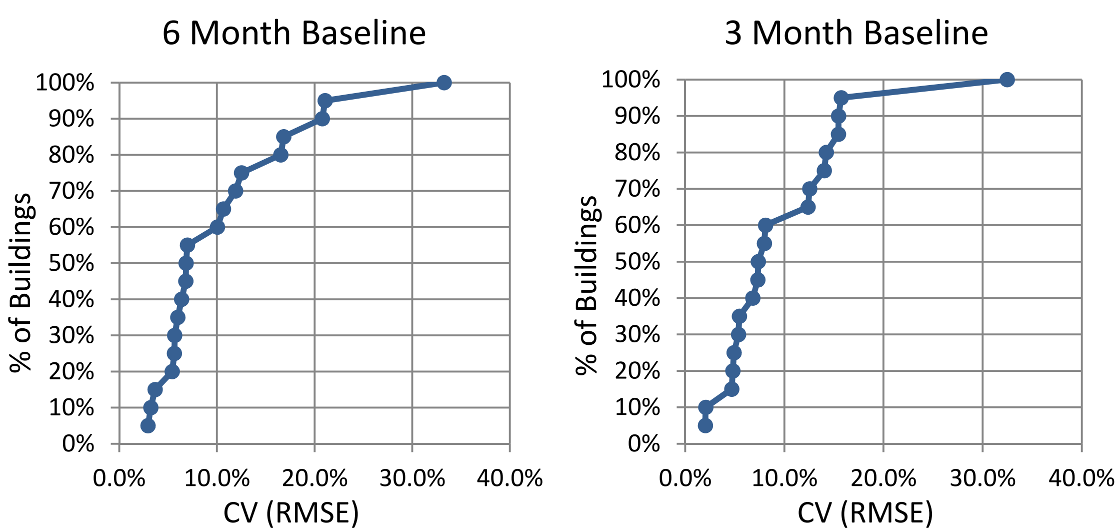
The goodness-of-fit metrics were compared by plotting them for each building, as shown in Figure 3-2. Perfect agreement would place all data points on a 45° line. Lower values of CV or higher values of R^2 indicated which baseline period duration produced better metrics and therefore better models. As shown in Figure 4-1, there isn't a clear indication that a three or six month period produces better models, as most points are reasonably close to the line.

Figure 4-1. Comparison of three and six month baseline model goodness-of fit metrics, CV(RMSE) and R^2



It is useful to look at the distribution of metrics over the population. The data was sorted and charted for the population of 20 buildings. Results are shown in Figure 4-2 below.

Figure 4-2. Comparison of the distribution of CV(RMSE) for the three and six month baseline models



Interpreting this chart, both three and six month baseline models showed that approximately 60% of buildings in each case had CV values lower than 10%, which is well below the program's 20% criterion for models. Real differences became apparent only in the highest 20% of buildings, and interestingly in these buildings the six month baseline models showed poorer goodness-of-fit results.

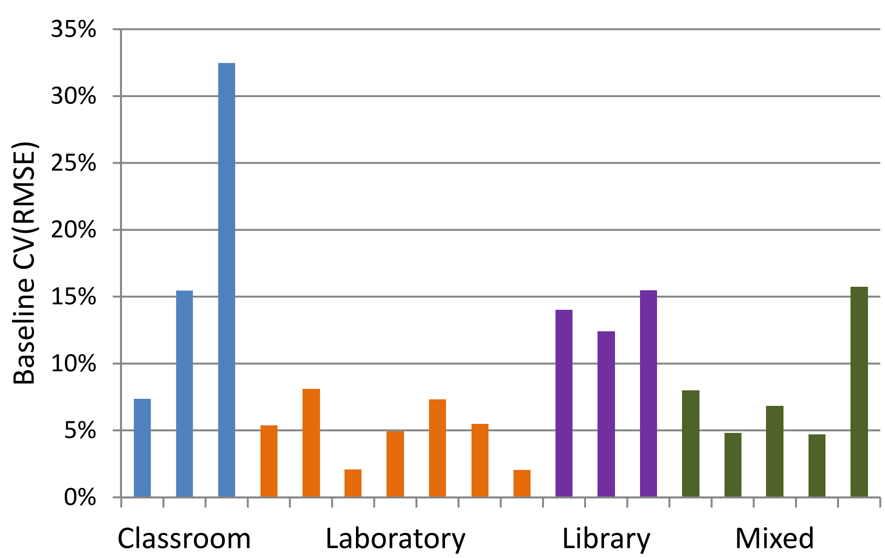
4.2.2 Predictability and Indicating Factors

While most buildings surveyed exhibited very good predictability for the method, parameters, and data selected, the data provided an opportunity to further investigate what factors were common to the most predictable buildings. Such insights were helpful in planning whole building M&V, so that implementers will know which buildings may require improved modeling, additional variables, more data, and so on. We investigated three factors: building type, energy use intensity, and square footage.

Building Type

We identified four types of buildings in our 20 building sample: laboratories, classrooms, libraries, and mixed use. A fifth type had a population of one: dormitory, which we excluded from this discussion. The mixed use building category was used for buildings were we could not attribute its space use type into any dominant category. Figure 4-3 shows the distribution of baseline model CV by building type. Given its small sample size, this chart shows that laboratories exhibit consistently low values of CV. Mixed use buildings are the next lowest category of buildings, but more variable. Libraries have higher values of CV, and are more consistent. Classrooms show the highest as well as the most variable values.

Figure 4-3. Baseline CV(RMSE) and Building Type



EUI and Predictability

Buildings with high energy use intensity (EUI) generally had good predictability, based on this data set (Figure 4-4); as the building EUI increases, the goodness-of-fit improved. Figure 4-5 shows which building types had the highest EUI.

Figure 4-4 EUI and CV(RMSE)

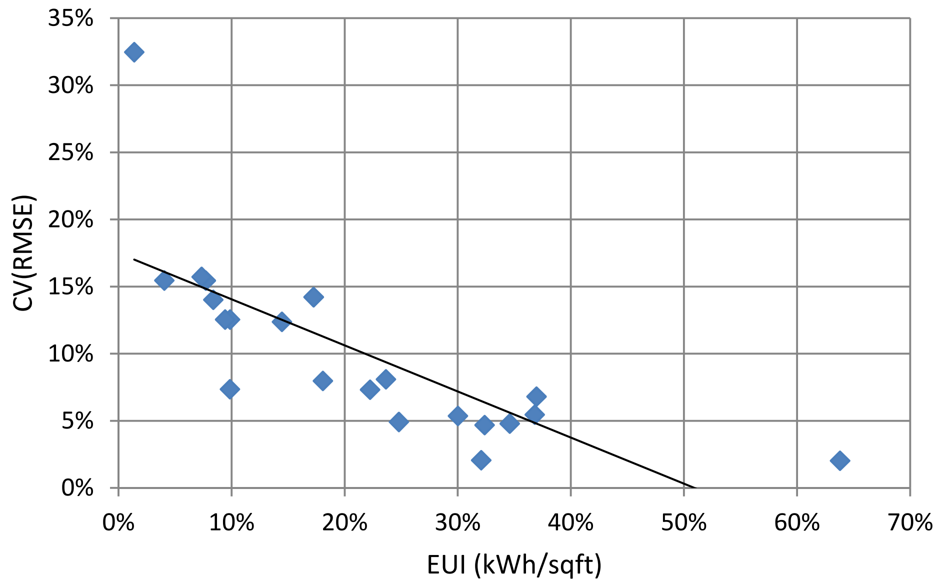
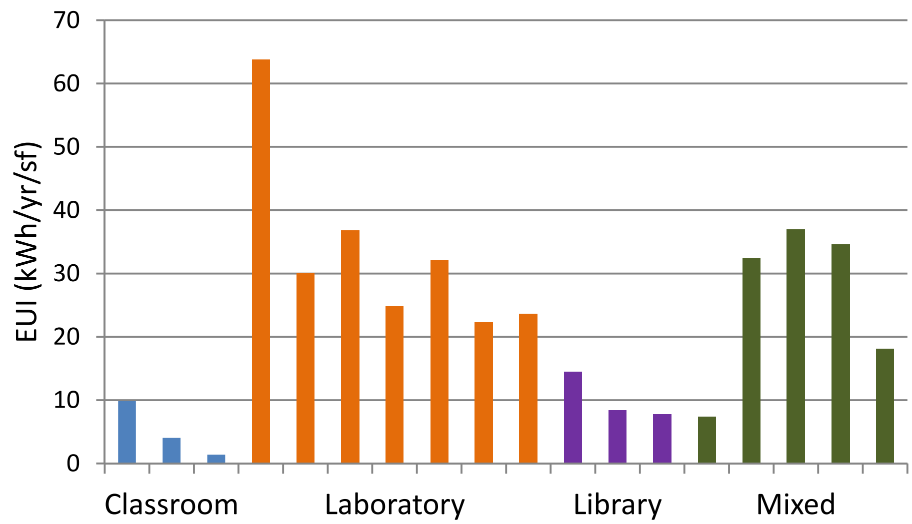


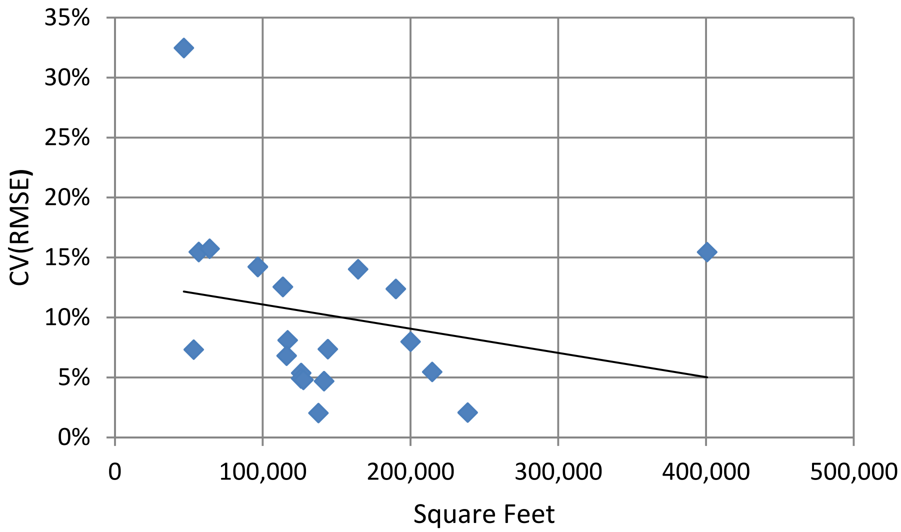
Figure 4-5. Building Type and EUI



Square Footage and Predictability

A building's predictability did not show a strong relationship with its square footage. Figure 4-6 shows that as building floor area increased, predictability slightly improved, but not conclusively.

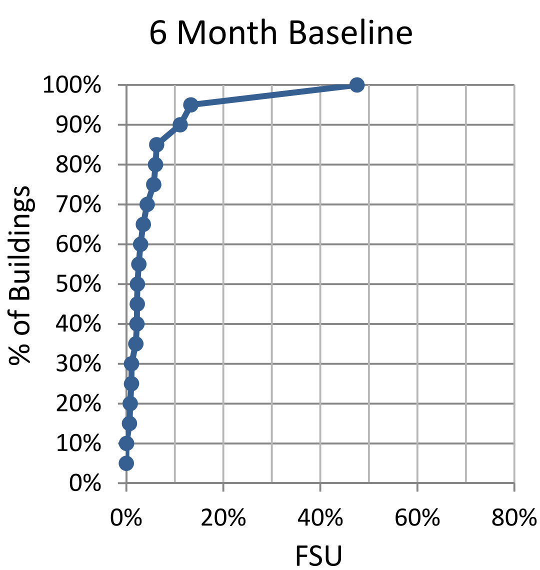
Figure 4-6. CV(RMSE) and Square Footage

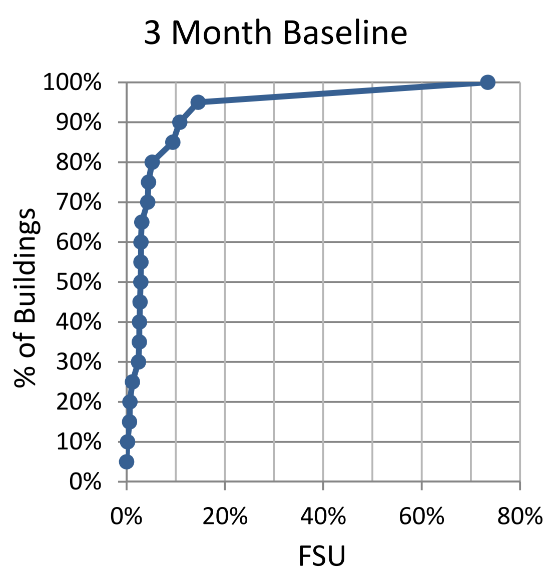


4.3 SAVINGS UNCERTAINTY

In its formulation of savings uncertainty, ASHRAE showed that it relates to a model's variability (CV), amount of data (n, m) and amount of savings (F). FSU was estimated for buildings using the three and six month periods to develop baseline models, using their calculated CVs, and each project's anticipated savings and amount of post-installation period data. In these cases, the amount of post-installation data was the equivalent of twelve months. Figure 4-7 below shows the distribution of results.

