Challenges in Evaluating Monitoring-Based Commissioning Programs in California

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ABSTRACT

The Monitoring-Based Commissioning (MBCx) program is a statewide California program for implementing energy efficiency measures in large institutional buildings. MBCx adds a layer of evaluation and management to California's traditional retro-commissioning (RCx) program, which aims to identify existing operational deficiencies and help achieve building energy savings through various system operation improvements and operational changes. MBCx puts systems in place for continuous data monitoring, which helps develop procedures to ensure the persistence of the measures implemented through the program. Clearly, such an approach, if successful, holds great promise for facilitating the management and evaluation of commissioning programs. This paper presents the evaluators' experience with the continuous monitoring system as it was actually implemented. We include a focus on the level of consistency with which the prescribed protocols were implemented, the level of detail present in the RCx actions taken, and the consequences of effective monitoring and evaluation of projects. In particular, we characterize the challenges of developing procedures to ensure data quality, validate statistical methods, define appropriate baselines, document specific RCx actions, and establish appropriate schedules for functional tests. A more comprehensive and robust data collection approach will provide greater confidence in program savings and measure persistence. Ultimately our findings will provide guidance for improving MBCx program design.

Introduction and Background

MBCx combines building energy systems monitoring with traditional building system RCx practices and protocols to identify existing system operational deficiencies and help achieve building energy savings through various system operation improvements and operational changes. In California, MBCx program is an Investor-Owned Utility (IOU)-sponsored program that provides a sustainable and comprehensive energy management program for college campuses. While most California IOU-sponsored incentive programs do not describe energy efficiency improvements based on energy stream monitoring, the MBCx Program is an exception where the incentives are based on the energy savings determined through pre- and post-monitoring. In addition, this program provides the opportunity to perform building benchmarking (kWh/ft^2 and kBtu/ft^2) at the start of the process, which helps identify whether the building is a suitable candidate for this program.

Presently, the MBCx program uses the IPMVP Option C[1] approach, where it utilizes three months of pre- and post-installation building-level energy usage coupled with an established regression methodology to determine annual energy savings for a facility. In addition, the program procedure requires the implementer to perform pre-MBCx and post-MBCx functional tests on building systems and equipment. The pre-functional tests are performed on the systems and equipment to document the current operation and their operational deficiencies, whereas the post-functional tests are performed to

[1]http://www.nrel.gov/docs/fy02osti/31505.pdf

assess and document the intended measure operations. However, during the evaluation of several MBCx projects under California Public Utilities Commission's (CPUC) 2010-2012 Custom Impact Evaluation[2], a number of issues were observed with the current program methodology related to building benchmarking, adequacy of energy usage data collection, use of valid statistical regression methodology, identification and documentation of independent variables, and adjustment of building energy usage baselines in a dynamic building environment. Furthermore, the evaluator faced some additional challenges during the evaluation of these MBCx projects. Some of these challenges include lack of reliable metered data, unavailability of adequate baseline data, flawed meters and insufficient documentation to assess a building's pre-existing operating conditions. These inadequacies and challenges can be overcome by adopting a consistent program methodology, using calibrated meters for each building energy stream, collecting adequate data at consistent time intervals, identifying all relevant independent variables, establishing the procedure to document all independent variables affecting the system performance, establishing appropriate baselines, and even using a non-Whole Building approach if required to quantify the MBCx savings.

This paper discusses the current MBCx methodology, presents evaluator's experience in evaluating the program, identifies the issues with the current MBCx methodology and discusses challenges in evaluating the MBCx program in California. Finally, this paper presents evaluator's perspective on the program and provides recommendations to improve the MBCx program design.

Present MBCx Methodology

Currently, the MBCx protocol utilizes a Whole Building analysis approach, and typically involves four phases: planning, investigation, implementation, and reporting. The planning phase determines the suitability of the building selected for the MBCx program based on its size, energy utilization index (EUI) and benchmarking against similar college campus buildings. The investigation phase identifies the operational deficiencies through system- or equipment-level metering and data trending. The implementation phase repairs faults and makes improvements in operating strategies. The final phase involves savings analysis and reporting and training of facility staff on the revised control operation.