Figure 4-7. Comparison of the distribution of FSU for the three and six month baseline models, using estimates in baseline period



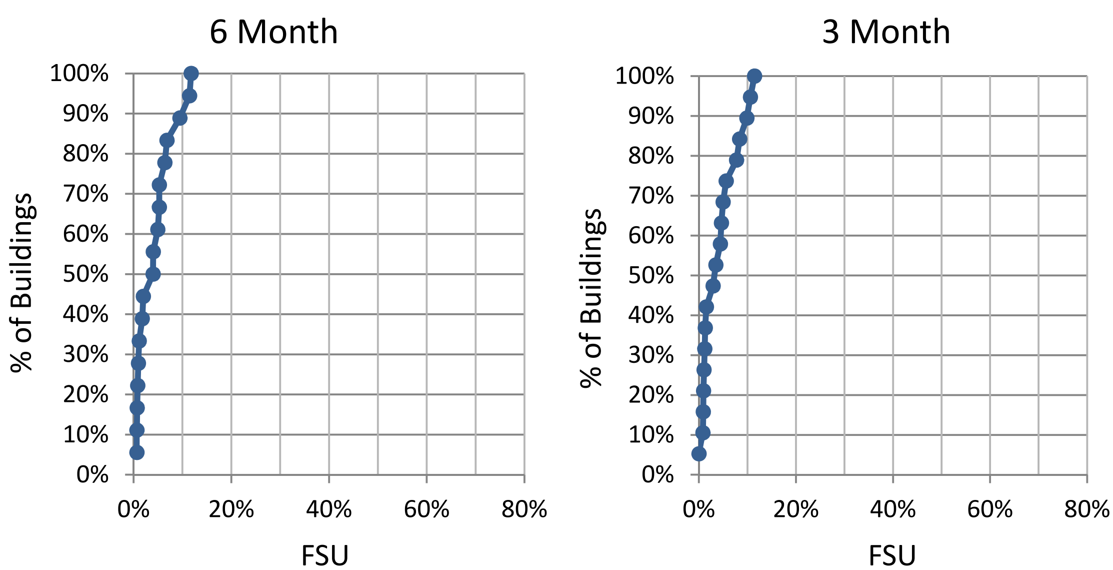


These charts told us that for both baseline period durations, in over 80% of the cases, the uncertainty in the savings was projected to be below 10%, and that there were no discernable differences in using three or six months of data to develop baseline models.

Uncertainty is the probability an estimate is within the level of precision, and statements of uncertainty must include both the precision and confidence level. For this work the associated confidence level was 68%. To understand the fractional savings uncertainty quantity in the distribution above, if the savings was an amount X, and FSU 10%, then the uncertainty in savings was expected to be below 10% of X. Stating the savings at a higher level of confidence would increase (or worsen) the precision, for example we could say that we are 95% confident the savings is within 1.96 x 10% = 19.6% of X. It is important to note that whether the uncertainty is expressed at 68 or 95% confidence, the uncertainty does not change.

After measures were installed, the actual FSU was calculated, using the actual savings achieved, and the actual post-implementation period amount of data. Results are shown in Figure 4-8. These charts indicated that as a group, the baseline savings uncertainty estimate was a reasonable estimate of the final results. Note that the buildings shifted positions in the distributions based on the baseline FSU estimate and the post-installation FSU result, but to unacceptable levels.

Figure 4-8 Comparison of the distribution of FSU for the three and six month baseline models, developed from post-installation period results.



4.4 COMPARISON WITH REPORTED SAVINGS

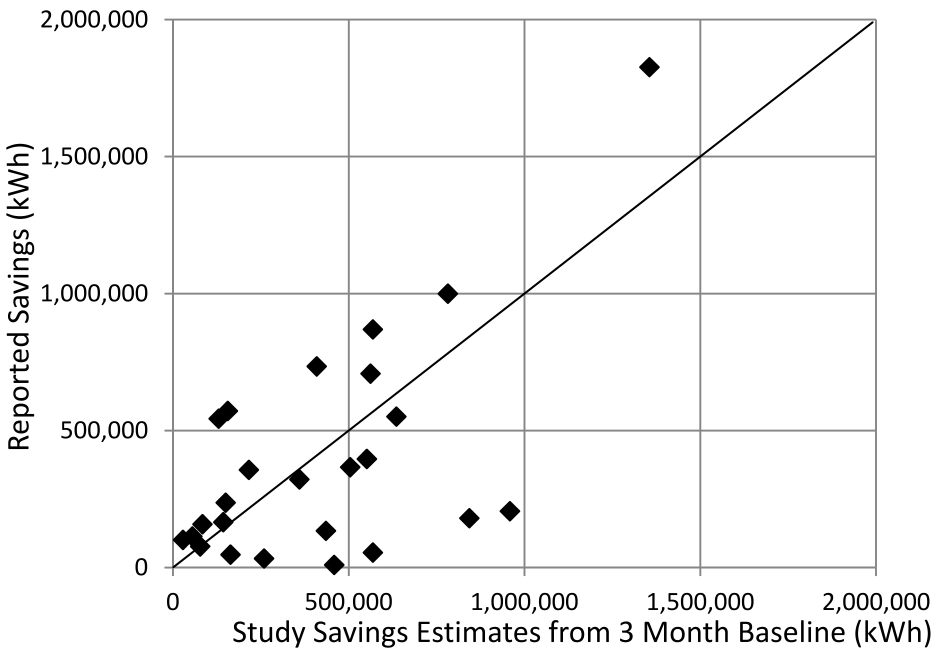
We estimated savings by using the same regression model and independent variables for all buildings. Using this approach, the model goodness-of-fit metric CV met the program guidance of 20% in all cases except one. Savings uncertainties estimated through this approach were also reasonable, with 80% of the cases showing values of 10% or less.

We compared the savings based on this approach with those reported in the MBCx projects. Figure 4-9 plots the reported savings versus this study's estimated savings. If the two estimates agreed, the points would fall on the 45° line. Points above the line indicate that the reported savings were higher, while points below the line indicate the study estimated higher savings. The chart shows there was no clear relationship between the two methods.

This outcome was not unexpected, as we found multiple different savings calculation methods employed among the reports. As described later in this report, we found some projects estimated with "bin analysis; others with "time-of-day" analysis. Many of the cases in which regression methods were employed used daily values of energy use and ambient temperature, not hourly as used here. These regression cases used linear regression or a change-point modeling method.[2]

We noted that implementation of whole building M&V using hourly or daily values of energy use and independent variables was relatively new to the industry. Not all practitioners were familiar with the methodology, and the leading industry standard M&V guideline IPMVP does not address it directly. In the case of ASHRAE Guideline 14, where the technical detail was described, the skill level required to implement it may not yet have been acquired by MBCx providers.

Figure 4-9. Comparison of Study and Reported Savings Estimates by Project



[2] Change point methods are described in ASHRAE's research project 1050, and echoed in ASHRAE Guideline 14-2002.

4.5 REVIEW OF M&V PROCEDURES AND REPORTS

Twelve MBCx reports were reviewed to answer the questions outlined earlier (Table 4-1). We found that savings estimates were rarely listed in the report at the outset of the project, but post installation savings were always presented. The savings that were estimated for the project were often achieved.

The M&V approaches varied by project, but the most common approaches followed IPMVP Option C. Other techniques included bin analysis, time of day analysis, and IPMVP Option B. The program required IPMVP Option C be followed for energy modeling, however exceptions could be made under certain circumstances. Meters were required to be calibrated prior to data collection, but reports had not described that this was done.

The most common independent variable was OAT, however building occupancy and day of week were also common. There were only a few instances of special adjustments made to the model (plug loads, batch processing, etc). All baseline models included at least three months of post data; however few models used baseline data from consecutive months. Several projects did not have three months of post-installation data. Some listed reasons include conflicts between installed equipment and existing equipment or project schedule constraints.

TABLE 4-1
Results of M&V Procedures Review of MBCx Reports

Building	Savings Method Used	Implemented Whole Building Method	Metrics Reported		
			R^2	CV	t-stat
Bechtel	Regression calculations (steam), Percent Reduction (electric)	No	steam ✓		steam ✓
Cory	Time-of-day, change point, and IPMVP Option C	Qualified yes	✓	✓	
Doe	Average Weekday and Weekend load shapes	No			
Gardner	IPMVP Option C (electric), IPMVP Option B (gas)	Yes	✓	✓	✓
Haas	Time-of day	No	✓		
Hildebrand	Bin analysis	No			
LSA	Bin analysis	No			
Academic Surge	IPMVP Option C	Yes			
Olson	IPMVP Option C	Yes			
Plant and Environmental Sciences	1440 Bin spreadsheet model	No			
Tercero	Report says Option C, analysis files show 'time of day' analysis	No			

The model goodness-of-fit metrics were only presented in roughly half of the reports reviewed. The metrics used for a given model varied based on the approach used. CV and R^2 were relevant for IPMVP Option C, but not relevant for bin analysis. However, in most cases that used IPMVP Option C, the CV and R^2 values were not given. When whole building meter data was not used for savings analysis, it was common for projects to develop savings estimates based on sub metered data, taken from the energy management system, or from data loggers.

4.6 INTERVIEW RESULTS

UC Berkeley and UC Davis campus MBCx managers were interviewed to obtain their feedback on how whole building data is managed currently and what their future plans are for use of the data provided by the building meters. We were interested in their current practices regarding data quality control. We asked about how the data is used in building management practices on campus, the ways in which it is available, and what tools are used. The summaries of their responses to each of these topics are included in **Appendix B**.

5. DISCUSSION AND RECOMMENDATIONS

Several important findings have been identified from the detailed analysis of data and results from the study of 20 buildings implementing MBCx and retrofit measures. These findings provide useful information that addresses the research questions posed at the outset of this project. In this section, we summarize the relevant findings and recommend ways in which the MBCx program may be improved.

1. How well suited are the UC buildings for this whole building approach? Are they reasonably predictable and do they generate savings estimations within reasonable tolerances?

We found that baseline models developed using an advanced regression algorithm using time and temperature as independent variables and using three months of data provided robust models with goodness-of-fit metric CV well within program M&V guidelines. While the models did not consistently generate R^2 values above the program's criterion, we note that this factor has less relevance in determining model or savings accuracy.

We examined the limited data set to determine whether there were more predictable buildings in it. It is important to note that all building types examined provided sufficient results to effectively utilize the whole building approach; and also that some types performed better than others. Based on our limited data, laboratories were more predictable as a group, followed by mixed use buildings. Buildings with high EUIs also tended to be more predictable. This information is useful when planning whole building M&V projects.

We found that the project's calculated savings uncertainties were predominately under 10%, with a large number under 5%. From a technical point of view, we find these values acceptable, however stakeholders must evaluate the risks these uncertainties represent and establish a suitable acceptance criterion. We note that estimations of savings uncertainties are not standard practice under California's ratepayer funded energy efficiency programs.

2. How well is the current whole building M&V guidance followed? What can we say about how it is implemented, and what gaps remain? How can these gaps be addressed?

We found there were multiple whole building M&V methods implemented in the buildings selected for this study. Less than 50% of the projects used a regression-based approach. Other "whole building" methods identified included bin methods and time-of-day analysis. The program's requirement to use three months of baseline and post-installation period data was generally met, however its requirements to meet the criteria for model goodness-of-fit metrics CV and R^2 were mostly unaddressed in the reports. We found that the modeling approach we employed was suitable for all projects in the sample, and provided good models that met the program's goodness-of-fit criteria. We note that this method may be made more accurate on a building-by-building basis, as we did not attempt to improve model accuracy by accounting for occupied and unoccupied periods or by including additional independent variables.

While the program's M&V guidance specified the data requirements, goodness-of-fit metrics criteria, and adjustments to typical weather conditions, it did not require a specific methodology be implemented. Hence practitioners were allowed the flexibility to implement their preferred methods. It should be noted that the state of art in energy modeling as documented in industry guidelines is dated and that the industry has experienced much development in energy modeling in the last few years. This development has shown that simple linear regression modeling with ambient temperature in combination with the limited amount of data available in a three month modeling period is often inadequate to accurately capture the energy use behavior in many buildings (PG&E, 2013).

Recommendations

More consistency and higher quality applications of whole building M&V may be achieved through the following recommendations:

- Modify MBCx program M&V requirements:
  - Specify that regressions be used for whole building energy models
  - Narrow the CV criterion from 20% to 15% or 10%
  - Drop requirements related to simple linear regressions (t-statistic)
  - Add FSU assessment to baseline phase, specify maximum acceptable FSU for baseline.
  - Specify modeling information that must be reported: independent variables, baseline period start and end dates, analysis time interval, amount of data, CV, R^2, FSU, etc.
- Provide software tools to streamline implementation of M&V – tools can be PG&E's UT M&V module, or other tools (examples include: ASHRAE change point toolkit and Energy Explorer). Campuses can also program their own systems using available public-domain software.
- Develop and provide more guidance and technical training on whole building M&V using short-time interval data. This would also help program evaluators and other stakeholders to better understand the methodology. Some guidance exists (CCC 2012, BPA 2011). The guidance can be customized for the MBCx program.
- Modify the program to have only qualified parties conduct the whole building M&V analysis. Campuses can also be trained and made responsible for whole building M&V and fulfilling program savings requirements. This would also serve the program's persistence goals by having campuses trained on monitoring and quantifying energy performance. The service provider pool can be expanded to include HVAC and control technicians to find and implement RCx measures.

3. What guidance in terms of data (amount, number of parameters, and accuracy), model goodness-of-fit metrics, and analysis is needed to assure savings are estimated within reasonable tolerances by involved parties?

In general, we collected enough data to complete the analysis for each building in the study. However there were data quality issues, such as gaps and erroneous values that we identified and removed from the data sets. It should be noted that a discussion of meter accuracy alone is insufficient. Errors in measurement of any quantity are subject to random and bias errors. While it is best to minimize both types of error, elimination of bias errors should take precedence in any data quality protocol process. A good discussion of measurement and modeling errors and their management is found in ASHRAE Guideline 14 (ASHRAE 2002). In simplified terms, the contribution of random measurement error is absorbed into the amount of variation exhibited by a model. This variation is quantified by the coefficient of variation, CV. Generally, the more data that is used in model development, the more the impact of random measurement errors is mitigated.

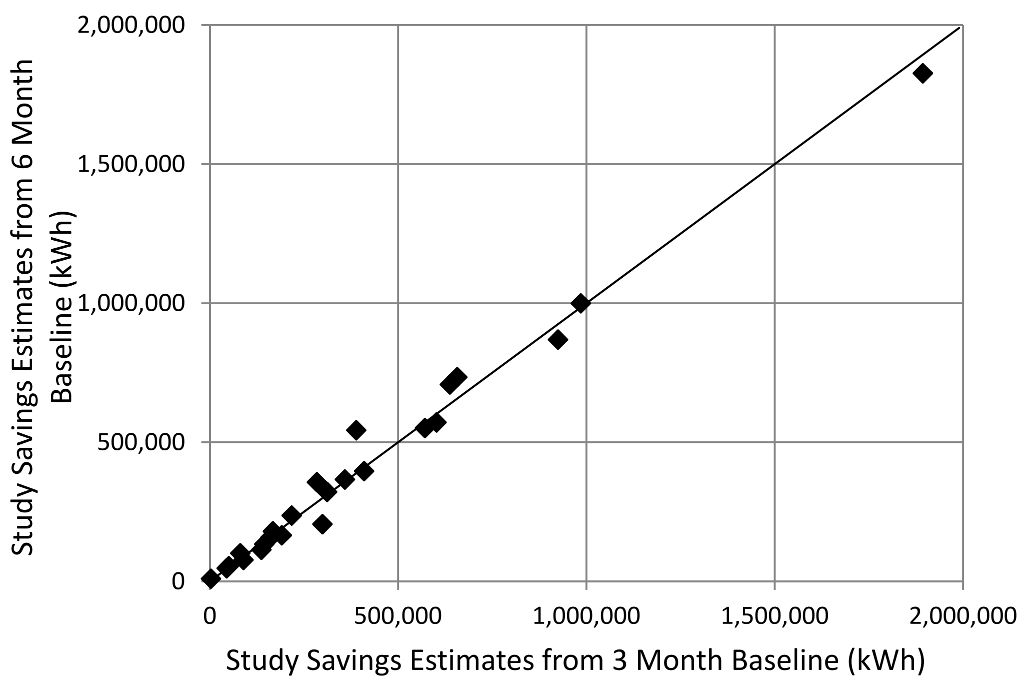
We also used weather data from local airports rather than from on-site weather stations. Particularly in the case of Berkeley, where the airport is in a different microclimate than the campus, the weather data may have been significantly different and introduced error in the analysis.

We conducted several analyses to understand how the amount of data affected savings and accuracy. We found that once the modeling method and independent variables were selected, baseline models developed from three and six months of data yielded comparable goodness-of-fit metrics R^2 and CV. Similarly, estimations of savings uncertainty, whether estimated in the baseline period, or determined for the final calculated savings, were similar for baseline periods of three or six months. Figure 5-1 showed the resulting savings estimates using three and six month baselines, indicating close agreement.

Using the time and temperature model in our analysis, the CV criteria of 20% or better was met in over 90% of the cases. We also calculated R^2, but the criterion was met approximately half the time. The CV is the more important metric, as it indicated how much variability existed between the model's predictions and the data. This was a factor in the accuracy of savings estimates.

Acceptable values of savings uncertainty could not be evaluated unless there was a criterion specified by project stakeholders. The uncertainty was low, below 10% (at 68% confidence) for most buildings, no matter the duration of the baseline period for model development. Savings uncertainty represented an amount of risk that the estimated savings would not be achieved. This can have financial impacts.

Figure 5-1. Comparison of Savings Estimations Using Three and Six Month Baseline periods



Recommendations

- Campuses should consider installing weather stations to obtain data on local climate conditions. This data should be monitored at the same frequency or more often than building energy data, because it is a critical data point used for modeling energy use in all buildings on campus.
- Augment program guidelines for retrieving and archiving data with good data quality practices: error checking, identifying and correcting gaps in data, flagging anomalous values, eliminating bias error, and so on.
- M&V guidance should be amended to specify more accurate modeling techniques based on regression models using time as well as weather as independent variables.
- Program has acceptance criteria for goodness-of-fit metric CV, but should establish acceptance criteria for whole building baseline models in relation to the amount of savings expected. ASHRAE's FSU provides a good formulation of this metric, as it incorporates the CV with the amount of baseline and post-installation period data, and expected savings, which allows an assessment of how accurate the resulting savings will be using the baseline whole building model. We recommend 10% accuracy at 68% confidence as the criteria until stakeholders can establish a preferred value.
- The program requires that baseline and post-installation energy use be normalized to typical weather conditions and savings estimated from these normalized values. As both models introduce uncertainty when calculating savings, a description of how to estimate this uncertainty should be included.
- The program should require savings be reported with their associated uncertainties.

4. How can unexpected energy use behaviors (non-routine events) be treated, measured, or documented, in order to maintain accurate savings estimations?

In this study, after removing periods of poor data quality, we plotted the energy use data and looked for anomalous behavior that indicated some non-routine event took place. Such behavior included temporary periods of high or low energy use or behavior that was different than earlier periods. There were not many non-routine behavior patterns in the data, but when we identified them, they were removed, and additional data was collected to meet the baseline period duration requirement.

The chief recommendation that the industry-standard M&V guideline IPMVP has for accounting for non-routine energy use in a building is to identify the cause and measure its impact in order to subtract it out from the analysis (EVO, 2012). While simple in concept, this is often difficult to implement, as the non-routine event may not be easily measureable, or may have occurred in the past and is no longer in effect.

Recommendations

We recommend following IPMVP advice to identify and measure the impact of non-routine events whenever possible. MBCx whole building M&V program guidance may be updated in the following ways:

- The program guidelines should require in M&V savings reports a description of how non-routine events were identified, their duration, and how their impacts were quantified.

- In the development of baseline or post-installation models, remove the energy use data for the period when the non-routine event occurred, and replace it with an equivalent amount of data from a previous or following period. The models of energy use may then be adjusted to typical conditions in order to estimate annual savings.
- Per IPMVP, identify the cause of the non-routine event and measure its energy use, if possible. Subtract the measured usage from the whole building data prior to development of baseline or post-installation energy models.

5. Can a more standardized M&V methodology be prescribed? What data and analysis can be performed in baseline periods to assess the whole building approach? What alternative verification methods should be pursued that maintain the program's overall goals of performance monitoring and persistence?

The MBCx program's M&V guidance goes a long way to establish the data requirements, goodness-of-fit metrics and their acceptance criteria. Nevertheless, after our review of project reports, project implementers were able to pursue alternate M&V strategies. We showed that each of these projects may be analyzed using the whole building approach, noting that the methodology we employed was unlikely to have been available at the time these projects were completed.

Recommendations

- Revise the acceptance criteria in the program guidelines to emphasize uniformity of method and its accuracy requirements. Also state explicitly what information about the data, independent variables, modeling, baseline period, post-installation period and so on must be reported along with the savings.
- Consider, as a program standard, use of software tools such as the M&V analysis module in PG&E's Universal Translator, or other tools capable of generating accurate empirical models with short-time interval whole building data. Such software tools enable data and analysis to be transferred not only to the campus staff in a useable format, but also assists technical reviewers in completing their required tasks. The UT tool has additional diagnostic modules capable of identifying operational faults in building systems.
- Allow campuses to program approved regression algorithms into their own metering and energy information systems. The transfer of this technology to campuses will enable them to both quantify savings for the program as well as integrate the system into their energy management practices to help maintain savings over time.

6. What measure-based verification activities can be included to meet the regulatory requirements of savings attribution without unduly burdening program expenses?

Changes in whole building energy use can come from many sources within the building. It is not apparent, without data from building subsystems, that the reduction in use was due specifically to the energy efficiency improvements, or whether it was due to other effects that normally occur in buildings. Trended data from controls systems or logged data from independent equipment, as well as standardized fault detection algorithms can be used to validate when improvements have been made without conducting detailed energy savings calculations. These algorithms combined with whole building load profiles can tie together the cause and effect of savings in the building as necessary.

To date, California's energy efficiency policies allow existing conditions to be used as baselines in retro-commissioning projects. The MBCx program's whole building methodology enables the savings of all installed measures to be quantified together.

Recommendations

- For the most common measures implemented in the MBCx program, such as economizer repairs, supply air set point reset controls strategies, and scheduling, describe standard algorithms for detecting these operational flaws in campus building systems.
- Consider for use in the program the UT's analysis modules for fault detection algorithms. Expand the number of such algorithms to meet the most common faults detected in buildings. Require that the data and fault detection analysis in the software be provided to campus program managers as part of training and at the conclusion of each MBCx project. Make such fault detection data and analysis software available to technical reviewers and evaluators.