Once a building is selected under this program, pre-MBCx functional tests are carried out on the building system and equipment to document their current operations and their operational deficiencies. The conventional MBCx approach is limited to whole building energy analysis, with metering/monitoring at the building level, and no separate analyses to estimate the energy savings for individual measures. The program necessitates either installing new meters on each energy stream or utilizing the facility's existing energy meters. In cases where multiple buildings are pooled together in one MBCx project, the buildings can share a common meter for chilled water (CHW) and heating hot water (HHW)/steam. However, each of these buildings must have its own electric meter.

As prescribed, the program calls for energy usage data collection three months before and three months after the MBCx project implementation, along with collection of data related to independent variables necessary to provide routine and non-routine[3] baseline adjustments, such as outside air temperature, occupancy level, additional process loads, and daily operating hours. IPMVP Option C is utilized to develop regression models relating each type of energy usage to the independent variables, either alone or collectively. Then typical meteorological year (TMY) weather data are utilized in both

[2]http://www.calmac.org/publications/2010-12_WO033_Custom_Impact_Eval_Report_Final.pdf
[3]Routine and non-routine baseline adjustments are described in the International Performance Measurement and Verification Protocol (IPMVP) available at www.evo-world.org.

pre- and post-MBCx regression models to generate projections of baseline and post-case energy consumption along with the projected annual savings.

Finally, a post-MBCx functional performance test (FPT) is carried out on the building equipment and systems to document proper operation of each measure. In addition, a MBCx program activity log provides guidance to college campus facility personnel on unresolved issues noticed during the MBCx treatment, along with future changes recommended for systems/equipment/components, and their potential impact on cost and energy savings.

Issues with Present Methodology

While operating conditions for individual retrofit measures may be fairly constant during the post-implementation period, a number of functional and operational changes may occur at the whole-building level. Typically, an MBCx program participant building is selected for evaluation one or two years after project completion. During this time, changes occurring in the functional use or operating hours of the building cause changes in energy consumption that are difficult to separate from the MBCx program impacts. For example, a large number of the current MBCx projects have been implemented in science and engineering facilities at college campuses, where additional equipment/processes/systems have been added to some of the buildings subsequent to project completion, while other equipment/processes/systems have either been taken out or have become defunct. While the likelihood of functional/operational changes increase over time, we also saw cases where these changes were happening during the course of program implementation, and these changes required special treatment by program implementers in calculating savings.

While the science and technology buildings found in the 2010-2012 Custom Impact Evaluation sample were good candidates for MBCx project selection because of their high EUI, one of the biggest challenges to the evaluation process posed by these buildings was the characterization of the heating and cooling loads. Almost all of these buildings carry significant process cooling and heating loads, which are dynamic, non-weather-sensitive, and subject to variation that cannot be controlled for in MBCx regression models based on outdoor temperature alone.

A number of issues were observed during the evaluation of the MBCx projects that had notable impacts on the project savings. Some of the underlying issues are enumerated below:

Validity of the Submitted Regression Model

MBCx protocol mandates the implementer use the short-term pre- and post-MBCx metered energy streams along with site weather data during the corresponding time frames to develop regression models to annualize the pre- and post-implementation metered energy use. Based on the evaluators' experience, it is evident that these regression models and their associated regression correlations are often misleading. The reasons are multifold. First, IOU program rules do not prescribe the statistical parameters that need to be considered for validation of any regression model, nor do they provide any quantitative threshold values for the commonly used statistical parameters, such as the minimum acceptable R-Squared value for linear regressions. Second, if there is no good statistical correlation of energy consumption with outside air conditions, using the regression equations for any calculation is potentially counterproductive as the errors are often propagated along the savings calculation. Third, because the building systems and their behavior are complex in science and technology buildings, and many system parameters interplay simultaneously, specifying a particular independent variable in the energy consumption model is neither reasonable nor appropriate. One such specific example is of lab buildings utilizing 100% outside air for their HVAC system, where the fan energy is usually driven by fume hood operation, and does not exhibit a strong linear relationship with outside weather conditions. Relying on regression models that do not provide good statistical precision may lead to inappropriate savings estimation. Figure 1 below shows the scatter plot between outside air and building baseline energy consumption with the implementer-provided regression equation and the R-Squared value for one of the MBCx projects that was evaluated under 2010-2012 Custom Impact Evaluation. The low R-Squared in the Figure 1 shows a poor relationship between the outside air conditions and the baseline energy consumption.