7. In what ways might whole building data be used to monitor and track energy use and persistence of savings? This question reviews how whole building energy use for the selected buildings trends over time, and explores ways in which it may be used to assure persistence.

Campus program managers reported that at the conclusion of MBCx projects, most key information for on-going maintenance of individual building energy performance gains was included in reports as descriptive narratives. What was needed was the data in usable formats, training, and campus policies requiring better energy management practices. Campus personnel have begun utilizing the metering and data initially provided by the MBCx program in user-friendly analysis platforms and informative dashboards. However these efforts are guided by different campus organizations, resources, and policies at each campus we interviewed.

The preceding discussion and recommendations have described two important ways in which campuses can use the data to monitor and track energy usage in their building management practices: (1) use of more accurate energy modeling algorithms to establish baselines from which to compare on-going performance, and (2) to provide the diagnostic algorithms service providers use to detect operational deficiencies in building systems. It was also noted by campuses that training could be more extensive and more integrated with building operations practices, so that campus personnel may continue to use these tools well after the projects are completed. Pursuing these recommendations would also serve to improve campus practices for tracking and maintaining energy performance.

8. How may MBCx program approaches and best practices be used to help California toward its strategic goals of deep and long lasting energy efficiency?

California's Universities are well positioned through the MBCx program to demonstrate new approaches to achieving and maintaining high levels of energy efficiency in buildings. The MBCx program has been recognized nationally as a good program model for retro-commissioning, continuous improvement, and other programs (Meiman, 2012). In addition to the potential benefits of whole building M&V as described in this report, the practice of quantifying savings “through the meter” is aligned with many other drivers in the market, among them:

- Demand response programs, where savings from temporary reductions in demand are quantified from data taken from the building meter. The process is similar to quantifying savings using whole building M&V, where empirical models are used to determine “what demand would have been” in the absence of the demand reduction activities. The modeling algorithms can be similar, as the time and temperature model used in this study was originally developed for demand response programs (Mathieu, 2011).
- Demonstrated reductions in building energy use from rigorous whole building analysis can motivate owners and stakeholders to participate in cap and trade markets, by demonstrating that they’ve met their carbon allowances or creating and selling carbon credits. These credits are based on reductions from existing condition baselines, which whole building M&V addresses directly.
- Some utility transmission grids are close to capacity and cannot serve customers adequately without expanding transmission lines and substations. Reduction of demand for customers on the existing grid may be a viable economic alternative. These reductions would be quantified from existing energy baselines.

For commercial sector buildings, each of these areas is relatively new. A lack of a rigorous industry-wide understanding of whole building M&V based on short time interval measurements of energy use data is a key barrier to their development.

As described in California’s strategic plan (2011), the goals include transforming the energy efficiency market to a more sustained and long term focus instead of procuring short-term load reductions. The incentives for the market should be to pursue deeper and more long-lasting impacts. Utilities are directed to grow the use of innovative technologies to enhance building operation practices through multiple initiatives, including whole building approaches.

The MBCx program’s use of whole building M&V can contribute to each of these goals. It can demonstrate a rigorous process for quantifying real energy reductions, and answer important questions about data and model requirements, required skills and training, and how software solutions may be integrated. It can inform how whole building data and management practices may be utilized to achieve long-lasting energy use reductions. Finally, it can provide a model for building owners and stakeholders to participate in additional markets and gain additional economic returns for their energy efficiency projects.

Next Research Steps

This study examined the applicability of the whole building M&V method in buildings from two campuses, and found the whole building method was viable for each building selected. While this study sample of 20 buildings was helpful, it was limited to two campuses, their climate zones, and a limited set of building use types. It remains unclear if the method is applicable to all building types on each campus. Further work on is required. The following describes four areas of study recommended to answer these questions and improve the application of the whole building methods for energy savings.

1. Expand the study to additional UC campuses. Apply the evaluation methods used here in a wider range of UC buildings across more campuses and climate zones. This study would help determine the predictability of different building types and the applicability of the M&V approach across a more representative building sample. Such a study should include smaller, less energy intensive buildings, residence halls, and other non-regularly scheduled buildings. Such buildings are less cost effective to include in the current MBCx program because of their generally smaller savings potential.
2. Develop acceptance criteria for the whole building M&V approach. Stakeholders should be convened to consider the issues related to return on investment in MBCx and energy efficiency projects. Risk factors including amount of savings and uncertainty, persistence, cost of financing, return on investment, and so on should be considered in development of an acceptance criteria for the whole building method, and alternative cost-effective M&V methods, should the whole building approach prove unacceptable.
3. Develop a top-down protocol showing which M&V strategies to prioritize and the evaluation steps and criteria leading to alternate strategies. Factors to consider include building predictability, savings uncertainty, integration with UC operations and management plans, monitoring resources, and so on. M&V approaches may include the whole building approach, a similar regression-based approach for building subsystems, and retrofit isolation approaches. Conduct case studies in applying the protocol.

6. CONCLUSION

This study reviewed several projects in the UC/CSU/IOU Partnership Program to identify its current progress in applying whole building measurement and verification and provide recommendations for improvement. A literature review was conducted to understand California's energy efficiency policies and strategic plans related to whole building approaches, and how the MBCx program's whole building M&V method can inform them. The review also included program guidance documentation, published papers and reports about the MBCx program over its ten year existence, industry standard M&V guidelines, and recent evaluation reports.

Whole building data from twenty buildings at UC Berkeley and UC Davis were collected. The data spanned the time from meter installation through the fall of 2014, and included at least six months of data prior to energy efficiency measure implementation (either from MBCx or retrofit projects), and at least six months of data after completion of measure implementation and before installation of any follow-on measures. We applied a consistent modeling approach using an advanced public-domain regression model with hourly data that included hour-of-week as well as ambient temperature as independent variables and found the method was viable for each project investigated. Using this modeling method, we compared model variability for baseline models developed with six and three months of data, and found no significant differences.

Using ASHRAE's formulation of uncertainty, we also found no significant differences between six and three month distributions of anticipated savings uncertainty (uncertainty estimated prior to measure implementation) or actual savings uncertainties (determined from post-installation data). From a technical perspective the whole building M&V methodology yielded an acceptable level of savings uncertainty of less than 10% in over 90% of cases. Currently, no criterion for acceptable savings uncertainty exists in program documentation; however one option would be to adopt this 10% accuracy at 68% confidence level based on results of this study as a placeholder until stakeholders can assess the financial impacts more thoroughly. From the limited building sample, laboratory buildings stood out as buildings that were most predictable using this energy modeling method. It is important to note that all building types examined provided sufficient results to effectively utilize the whole building approach, some types performed better than others. In descending order, the predictability of other building types was mixed use, libraries, and classrooms. The data showed that energy use intensity of a building also was a good indicator of building predictability. Such indicators can be helpful in planning whole building M&V for campus projects.

Having successfully run the advanced regression algorithm for each building in the study, with no filtering for occupied or unoccupied periods, and finding that the buildings exhibited good predictability and yielded savings with reasonable uncertainty levels, we conclude that the whole building approach is appropriate for all UC buildings and building types reviewed.

We compared savings estimated using the advanced modeling method with individual project savings as found in the project reports, and found significant differences. The main difference was in each project's M&V methodology. Reviewing the description of M&V methods in the MBCx reports showed that the whole building approach was pursued in less than 50% of the cases. The M&V Guidance allowed campuses to assess different M&V options and select different methods with administrator approval. We surmise multiple reasons why the campuses and their service providers did not pursue regression-based whole building analysis, including a lack of experience in applying the method, a lack of analysis tools, limited project budgets, or more comfort with other approaches.

Discussions with campus program managers yielded important information about progress in taking advantage of metering installed during the MBCx program and plans for integration of energy use information in on-going building maintenance practices. The status quo for identifying and resolving data quality issues were identified, and plans for maintaining data quality were described. Each campus had different approaches and resources for capturing and using the whole building data, however they shared a common goal to provide tools and training to better integrate energy management into building maintenance and operations.

The investigation also identified several opportunities to improve the current MBCx process and support a more robust whole building approach. Based on the literature review, analysis results, project report reviews, and interviews with campus managers, several recommendations for improvement were made:

1. Upgrade MBCx program whole building M&V requirements to require or prefer one standard regression-based whole building methodology for all MBCx projects, narrowing the criteria for CV, and introducing ASHRAE's method for predicting savings uncertainty based on CV, amount of savings, and planned post-installation measurement duration.
2. Program stakeholders should examine past results and set a criterion for acceptable uncertainty in savings estimations, enabling campuses to determine whether the whole building approach should be pursued, or whether to pursue a retrofit isolation method based on system sub metering.
3. Increase reporting requirements to clearly define important parameters used to determine savings, including start and end dates of data used, quality assurance steps, identification and treatment of non-routine events, values model goodness-of-fit metrics, modeling method used, and savings. Savings should be reported with its associated uncertainty.
4. Split the responsibility for savings quantification from savings opportunity identification. Require campuses to collect and analyze building data, set baselines, and quantify savings according to program requirements. This transfers the monitoring and tracking of building energy performance and savings from service providers to campuses, with the added benefit that campus personnel incorporate the data and analysis into on-going practices. Campus personnel could engage with a larger pool of service providers, including commissioning agents, HVAC and controls contractors to identify and correct operational deficiencies under the MBCx program. Deficiencies may be corrected as they are found rather than after reports are generated.
5. Provide software tools for the whole building M&V analysis or assist campuses in programming the method in their energy information systems. Service providers may use software tools for analysis and upon project completion, deliver the data and analysis in software tool form directly to those responsible for maintaining use over time.
6. Include fault detection and diagnostic algorithms in software tools. Establish the key diagnostics determined in individual building projects as a resource for addressing on-going maintenance of energy performance.

The MBCx program is uniquely positioned to demonstrate how a whole building approach can address several barriers to achieving deep and long-lasting savings. It can demonstrate the value of high frequency data made available from smart meters. It can demonstrate the effectiveness of new empirical modeling methods in M&V applications. Its M&V guidance can serve as a model for other non-public sector programs, through software applications in individual tools or programmed into enterprise-wide energy information systems. It can standardize the M&V process, which has benefits in streamlining technical review and evaluation. Its data and analysis methodologies may also be integrated into building management practices, which serve to maintain and continue achievement of gains in energy efficiency over longer terms. These are the key steps to success identified in California's energy efficiency policies and strategic plans.

BIBLIOGRAPHY

American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE). *Guideline 14: Measurement of Energy and Demand Savings*. available at: www.ashrae.org. 2002.

Anderson, M., McCormick A., Meiman A. & K. Brown, *Quantifying Monitoring-Based Commissioning in Campus Buildings: Utility Partnership Results, Lessons Learned, and Future Potential*. Proceedings of 14th National Conference on Building Commissioning: May 2-4, 2007.

Bonneville Power Administration (BPA), *M&V Verification by Energy Modeling Protocol*, conduitnw.org.

Brown, K. & Anderson, M.K.J. 2006. *Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects*. Proceedings of 13th National Conference on Building Commissioning: April 19-21, 2006.

California Commissioning Collaborative (CCC), *Guidelines for Verifying Savings from Commissioning Existing Buildings*, prepared under funding from California Energy Commission, 2012. www.cacx.org.

California Energy Commission (CEC) Staff Report. *Comprehensive Energy Efficiency Programs for Existing Buildings Scoping Report*. Report no. CEC-400-2012-015. Available at: http://www.energy.ca.gov/2012publications/CEC-400-2012-015/CEC-400-2012-015.pdf. August, 2012.

California Public Utilities Commission (CPUC). *Energy Efficiency Policy Manual, version 5. Applicable to post-2012 Energy Efficiency Programs*. Report no. R.09-11-014. Available at http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/. July 2013.

CPUC. *California Long Term Energy Efficiency Strategic Plan, Achieving Maximum Energy Savings in California for 2009 and Beyond*. Available at: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/index.htm. September 2008.