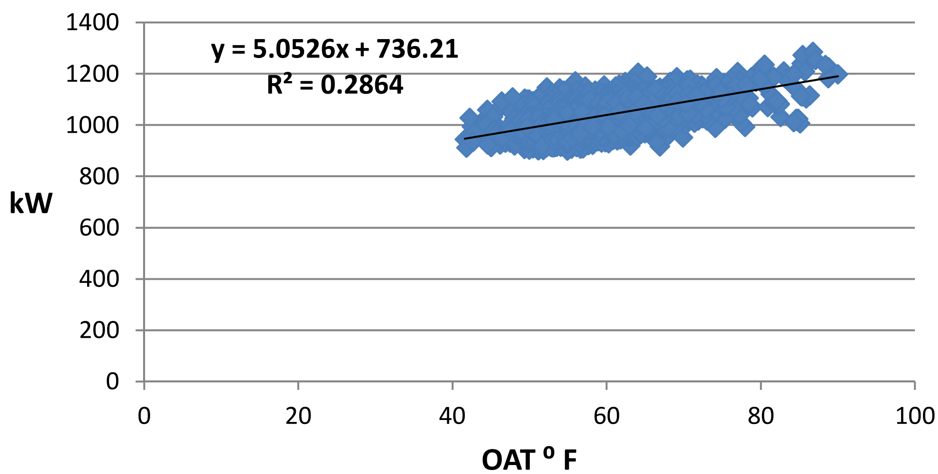

Figure 1 : Baseline Energy Use vs Outside Air Temperature

Negative Claimed Energy Savings that May Not be Due to MBCx Measures

During this evaluation, the evaluator found a couple of instances where the final claimed savings reported negatives (i.e. load increases) either for electricity or natural gas usage. As the prescribed savings calculation approach relies on short term pre- and post-MBCx monitoring, which are extrapolated against the TMY weather data for determining the annual baseline and post-MBCx energy usage, it is possible that the building might see an increased post-MBCx annual energy usage in any particular energy stream or in all forms. The increase in use can, at times, be attributed to non-program changes at the facility or faulty energy modeling and not to measure performance.

Retrofit Measures Implemented During and After MBCx

The MBCx implementers normally come across instances where the building requires some kind of system or equipment retrofit that is either part of the MBCx exercise or is done as part of separate retrofit programs. For the cases when the retrofit is part of the MBCx exercise, no separate savings quantification and impact analysis is required on the final MBCx savings. However, for the instances where retrofits are implemented during the MBCx timeframe under different programs, it necessitates calculations to quantify the impact of retrofit measures. In addition to this, there are possibilities that the building may see some retrofit measures during the period after MBCx is complete and prior to CPUC's custom impact evaluation. Savings from these additional retrofits are often not readily distinguishable from the MBCx savings, which poses challenges in isolating the post MBCx retrofit effects.

Benchmarking of Project Sites

The MBCx protocol mandates that the implementer use the historical energy usage data along with the building's total conditioned area to determine the EUI and compare it with similar buildings on the campus. This helps the implementer to determine the suitability of the selected building for the MBCx program. However, the evaluation team found instances where the reported pre-MBCx EUI was in error, based on the available site energy information. Such cases often coincided with sites where a good correlation of energy usage with the outside weather conditions did not exist. Therefore, the calculated EUI for these cases did not represent the actual EUI of the building, which can lead to incorrect selection of the building during the project application phase. In one of the projects, the implementer estimated baseline EUI at 15.8 kWh/SF, as compared to the building level EUI at 10.1 kWh/SF for similar college buildings. The evaluation team re-calculated the baseline EUI from the utility metered data and determined the actual baseline EUI to be 6.4 kWh/SF for the building, which was significantly lower than the value of the EUI of the similar college buildings and as well as implementer's EUI claim for the building.

Recommended Changes Incompatible with the Building Equipment Capability

The facility operators often find constraints with the HVAC equipment that limit their ability to fully implement the revised control sequences. In addition, equipment manufacturers' suggestions on preferred operating sequences on a piece of equipment often lead the facility staff to bypass the modifications suggested in the MBCx project. For example, during the site visits at some of the older campus buildings, the evaluation team noticed that the majority of HVAC instrumentation had limitations in acting over the full or partial range of control changes made during MBCx treatment. Because of time and budget constraints, the facilities often inadequately accommodated the need for control hardware and software changes during the MBCx projects.