CPUC. *California Long Term Energy Efficiency Strategic Plan, January 2011 Update*. Available at: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/index.htm. January 2011.

CPUC. *2010-2012 Work Order 033 Custom Impact Evaluation Report*. Available at: www.energydataweb.org. March 14, 2014.

Efficiency Valuation Organization (EVO). *International Performance Measurement and Verification Protocol (IPMVP)*. Available at: www.evo-world.org. 2012.

EVO. International Energy Efficiency Financing Protocol (IEEFP). Available at: www.evo-world.org. 2009.

Granderson, J. and P. N. Price, *Evaluation of the Predictive Accuracy of Five Whole-Building Baseline Models*. Report no. LBNL-5886E, Lawrence Berkeley National Laboratory, Berkeley, CA. 94720, August 2012.

Haves, P., C. Wray. D. Jump, D. Veronica, C. Farley. *Development of Diagnostic and Measurement and Verification Tools for Commercial Buildings.* California Energy Commission, Publication number: CEC-500-2015-001, http://www.energy.ca.gov/2015publications/CEC-500-2015-001/CEC-500-2015-001.pdf, (Jan. 2015)

Mathieu, J.L., P.N.Price, S. Kiliccote, & M.A.Piette. *Quantifying Changes in Building Electricity Use, With Application to Demand Response*. SmartGrid, IEEE Transactions, vol. 2, Issue 3, pp.507-518. August 2011.

Meiman, A., Anderson, M, and K. Brown, *Monitoring-Based Commissioning: Tracking the Evolution and Adoption of a Paradigm-Shifting Approach to Retro-Commissioning*, Proceedings of the 2012 ACEEE Summer Study of Energy Efficiency in Buildings, Panel 4. Washington DC: American Council for an Energy-Efficient Economy.

Mills, E & P. Mathew. *Monitoring-Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects*. Prepared for: California Energy Commission Public Interest Energy Research (PIER) Technology Demonstration Program, LBNL Report LBNL-1972E, June 2009.

Mills, E., N. Bourassa, M.A. Piette, H. Friedman, T. Haasl, T. Powell, and D. Claridge. *The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings*, Proceedings of the 2006 National Conference on Building Commissioning, Lawrence Berkeley National Laboratory Report No.56637. 2004.

Pacific Gas & Electric Company (PG&E). *Commercial Building Energy Baseline Modeling Software: Performance Metrics and Method Testing with Open Source Models and Implications for Proprietary Software Testing*. ET Project Number ET12PGE5312. Available at: http://www.etcc-ca.com/reports/commercial-building-energy-baseline-modeling-software-performance-metrics-and-method-testing. 2013.

University of California, California State University, and Investor Owned Utility (UC/CSU/IOU) Partnership Program. *MBCx Project Guidelines and Minimum Requirements, MBCx Program 2010-2014 Higher Education / Investor Owend Utility Partnership Programs*. Available at www.uccsuiouee.org. Updated August 2013.

UC/CSU/IOU Partnership Program, *UC/CSU/IOU 2013-2014 Energy Efficiency Partnership Program Information Package, version 3*. Available at www.uccsuiouee.org. March 2013.

APPENDIX A: RESEARCH PLAN

INTRODUCTION

The University of California, California State University, and Investor Owned Utility (UC/CSU/IOU) Partnership's Monitoring Based Commissioning (MBCx) program is in its tenth year. This innovative program provides advanced whole-building energy metering systems and building subsystem monitoring in advance of conducting building retro-commissioning (RCx) investigations. The added energy monitoring was intended to fulfill multiple objectives: (1) understanding of when and how much energy individual campus buildings use throughout the day and year, (2) identification of measures that improve building operations and save energy, and (3) ability to track and maintain building energy performance over time. In the early years of the program, a whole-building measurement and verification (M&V) approach was established to quantify savings from MBCx projects, and remains the preferred method to the present time.

Recently, the University of California has had strong interest to leverage this whole building approach in order to accurately quantify energy savings that translate to associated carbon reductions to meet its Presidential Initiative. The University also recognizes that there is significant value in the approach's potential to ensure long term persistence of energy efficiency investments, to enable more opportunity for demand response program participation, and to track energy reduction for California Air Resources Board regulatory reporting.

Pacific Gas & Electric Company (PG&E) as administrator of public goods funding for energy efficiency has responsibility to develop cost-effective and integrated programs that deliver savings. PG&E recognizes that new initiatives to achieve deep and long lasting savings must be developed. PG&E desires to investigate the MBCx program's whole building approach as a model for energy efficiency programs to achieve deep, cost effective, and long lasting savings in its service territory.

In light of recent MBCx program evaluations, and in an effort to improve program procedures in order to achieve deeper and more cost-effective savings, PG&E and the University of California initiated this study to evaluate the use of whole-building M&V in MBCx projects, and identify areas for improvement in meeting these program goals. Twenty (20) buildings on two UC Campuses: UC Berkeley and UC Davis will be investigated.

A review of relevant literature was performed to provide background and context about key issues that the study may address. The literature reviewed included MBCx program documentation, California's energy efficiency policies and strategic plans, regulatory requirements and recent evaluation results, and related work.

This plan describes the important research questions to be investigated as part of the study. The research methodology is presented, which describes the data and building information requirements, and specific steps for evaluating baseline model development and savings estimations. The goals of the research are to identify and recommend ways the program may achieve its near-term goals of improving MBCx program cost-effectiveness, and long-term goals of achieving and maintaining deep energy savings.

LITERATURE REVIEW

MBCx Program Design & Early Results

Soon after the MBCx program launched in 2004, Brown and Anderson (2006) described the program and its goals in two papers for the National Conference on Building Commissioning. They described MBCx as employing "remote energy system metering with trend log capability to identify previously unrecognized inefficiencies in energy system operations," and to "facilitate the application of diagnostic protocols, document energy savings from operational improvements, and ensure persistence of savings through on-going retro-commissioning." Their vision to enhance retro-commissioning (RCx) practices with advanced permanent monitoring would result in a robust program model for university campuses, and for other (non-university) programs as well.

The MBCx program concept to combine monitoring capability with RCx was designed to address the degradation of energy savings by providing actionable information about a building's energy performance. The papers discuss program design issues, such as:

- Conducting MBCx-only projects initially (no retrofit projects) to demonstrate the added value of metering,
- Demonstrating that RCx provides peak demand reductions, and that such reductions may be quantified with a high level of rigor,
- Adding system-level operational and energy sub-metering trending capability as well as whole-building energy metering to enable on-going performance diagnostics and actionable information to maintain energy performance,
- Emphasizing in-house staff training on RCx, monitoring, and on-going diagnostic techniques, and
- Enabling a higher degree of savings verification.

The papers further describe results from the first set of 21 MBCx-only projects, in which 124% of targeted portfolio kWh, 121% of kW, and 132% of natural gas therms were achieved while expending only 64% of the portfolio's funding. On a project-by-project level, there was a wide variation in results, with roughly one third of the projects showing high costs and little savings. This suggests the portfolio may be improved with the application of suitable screening criteria.

In a follow-up report, Meiman, Anderson, and Brown (2012) report on the evolution of MBCx program design through three program cycles, update its savings achievements, and reference in-state and national RCx programs that have adopted many of the MBCx program's best practices. They describe the MBCx program's evolution to a performance program, where incentives are paid on verified savings, up to 80% of project cost. Its preferred savings accounting protocol is based on IPMVP Option C with the short-time interval whole building data obtained through the installed meters. In the latest program cycle (2009-2012), through 2011 20M kWh/yr and 1.7M therms/yr have been achieved, while realization rates remain high at 90 and 97%, respectively. Their report discusses efforts beginning on individual campuses in regard to utilization of energy data, use of monitoring, staff training, and addressing persistence that support pursuit of deeper and more long-lasting energy savings in campus buildings.

Mills and Matthew (2009) examined the performance of 24 MBCx projects and compared their results with that from a larger database of commissioning projects in their previous "Meta-Analysis" database (2004). They counted over 1100 deficiency interventions in the building's heating and cooling plants, air distribution systems, and terminal units. The interventions included adjusting set-points, modifying sequences of operations, mechanical fixes, and calibration. These interventions yielded on average 9% electricity savings (kWh) and 4% peak demand savings (kW), with a payback of 2.5 years. The shortest paybacks were found in laboratory facilities. They concluded that MBCx is a highly cost-effective approach to achieving savings, and has the potential to prove its program theory that enhanced monitoring will lead to persistence, and additional savings opportunities.

MBCx Program Whole Building M&V Procedures & Recognized Guidelines

The UC/CSU/IOU Partnership program's whole-building M&V procedures are provided in the Information Package (2013). It provides general guidance for conducting whole building M&V to verify the savings in MBCx projects implemented on each campus. It directs implementers to conduct IPMVP Option C when possible, defaulting to Options A, B, or D with justification. For Option C, typical savings should be at least 5% of baseline year annual usage. While leaving implementers the freedom to develop the best-fitting energy models possible for each project, the MBCx M&V guidance requires that ambient temperature, building operation hours, and occupancy be tracked and considered in model development. It also requires the building be monitored for major changes in load that otherwise cannot be accounted for by independent variables. For most buildings, energy models must be developed using 3 consecutive months excluding January and July, of energy use data at high measurement frequencies such as hourly or daily. It doesn't provide any specification of the range of energy use or ambient temperature data, however. It specifies that regression-based models developed from this data have at a minimum an R^2 value (coefficient of determination) of 0.75, and a maximum CV(RMSE) of 20% for energy models, and 30% for demand models. It also requires t-statistics for each coefficient in its empirical energy model have values of 2 or greater.

ASHRAE Guideline 14-2002

ASHRAE recognized that evaluating savings uncertainty is an important aspect of savings estimation. Its M&V Guideline (ASHRAE 2002) requires uncertainty estimation in order to be compliant. Savings uncertainty must be estimated within 50% at the 68% confidence interval in order to comply. This is a very minimal requirement, and included to encourage the practice of estimating savings uncertainty in the industry. Guideline 14 provides detailed definitions of sources of error, error propagation, statistics, and uncertainty estimations for whole building approaches based on monthly billing data as well as short-time interval data. For each measurement frequency, it describes the relationship between the model goodness-of-fit metric CV(RMSE), the amount of savings, the degree of autocorrelation, and the savings uncertainty. It provides a methodology to pre-assess whether using simple regression-based modeling in an Option C approach would be appropriate to quantify savings within a stakeholder's criteria for accuracy.

International Performance Measurement and Verification Protocol

The International Measurement and Verification Protocol (IPMVP) (Efficiency Valuation Organization 2012) provides a high-level discussion of the different Options to implement M&V for energy conservation projects. Option C Whole Building is described in general terms and some technical discussion is provided in an appendix on uncertainty. IPMVP's Option C was developed based on use of monthly billing data, and its discussion of data requirements and technical requirements are used throughout the world. IPMVP requires adherence with its principles and methods, particularly in its specification of M&V plans and reports, which are still the industry standard today. IPMVP is the most cited M&V guideline in the Utility and performance contracting industry.

California's Energy Efficiency Policy

A broader perspective of the importance of energy efficiency in California is described in the California Public Utilities Commission's (CPUC) Policy Manual (2012). In addition to establishing energy efficiency as the highest priority procurement resource, setting aggressive energy savings goals, and other policy objectives, the policy manual requires implementation of California's long-term efficiency strategic plan. The strategic plan articulates near-term, mid-term, and long-term strategies to achieve the goals. An example of a long-term strategy is one of California's "Big Bold" Initiatives of achieving net zero energy use in new commercial construction by 2030.

The utilities were directed to align their programs with the strategic plan goals and identify steps to achieve them. The plan directs energy efficiency portfolios to pursue market transformation, which it defined as "long-lasting sustainable changes in the structure or functioning of a market achieved by reducing barriers to the adoption of energy efficiency measures to the point where continuation of the publically-funded intervention is no longer appropriate..". The manual directs utilities to pursue integrated demand side management (e.g. energy efficiency, self-generation, advanced metering, and demand response) while minimizing duplication of effort and reduce transaction costs.

The policy manual acknowledges that the standard cost-effectiveness tests, for example total resource cost (TRC) test, are limited for certain programs. For programs that structurally change the marketplace, utilities must identify objective, quantitative indicators of the progress of a program toward the short and long-term goals. It states that integrated metrics shall be developed for programs that employ more than one technology or approach, such as whole building programs.

Establishment of a baseline for TRC savings and costs are described in the policy manual for several types of measures: replace on burnout, normal replacement, new construction, and early retirement. The first three cases require applicable codes and standards, regulations, or industry standard practices to be used as the baseline. The latter allows the existing equipment baseline to be used, but only for the remaining useful life of affected equipment. It is unclear how to apply these definitions in the case of MBCx because no equipment is replaced, only operational improvements are made and such improvements do not require a building permit. Traditionally, existing conditions have been used as baselines in RCx programs in California.

California Energy Efficiency Strategic Plan

California's strategic plan (2011) aims to transform the market for energy efficiency to a more sustained and long term focus instead of procuring short-term load reduction with limited market impacts. The marketplace should be incentivized to pursue deeper and more sustained long term impacts. The plan directs utilities to develop programs with an end-game for the technology or practice that uses metrics to identify when practices become standard, or incorporated into codes and standards. For commercial buildings, the vision is to grow use of innovative technologies and enhanced building design and operation practices in the coming years through a combination of comprehensive whole building programs, technology development, market pull, professional education, targeted financing and incentives, and codes and standards.

The second of the three goals described in the strategic plan for commercial buildings is that 50% of existing buildings will be equivalent to zero net energy buildings by 2030 through achievement of deep energy efficiency and clean distributed generation. One of the three anticipated strategies is providing access to information that promotes benchmarking, increasing advanced metering infrastructure, and improving operation and maintenance practices to increase energy efficiency. One of the primary enabling strategies is to offer integrated delivery of program demand-side management (DSM) solutions.

The Comprehensive Energy Efficiency Programs for Existing Buildings scoping report (2012) describes infrastructure that must be in place in order to improve existing building energy efficiency at scale. It describes the challenges faced by such a diverse building stock and unique occupancy. Three areas are cited where infrastructure may be improved: 1) energy efficiency investing, 2) workforce development, and 3) energy assessments and ratings. The report cites a need for cost-effective audits and existing building commissioning (EBCx) investigations to deliver whole building approaches in the commercial market. It recommends that the Smart Grid infrastructure, where energy use data is available in short time increments, is a tool to be leveraged to achieve these economies for energy assessments.

Private Sector Investment in Energy Efficiency

The Efficiency Valuation Organization's International Energy Efficiency Financing Protocol (IEEFP 2009) estimates that current worldwide potential for financing energy efficiency and renewable projects exceeds $100 billion. California's Energy Efficiency Strategic Plan targets 250 million square feet (1/20th of existing commercial building space) each year through 2030 to reach deep levels of energy efficiency improvement and clean generation through whole building approaches. However IEEFP cites several major barriers to widespread implementation of proven energy efficiency technologies, with one of the most significant being a lack of viable financing. It cites the reason is due not to a lack of funds, but a lack of commercially attractive terms. It describes the disconnect between traditional lending practices and financing needs of energy efficiency projects, and why most loans are collateralized based on the owner's asset (the building) and not on the potential returns the energy efficiency project provides. It describes three risk factors that must be addressed to assure lenders that energy efficiency is a good investment opportunity:

1) Quality of audit's savings estimations,
2) Quality of implementation, and
3) Proof that savings are realized.

For many buildings, the whole-building M&V approach clearly addresses the third element, while minimizing data acquisition and analysis costs.

Related Work

PG&E recently sponsored research (2013) into the development of an evaluation methodology and protocol for whole building energy models. The goal was to develop a method for stakeholders to assess the accuracy of any empirical modeling algorithm – whether publically available and open-source, or proprietary as embedded in Energy Management and Information Systems (EMIS). A model's prediction accuracy is directly related to the uncertainty of its saving estimates in whole building M&V applications. Two years of data from almost 400 buildings in PG&E territory were used to examine the predictability of buildings. Model goodness-of-fit and accuracy metrics were defined and quantified. The report described prediction accuracy results for model training periods of 12, 6, and 3 months in predicting 12 months of energy use. The models showed little difference in the 12-month predictive accuracy using 12 and 6 months of training periods, and showed that some models maintained accuracy and others did not for 3 month training periods. The report also described how buildings may be screened to remove the worst buildings from a portfolio, as well as described how accuracy improved for portfolios of numerous buildings.

Work Order 033 Evaluation Study

The most recent evaluation report of programs that included the MBCx program was Work Order 033 (2014). This report presents the energy savings impacts for efficiency projects in the non-deemed commercial, industrial, and agricultural sectors for the four main California Investor-Owned Utilities. The commercial sector included the statewide UC CSU program. It presents gross and net impacts for the entire portfolio, net-to-gross ratios (NTGRs) on a program-category basis, and resulting gross realization rates for the entire portfolio of projects. The approach taken was to group these categories of projects and measures together, stratify by savings claims, and select a stratified sample for high and low rigor analysis. This activity produced the gross (from existing baseline) and net (above code and standard efficiency requirements) savings impacts. NTGR surveys were performed for 27 program groupings, among them the UC CSU program.

Section 2.2 of the WO033 report states that the overarching goals of the impact evaluation were to verify and validate the energy efficiency savings claims reported from programs, to provide feedback on how well program procedures and savings calculation methods aligned with CPUC policies, requirements, and expectations, and to provide recommendations on how custom projects can be improved or refined.

Since MBCx projects were evaluated together with industrial, agriculture, and other commercial projects, specific feedback on MBCx projects alone could only be obtained from individual site reports for a small group of projects (10 total). The final site reports (FSRs) showed that due to various reasons, evaluators based their evaluated savings on alternate methods, including measure-by-measure engineering calculations and computer simulations, rather than on whole building M&V procedures.

An Appendix G to the report summarized recommendations regarding the MBCx program, including it M&V procedures. For 10 projects, evaluated results were compared with the program's claimed savings. They found realization rates of 58% for kWh, 108% for kW (evaluators determined kW savings where no savings were claimed in some sites, hence the high realization rate), and 35% for therm savings. Details of how evaluators arrived at their "ex-post" savings are available in the FSRs.

Appendix G echoes the MBCx programs whole building M&V guidance, and discusses that when evaluators appear up to two years later, the buildings have undergone significant operational changes that make evaluation difficult. It also describes that there are significant process loads that cannot be explained by the regression based energy models developed for whole building M&V.

RESEARCH QUESTIONS

Review of the goals of the MBCx program and its M&V procedures provides the context with which we can investigate how well some projects are fulfilling expectations. By examining multiple sites, some that are very successful with high savings that persist, and some where results are more modest, we can begin to understand the elements that lead to the desired outcomes and address ways in which the program may be improved.

The MBCx program approach provides a unique opportunity to examine questions and resolve issues to promote more widespread private sector investment in energy efficiency. One of the many goals of the MBCx program was to facilitate the achievement of more robust and longer lasting savings through the addition of permanent measurement. Many of these goals are echoed by California’s long-range energy efficiency goals and strategic plans.

Key research questions this study may address include:

1. How well suited are the UC buildings for this whole building approach? Are they reasonably predictable and do they generate savings estimations within reasonable tolerances?
2. How well is the current whole building M&V guidance followed? What can we say about how it is implemented, and what gaps remain? How can these gaps be addressed?
3. What guidance in terms of data (amount, number of parameters, and accuracy), model goodness-of-fit metrics, and analysis is needed to assure savings are estimated within reasonable tolerances by involved parties?
4. How can unexpected energy use behaviors (non-routine events) be treated, measured, or documented, in order to maintain accurate savings estimations?
5. Can a more standardized M&V methodology be prescribed? What data and analysis can be performed in baseline periods to assess the whole building approach? What alternative verification methods should be pursued that maintain the program’s overall goals of performance monitoring and persistence?
6. What measure-based verification activities can be included to meet the regulatory requirements of savings attribution without unduly burdening program expenses?
7. In what ways may whole building data be used to monitor and track energy use and persistence of savings? This question reviews how whole building energy use for the selected buildings trends over time, and explores ways in which it may be used to assure persistence.
8. How may MBCx program approaches and best practices be used to help California toward its strategic goals of deep and long lasting energy efficiency?

RESEARCH METHODOLOGY

In order to address some of the research questions described above, twenty buildings at UC Berkeley and UC Davis that have implemented MBCx projects or installed retrofits will be investigated. We will seek projects in buildings that were completed at least two years ago, and with energy use data from installed meters up to a year prior to the first installed measures. For selected buildings, we will obtain all related project documentation, including MBCx reports, data and analysis spreadsheets, and program completion forms. Building size in square feet, use type, annual energy usage, and similar information will be compiled.

From this selection of sites, we will apply a consistent and uniform M&V procedure across all projects. We will use an advanced regression based public domain energy modeling algorithm made available by Lawrence Berkeley National Laboratory (Mathieu, et. al., 2011). This advanced modeling approach includes time-of-week and ambient temperature as independent variables, and has been shown to be more accurate than models based on ambient temperature alone. Baseline energy models for each building will be trained with available baseline period energy use and ambient temperature data. For each building, the model goodness-of-fit metrics R^2 and CV-RMSE, and model accuracy metric mean bias error (MBE) will be quantified and tabulated. Relationships between goodness-of-fit metrics, amount and range of baseline data, baseline model accuracy, building size, space use, expected savings, and operational characteristics will be investigated.

Savings will be estimated over post-installation periods, and for subsequent MBCx or retrofit projects in each building. The uncertainty of these savings will be estimated using ASHRAE Guideline 14's method based on fractional savings. These savings estimates and their uncertainties will be compared to the program's reported savings estimates for each building. For some projects, additional data will be collected for building subsystems that have been treated with RCx measures. These subsystem level savings will be used to the extent possible to corroborate savings identified at the whole building level.

The amount of savings, amount and range of post-installation period data, and savings uncertainty, and baseline model parameters identified above will be investigated to identify key insights and relationships useful for improving program M&V guidelines. For example, we will look for relationships between the amount of baseline period data, the predictability of energy use, and the uncertainty of savings among the buildings.

Each building's whole building energy use will be plotted over time from the installation of each meter through the present time, as data allows. The installation completion dates will be collected and included on each plot to delineate when savings are expected to start accruing. Using the baseline models, each plot will indicate what the baseline use would have been (called the "adjusted baseline"), so that the impacts of MBCx or retrofit measures can be visualized. We expect the energy use patterns to show a significant level of non-routine behavior. Based on these plots, we will seek information about unexpected changes to building operations. A short survey of building operators will be conducted to understand these changes and discover whether or how building energy performance is maintained over time.

The whole building data, baseline model development, savings estimates, and evidence of savings persistence will be compiled for each building. Evaluation of this information will be used to identify and inform ways in which the program's M&V procedures and persistence strategies may be improved in the short term to demonstrate the program's cost-effectiveness, and in the long term to help address California's energy efficiency goals. A draft report will be circulated for review and comment by project stakeholders, and comments will be addressed in its final report.

APPENDIX B: INTERVIEWS OF CAMPUS PROGRAM MANAGERS

We spoke with MBCx program managers from UC Berkeley and UC Davis in two separate conversations on December 23rd, 2014 to discuss several survey topics described in the main report. The following notes summarize responses from the survey which are broken up into three sections: the accuracy of building data, management and use of building data, and lessons learned.

Accuracy of Building Data – UC Berkeley

Aberrations in readings can be attributed to hardware issues such as meter and data acquisition malfunctions, and is rarely, if ever, attributed to software issues. The meters themselves report an error on the website when they fail, which happens occasionally. The campus building engineers were concerned with the cost of periodic calibration versus the value that more accurate data would provide. These metering systems are not considered critical equipment, such as an exhaust fan or a chiller. Failing meters are often overlooked. There is little to no calibration of the meters.