Regression Models with Outside Weather Conditions

While the installed energy meters at the building level provided post-MBCx interval data from project completion until the evaluation, the evaluator, in some cases, did not find a good regression correlation of the individual building energy usage with the outside weather conditions. Although the three-month post-project period used in the MBCx program may provide a reasonably good looking model, this model can fall apart in an extended comparison. In some cases, this is evident even during the post-MBCx assessment by the MBCx providers. Although this outcome is understandable for science and technology buildings, which have a significant portion of process loads, the evaluators also found this anomaly for regular classroom buildings on a college campus.

It should be noted that some science and technology buildings exhibited a very good regression correlation of energy usage with outside weather conditions, for both occupied and unoccupied periods. On an interesting note, the evaluator observed that in a particular case with water-cooled chillers, the chilled water usage provided a slightly better regression model when plotted with dry-bulb temperatures than when plotted with wet-bulb temperatures. Another college building that gets evaporative pre-cooling from a common campus condenser loop, and it's remaining cooling from metered chilled water, did not produce a good regression model for chilled water consumption with outside weather conditions.

This demonstrates that buildings do not necessarily provide good regression statistics using a simple correlation to temperature under all conditions, and alternative methods are needed.

A general concern with the overall program approach, as implemented, is that three months of pre- or post-retrofit data are not sufficient for a regression-based annualizatin process. In most climate areas, three months of data do not provide enough seasonal variation to adequately inform the regression models. Recent work by LBNL in the assessment of automated M&V modeling shown in Figure 2 has corroborated this finding in showing that three months of data are insufficient for baseline model development, but that reducing the model training period from twelve months to six months does not provide a significant drop off in model accuracy.[4]

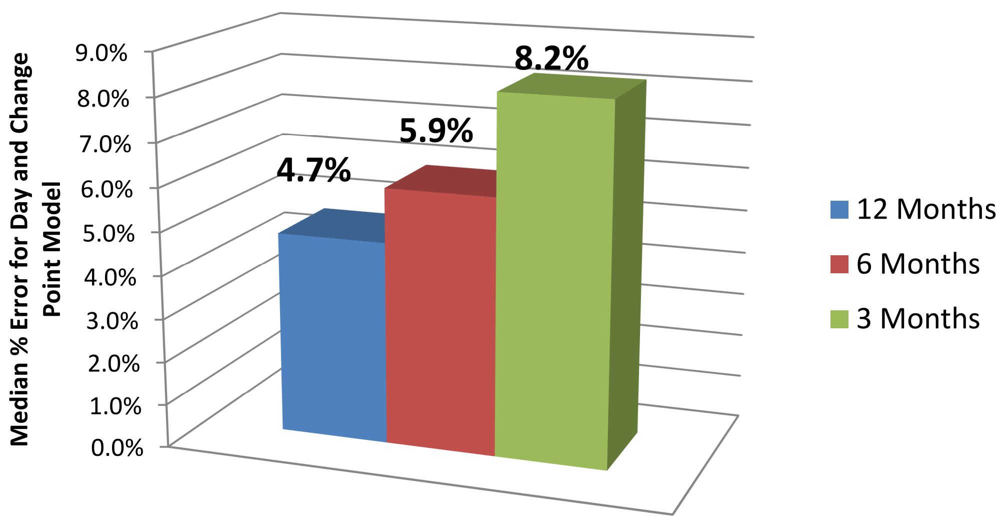

Figure 2: Comparison of Accuracy Predictions among 12-Months, 6-Months and 3-Months Training Period Data

Adjusted Energy Usage Baseline

The MBCx protocol calls for installing meters, which are used to establish the baseline energy use. However, MBCx implementers often find some major changes in the building after the baseline is established that call for modifying the building's annual energy usage baseline. As the implementers are tasked with a definite timeline to complete the pre- and post-MBCx monitoring, perform the pre and post-functional tests, systems/equipment commissioning, and final training and hand-off, it is not feasible for the MBCx implementer to redefine the baseline energy usage with an additional three months of energy monitoring after any major baseline modification. Furthermore, as the implementer may notice additional changes that should have been factored into the baseline conditions while the MBCx investigation phase progresses, it is not possible to redraw the baseline every time with three months additional monitoring after any major baseline adjustment, as this might stretch establishing the baseline out indefinitely. In order to avoid these repetitive exercises, the implementer adopts a calculated