The energy dashboards and the web-based data collection systems are in house tools that are used to monitor energy use in campus buildings. The university also has a building energy service provider who monitors the energy use of buildings on campus and sends updates when meters malfunction. There is no policy for fixing the meters, as they are not fire or life safety equipment. If a meter fails for less than a week, no one will likely be alerted. If the meter fails for more than a week, they are more inclined to investigate the issue because more people are looking at the data, including campus utility engineers. Meter repairs are included in repair work categories. It's a matter of the amount of resources available at the time.

They rely heavily on manual labor to do readouts when the web system or the dashboard is not available or accurate. A lot of people regularly look at the data. Building managers and students will often alert staff of meter issues. Engineers review data from their assigned zone on a weekly basis and look at the trends for aberrations.

Accuracy of Building Data – UC Davis

Network errors cause the meter to skip points, fill in values incorrectly, or spike to large values. They are developing a validation algorithm that cleans up data, which currently they must sort through manually. There is also a lack of constant visibility of the data, which means they may not catch errors for a long time after they start.

Meters were installed without allocating the workers and management structure to maintain them. There are a lot of meters to track and maintain. More recently there has been more of an interest in building data, but for the first five years after the meters were installed, no one reviewed it. For a long time, there was no expertise to see if the meter values made sense. There was nothing with which to compare them. More recently, the data receives more scrutiny. The campus is currently working to improve meter accuracy. A time series data historian is used, which has many features for storing, reviewing, analyzing, and viewing the data. The team is also building a web application for cleaning the data and posting it on the internet.

Personnel resources are a limiting factor. Recent high turnover in the building management team has caused more challenges as well. They are hiring an engineer to develop the system and another team to build the web application.

Management of Building with Data – UC Berkeley

Building management involves multiple groups on campus. In the incentive program, all buildings are assigned a baseline and tenants are given monthly statements of their current use. The dashboards are used to catch issues in a building and track energy use. The campus is currently working out a deal with local research teams in which the university receives daily updates on whole building energy use. This system would compare the current 24 hour profile to an average day for that building, a model, and similar buildings in the area. There are currently three levels of energy management systems on campus: monthly statement, day to day usage reports, and the dashboard which allows for user engagement.

There is a new pilot project to create an asset management team. Their current focus is not on efficiency, but this asset may be incorporated.

The level of technology and the level of labor often have an inverse relationship. An ideal system would have a high level of technology with little labor. A fault detection diagnostic should be a mandatory component in energy efficiency projects. This technology would take advantage of sensor data to diagnose the causes of energy changes in a building. It would be useful if these could be incorporated into an energy management system. Currently the systems lack the means to determine the source of energy aberrations using diagnostic tools.

Management of Building Data – UC Davis

The MBCx program has become too much of a project based approached. It moves on quickly from project to project, and despite the small training aspect of the program, which usually occurs at the end of each project, the campus does not retain the insight on building operations and analysis capability. They are not left with a good way to look at the data. It has become cumbersome to go through the MBCx process. "Why can't we just do a project if we have a good metering system and we can find savings? Why go through the MBCx process, when it's easier to do it ourselves?" Energy projects have been moving quickly and savings are not monitored sufficiently after the installation. Projects are driven by the calendar year and getting documentation submitted. They're now trying to pull away to a system where they can promote monitoring and find more sources of savings in-house.

They currently have their own campus energy dashboard where people can pull data from buildings themselves (eco.ucdavis.edu). The goal is to make more data available to more people. They also want to build analytics tools. Some will be integrated into their system, but some will use programs such as Universal Translator. They are trying to build more expertise in-house, so it's best to hire in-house to solve these issues.

Some upcoming projects that will result from this new infrastructure will be campus wide monitoring to determine opportunities to optimize scheduling, optimize set points, install outside air economizers, and optimize chiller operation. We also want to do diagnostics in pie system.

Lessons Learned – UC Berkeley

Training is the largest issue. Campus personnel should be more aware of the changes that occurred as part of an MBCx project. There should also be resources or methods to evaluate a problem in a building at their fingertips. Standardization could also improve such as the calculation methodologies, locations of the data points for data collection, etc. Often two people will come up with two completely different savings estimates. If the savings calculation methodology was more standardized, this problem would not exist.

Lessons Learned – UC Davis

There is a standard sequence of operations for use in all buildings on campus. Once they know what measures they want to install, they can look for savings in their analytics software. They ultimately want to have more control over what gets done. A lot of work is contracted out and they haven't benefitted as much as they could have. All of the engineering knowledge from those projects disappeared when they were contracted out.

They like the whole building approach. A good monitoring system is necessary in order to make sure the savings are realized. The monitoring after the fact has not been done very well in the past. There is also not a good translation to campus staff on the new work that was completed and how to monitor savings going forward. It is common to find problems when you go back and look into a past project in a building. In one example, heating and cooling in a building was not properly adjusted, which leaves a lot of people uncomfortable. In most cases, projects were closed out but not followed up on, which causes a loss of those savings or unhappy tenants. The campus is trying to change how projects are closed out by continuing to monitor afterward and work with the occupants of that building to make sure they are happy.

The campus would recommend simplifying the process of getting projects approved. It was noted that the process has always been a challenge: a lot of work, a long review process, pulling data multiple times, and higher state codes and standards. This has caused a decrease in overall savings. A simpler program would be more economical and require less training.

APPENDIX C: FEEDBACK ON WO033 APPENDIX G

The 2010-12 Work Order 033 Custom Impact Evaluation Final Report, Appendix G "Areas of Interest" provided discussion of several issues related to the MBCx program's application of the whole building M&V approach. In this appendix, we did not comment on the project-level gross impacts described in Appendix G, rather we narrowed our discussion to the number of issues the authors identified and described about application of the whole building approach. As the whole building analysis methodology has developed beyond simple linear regression, upon which many of the Appendix G issues are described, we sought in some cases to correct erroneous statements, and in others to agree and expand upon the authors conclusions.

We summarize and address each issue below. Note we comment on one additional issue discussed prior to the reports list of issues first, otherwise we use the same issue numbering convention.

p. G-5. Time Elapsed until Evaluation. In the second paragraph, the authors state that "while operating conditions for individual retrofit measures may remain fairly constant during the post-implementation period, a number of functional and operational changes may occur at the whole-building level." An MBCx project may be selected for evaluation 1 to 2 years after completion, and during this time, changes to the building can cause changes to the energy use patterns at the whole building level. It further cites science and technology buildings where it states that almost all of these building carry process loads that are not weather sensitive, "that cannot be controlled for in MBCx regression models based on outdoor temperature alone."

It is acknowledged that building's energy use patterns are dynamic and its energy loads may change over time often in an unpredictable manner due to additions or removal of equipment, changes in occupancy, and so on. However, these changes typically do not occur in rapid or random fashion. Buildings that do exhibit these changes can be screened out for a different verification method. For the majority of buildings, the energy use patterns immediately prior and immediately after measures are installed represent a period of consistent behavior without major changes. This snapshot in time is enough to quantify savings, as advanced regression models can accurately capture baseline and post period energy use patterns. The industry needs consensus on how these short periods in time may be used to represent annual usage patterns. Research organizations are conducting ongoing work in this area. The MBCx program's whole building M&V guidance document may be updated to describe how to properly screen buildings, and to properly represent annual energy use based on shorter monitoring periods.

In regard to the process load comment, we note that the presence of process loads does not disqualify application of the whole building approach, even if its regressions are based on outdoor air temperature alone. If the process loads are sporadic and highly variable, and significant in relation to whole building usage, these buildings should be screened from applying the whole building approach. Often however, the loads are constant, and while they raise the building's base load, they do not affect its variability which may still be explained by measureable independent variables. Again, this is a matter of screening and modeling assessment.

Issue 1, p. G-5. Validity of Ex-Ante Regression Model. It states that the program rules do not prescribe the statistical parameters that need to be considered for any regression model, nor provide a quantitative threshold for statistical parameters, specifically citing R^2. It goes on to state that if the statistical correlation of energy consumption with outside air conditions is insufficient, using the regression equation can propagate errors. It states that relying on models without good statistical precision may lead to inappropriate savings estimation. It recommends that regression guidelines should be developed and its requirements reviewed as part of the MBCx program process.

The first statement is erroneous. This study did obtain the program's M&V guidance document, and it very clearly states to calculate the R^2 and CV for whole building regression equations. It also recommends that R^2 values should exceed 0.75 and CVs for energy savings should be less than 20%. The second statement is also misleading; as R^2 is an indicator of how much of the variation in the dependent variable (energy use) is 'explained' by the independent variable (outside temperature). R^2 is not a measure of precision, and often a regression with a low R^2, such as a long term average, can be an appropriate model of building energy use. We note that R^2 increases with other independent variables, whether they affect the dependent variable or not. A better measure of the precision of a regression model is the standard error of the regression, which tells what average distance the data is from a fitted line. Another indicator of precision is the CV, which explains how much variation there is between the data and prediction in comparison with the average value of the dependent variable. CV is commonly used in the industry. ASHRAE Guideline 14 shows its relationship with other parameters when estimating savings.

The recommendation to develop regression guidelines is solid, as the preceding discussion has shown that there is still a lack of understanding about the use of regressions in the industry.

Issue 2, p. G-6, Regression Models with Outdoor Weather Conditions. The issue described is that the evaluator did not find good regression correlation of building energy use with outdoor temperature in some cases. It is stated that the model based on three post period months can fall apart over extended periods. It recommended that the baseline and post trending periods should be extended to six months, and stated that its California Evaluator Protocols recommended twelve months for billing analysis.

This study found good regression correlation for each building included in the study. Per our response above, expecting a regression to hold up over a 1 to 2 year period is often unrealistic. Whole building savings analysis should use data and models that describe the energy use patterns immediately before and after measures have been installed. Establishing the whole building methodology to generate reliable and industry accepted savings estimates based on the conditions just prior to and after measures are installed is a promising area for development. Finally, we note that billing analysis traditionally refers to use of data from monthly bills, and a year of bills generates only 12 data points. With short-time measurements of energy use, much more data about a buildings energy use patterns is available in a much shorter time period.

Issue 3, p. G-6. Adjusted Energy Use Baseline. The issue was concerned with adjustments to baseline energy use due to major changes in the building after baselines were established that called for modifying the baseline use. It further described the logistical problems implementers had in making these adjustments that were often found to be in error. It recommended that more thorough data collection and analysis be done, that the whole building approach is not appropriate in all cases.

The adjustments discussed are what IPMVP calls "non-routine" adjustments. We agree that these should be identified during MBCx investigations, and that the M&V protocol should include steps for vetting the regression models to determine in advance whether the approach is appropriate for the project. This issue has been outlined above and in the main report.

Issue 4, p. G-7. Negative Claimed Savings. The issue described negative savings that can be attributed to non-program induced changes or faulty energy modeling, and that because of the short three month baseline and post monitoring periods, these effects can be missed. It recommends that records of each measure and other events be recorded in order to verify that the work was done correctly, and to allow the evaluators to implement a retrofit isolation approach.

We agree that measure installation dates should be recorded and further recommend that the program's M&V guidance should expand its "M&V approach" hierarchy to first assess the whole building approach, examine factors that prevent it from proper implementation, then recommend retrofit isolation, or system level approaches, and if that proves untenable, complete a measure-by-measure approach.

Issue 5, p. G-7. Retrofit Measures Implemented During and After MBCx. The report stated that this situation was found frequently and created challenges in isolating MBCx from retrofit impacts. Similar to Issue 4, it recommended that a record of all changes to the building be kept and passed to evaluators.

We agree that this is a good practice. We have also recommended that implementers prepare diagnostic tests that demonstrate the impact of MBCx measures to system operations, and show the before and after change in operation to further attribute the impact of the measures in the whole building approach. In the study, we selected projects with many months of time between MBCx and retrofit installations. Successive installations of energy efficiency measures should be encouraged, and therefore it is in California's interest to encourage project throughput. This further supports the MBCx program's establishment of a whole building method based on 3 months of data.

Issues 6 and 7 of WO 033 Appendix G are not addressed as they relevant to the whole building approach.

Issue 8, p. G-9. Reliability of Energy Meters and Flawed Metered Data. The issue described was that the majority of meters were old and not calibrated. New meters did not meet the meter accuracy requirements specified in program documents. Use of this data produced flawed and inaccurate models. It recommended that building level meters be supplemented with additional monitoring of building process parameters to isolate the impact of measures. It notes that most campuses have EMS capability to trend data for 6 months.

The first recommendation should be to establish a data quality regimen for the buildings that are metered on each campus. We noted that campus building managers are beginning to recognize the metering and data as a resource, and use it in managing buildings. Many steps must be taken, including establishing data review platforms and training on data review procedures. The diagnostic algorithms described earlier should also be included. Establishment of data quality control procedures and regular review of the data by stakeholders, will provide a timely method to identify and correct metering and data problems. We do not recommend that facility managers be made responsible for measure-by-measure savings calculations as a means to prolong savings benefits. We agree collecting and providing six months of data trends to evaluators will help with evaluation activities.

APPENDIX D RESPONSES TO DRAFT REPORT COMMENTS

After reviewing the draft report, several comments were received. There were several good comments about how to implement the report's recommendations, or what the implications of implementing these recommendations would be. How these recommendations may be implemented is beyond the scope of this study, instead the author's address how these recommendations may be implemented. Note this does not commit the project sponsors to taking these action items. The comments are reproduced in this Appendix for discussion purposes only. The author's responses and action items taken have been included after each comment.

Comments:

1. The study appears to suggest using specific criteria for developing regression models, mandating the use of hourly data with weather and time independent variables. I think this is fine for a first cut at a regression analysis, but I would like to see the option for grouping data into daily or weekly intervals. I've seen plenty of buildings that did not produce good regression models when using hourly data, but they produced much better and acceptable regressions when using daily data. This is fairly inherent to the building operating profiles, where an EMS will start and stop equipment at certain times of days, which may vary between day of the week and time of the year.

Response: This point is well taken. When using linear regressions and change-point models, we find that better models are possible when the energy use and temperature data is rolled up to daily values, as opposed to hourly. This has the effect of eliminating much variation between the model predictions and the data (achieves lower CV). However, it may require that more data be collected to obtain a good representation of the building's energy response with temperatures – which may increase data collection periods. There are always trade-offs. While the study did use a model that performs very well with hourly data, the study does not recommend that such a model be used in all cases. The recommendation is to emphasize that certain accuracy and model fit criteria should be met when using the whole building method. This allows flexibility so that campuses may select a regression model type and analysis method that best meets their needs while still meeting program requirements.

2. One concern as an MBCx implementer will be what to do if the recommended CV and FSU requirements cannot be met? Most of the buildings in the PG&E study met the suggested requirements, but it would be interesting to know how the regression models for the buildings that did not meet the CV and FSU recommended requirements could be modified so that they did meet them, either by using different time intervals or additional variables.

Response: All of the buildings in this study could be modeled within good model fit and accuracy requirements. We recognize that this may not be true in all cases, so the actual recommendation should be to continue to assess the models using different analysis time intervals, modeling occupied and unoccupied periods separately, or using different regression models, and so on. However, an equally important aspect is standardization, which promotes industry acceptance should be made. But allowing too much flexibility can may not improve the current applications of the approach.

The MBCx program's M&V procedures should include a top-down approach. Such an approach could be: (1) assess use of a whole building approach using short-time interval data, (2) assess a whole building approach using monthly data, (note both of these assessments are not time intensive and can be accomplished well in advance of measure implementation), (3) asses a system approach using the same short-time interval regression approach and acceptance criteria, this entails isolating the affected building subsystem and obtaining the energy use of all components, and (4) if all else fails, use a retrofit isolation approach.

3. The study suggests dropping the whole building regression requirements for the coefficient of determination, R^2, in favor of the CV(RMSE). It's unclear to me why this recommendation is being made other than a preference for one statistical test over the other. Perhaps more discussion on why the coefficient of determination is not a recommended statistical test for a whole building regression analysis would make this more clear.

Response: The study emphasizes that a model's accuracy in predicting building energy use is important, and this is reflected in the CV(RMSE) metric. R^2 is a measure of how well the independent variables are correlated to the dependent variable, and is often erroneously used to explain accuracy. R^2 can say whether its important to include certain independent variables in the regression, and therefore to collect that data or not. There are other tests for the significance of independent variables that may be used as well (e.g. t-test and F-test). Some work is needed to determine the most appropriate test metrics and criteria for use in the approach.

4. The study suggests removing non-routine data from the collected data sets. While this can certainly improve the resulting whole building regressions, won't it just remove the high and low values from the data? It seems like this could easily be gamed by an implementer or third party contractor.

Response: Removing NR events from the data won't necessarily remove the high and low points, as they do not always cause outliers. The time, duration, and magnitude of NR events should be identified before regression models are developed. This should be included in any new program protocol to prevent gaming.

5. Developing acceptable whole building regression models can be quite time intensive. It does not especially lend itself to small buildings with low savings. It would be nice to see CV and FSU requirements that vary based upon the expected incentive. While the FSU predicts the uncertainty, a high uncertainty in a low incentive project may be acceptable as the level of risk is much lower than a large incentive project with the same uncertainty.

Response: The FSU depends inversely on the amount of savings: the higher the savings, the lower the FSU. It depends directly on the predictability of the building: the lower the predictability (higher CV), the higher the FSU. If savings are not high, and the building is not predictable, the FSU will likely be unacceptably high. Acceptable levels of FSU should be considered by stakeholders for any program design. Note that for multiple buildings in a program, savings uncertainty decreases roughly as the square root of the number of buildings, so on a portfolio basis, the savings reporting may be acceptable.

6. The Study references a report by Price et.al., 2013. Which study is this in the Bibliography? The only study with Price as an author was published in 2011.

Response: That was an incorrect reference. It should have read PG&E, 2013, which is in the Bibliography. Price and several others are co authors. It has been corrected and the correct reference is in the Bibliography.

7. p.4. Another practical reason to the need of a whole building M&V method is that UC Berkeley is taking a more comprehensive approach to our buildings. The recent establishment of a new Asset Management department has allowed us to take a whole-building approach, rather than a system-only approach, to enhancing and upgrading our buildings for energy efficiency.

Some of concurrent whole building work will involve building envelope, HVAC and lighting systems.

Without a unifying methodology or data point to measure energy savings, the UCs are left with little to no alternative other than to leave incentive dollars on the table or to allocate significant resources just to get energy savings calculations. This also hurts our conservation efforts since certain measures as a stand-alone have lengthy enough payback periods (i.e. window replacement).

Response: The last sentence of the first paragraph has been modified to:

In addition, the University recognizes significant value in the whole building approach's potential to: ensure long term persistence of energy efficiency investments, better manage its buildings, enable more opportunity for demand response program participation, and to track energy reduction for California Air Resources Board regulatory reporting.

8. p.4. There was also a study by LBNL "Evaluation of the Predictive Accuracy of Five Whole-Building Baseline Models" (LBNL-5886E) that discusses the different products and models readily available in today's marketplace.

This report also conclusively spells out the superiority of these model types as opposed to mean-week and standard regression / change point models.

Response: This sentence has been included in the Introduction section, p. 5:

Recent studies have advanced the practical application of whole building M&V methods. Granderson and Price (LBNL, 2012) demonstrate the accuracy of different whole building methods over and above linear and mean week methods.

The reference was also included in the bibliography.

9. p.13 Fig 4-2. I wanted to check – it appears to me that visually alone, the "6 Month Baseline" graph shows higher percentage of building that has a lower CV? It does, however, have 2 more buildings in the larger than 20% category.

Did the numerical results showed otherwise? If it's easy to pull, might be worth including the table to supplement this graph?

Response: The distribution of points was used to demonstrate the point made about what population of buildings met a certain CV criteria. Many factors can contribute to why the CV from one building is lower or higher for each model training period, but this discussion would not illuminate the main point, and was not included.

10. p. 17. This is a good example of confidence level and fractional savings uncertainty. But, my worry is that this can be interpreted also as "the lower the confidence level, the lower the level of uncertainty" … and therefore a better savings estimate.

Response: Yes, this might be a problem of interpretation, and we have seen ideas proposed that a possible solution would be to have less confidence and therefore higher precision. But both concepts are necessary for the statement of uncertainty. Taken to the extreme, one could say we have 0 confidence that the savings is without error.

Paragraph now reads*:*

Uncertainty is the probability an estimate is within the level of precision, and statements of uncertainty must include both the precision and confidence level. For this work the associated confidence level was 68%. To understand the fractional savings uncertainty quantity in the distribution above, if the savings was an amount X, and FSU 10%, then the uncertainty in savings was expected to be below 10% of X. Stating the savings at a higher level of confidence would increase (or worsen) the precision, for example we could say that we are 95% confident the savings is within 1.96 x 10% = 19.6% of X. It is important to note that whether the uncertainty is expressed at 68 or 95% confidence, the uncertainty does not change

11. On #5. As a note: Over the long term, we have found little to no correlation of exact dates of measures installation / completion to ex-post savings viewed on graphs.

If UCB was to track a whole portfolio of energy savings projects across campus it was less important for us to know the exact dates/times when measures were implemented. Practically speaking, I don't think it's even possible to assign a single "completion date" on any ECMs since there's usually staging and testing time. With that in mind it usually is more practical for building managers / facilities services to track savings at monthly intervals once all ECMs are 100% operational.

We have a different sort of "need" than what was written in the report. Performing precise M&V where an engineer might be studying 24-hour profiles and ascertaining the impact of measures makes perfect sense, and, so does a set of whole-building tracking parameters for building managers and facilities personnel.

Response: We evaluated one building-by-building M&V approach that has the potential to meet the need of all stakeholders (program administration, utilities, and campuses) with transparency and standardization. It's correct that the approach requires knowledge of when measures are fully operational in order to quantify savings for the MBCx project. This approach does lend itself to portfolio analysis, but that was not assessed or in scope for this report.

12. p.30. Relating to #5. UC Berkeley is currently working with Pulse Dashboards and BuildingsAlive to provide unambiguous feedback to building managers on electricity usage. These are whole building models and dashboards that provide transparency to the public. From our experience, this is a key strategy for a successful energy management program and is needed to get buy in.

Most contractors rely on self-developed and/or proprietary software that requires their input/assumptions. This only leaves campuses with only a contractor report on ex-ante savings, and prevents our facility staff to check for persistence of measures.

With a whole building approach, feedback can be seen on a 15-minute basis and whole building energy graphs also serve as a high-level alert to the lack of persistence of a measure (i.e. failed lighting occupancy sensor leaving lights on 24/7).

Response: In the executive summary, a similar recommendation was made to get campuses to conduct the whole building savings analysis, and in this way provide standardization, capture the skills internally, and use it in an on-going manner.

13. p.43. On the accuracy of UC Berkeley data – I may have misspoken in our conversation.

We do not have a special policy for handling failed meters, instead, it's lumped into the work category of other repair projects. Since meters are not life safety or critical equipment, I would say that on average, we would not repair a meter within a week of failure. Instead, meter repair times are usually in the 2-3 week range.

We also have a set of standards for our meters, and these are factory calibrated and revenue grade meters that meet industry standards.

And, because we have multiple folks looking at the data from these meters, it is easy for us to spot aberrations in energy use, as well as meter failures. We have utility engineers and analysts who are dedicated to collect and review this information. The Energy Incentive Program has also made the campus departments and students looking at this data but to what extent I can't tell. Overall, the campus has used our metered data and have paid over $1.9 million in incentive payments in the last two years.

Response: Paragraph changed to:

The energy dashboards and the web-based data collection systems are in house tools that are used to monitor energy use in campus buildings. The university also has a building energy service provider who monitors the energy use of buildings on campus and sends updates when meters malfunction. There is no policy for fixing the meters, as they are not fire or life safety equipment. If a meter fails for less than a week, no one will likely be alerted. If the meter fails for more than a week, they are more inclined to investigate the issue because more people are looking at the data, including campus utility engineers. Meter repairs are included in repair work categories. It's a matter of the amount of resources available at the time.