[4] Evaluation of M&V Accuracy and Savings Uncertainty, Jessica Granderson,Ph. D

approach for estimating the impact of any baseline modification measures, and adds/subtracts the energy impacts from the baseline energy, to obtain the adjusted energy usage baseline. Sometimes, this calculated approach does not reflect the accurate impact of these baseline modifications, which introduces errors in re-establishing the adjusted baseline energy consumption. Additionally, this method may require extensive data collection, analysis of data, model development and validation of the engineering models which can be time consuming.

Reliability of Energy Meters and Flawed Metered Data

Discussion with facility operators revealed that the majority of the existing meters used for the MBCx program were old and had not been calibrated for years, and, similarly, new meters installed as part of MBCx exercise often did not meet the meter accuracy criteria specified in the MBCx project guidelines[5]. These problems produced flawed and/or inconsistent data that provided inaccurate models of pre and/or post project energy consumption. The implementer should check that all the collected data from the EMS is recorded at a consistent interval (e.g. every 15 minutes) and identify inconsistencies at an early stage, so that they can be rectified early enough to avoid tedious effort to align data sets or having to discard unusable data. A non-aligned data set can introduce errors in the saving analysis which in turn will lead to an inaccurate savings estimate.

Evaluator's Recommendations

As described in the previous section, the 2010-2012 custom evaluation identified several key issues and challenges in evaluating MBCx projects. Some of these challenges are due to inappropriate implementation of the program protocols whereas some of the other of the issues were purely related to inadequacies of MBCx methodology that needed refinement. Based on these findings we provide the following recommendations for MBCx programs:

- In order to adequately collect both baseline and post-case conditions, the trending periods should be increased to a minimum of six months before and after the treatment. We note that California Evaluation Protocols require 12 month pre- and post-retrofit data for billing analysis, as shorter periods do not always adequately capture a building's response to weather. In addition, the project implementer should collect trends of all affected control points in the post-MBCx phase in order to verify the implemented measures are working as implemented.
- Apart from collecting longer term pre- and post-trend data, the IOUs should develop regression guidelines prescribing the statistical parameters that need to be considered for validation for the regression model. These guidelines should include model limits, procedures to assess reasonability of the independent variables, methods to check if the regression coefficients are within an expected range, and provide the ranges of acceptable R-Squared and t-statistic values for linear regression.
- In order to avoid inappropriate selection of buildings during the MBCx site selection process, both the campus and the implementer should be careful in calculating the EUI and comparing the project sites with similar buildings in the campus.
- To the extent possible, the building-level meters should be supplemented with additional monitoring of building process parameters to isolate the impact of individual measures. As most

[5]MBCx Project Guidelines and Minimum Requirements, Monitoring Based Commissioning (MBCx) Program 2010-2014 Higher Education / Investor Owned Utility (IOU) Partnership Programs, Updated August 2013

of the MBCx projects are implemented at college campuses that have a decent EMS with data storage capability, the MBCx provider should work with the campus in collecting baseline system operation trends for six months pre and post. The MBCx log should provide both qualitative and quantitative estimation of individual and relative impacts of each MBCx measure or any other non-program impacts, as this will help the evaluator prioritize measure impact evaluation activities.

- A record of each measure implemented, along with post-implementation functional performance tests, should be retained to identify the specific activities done within each project and verify that the work was done correctly. This will allow the M&V team to implement a retrofit isolation approach as needed. The campus facility should keep a record of all building operation changes at a central node. This will help the evaluation in getting the actual project background and an appropriate perspective. This will also help IOUs in documenting other retrofit project information along with the MBCx project documents for a comprehensive impact evaluation.
- In order to ensure the implemented measures produce energy savings opportunities, the project implementer should assess the facility control system and make sure that the existing control system is compatible with the control changes proposed as part of the MBCx retrofit. Additionally, the implementer should collect trends of all affected control points in the post-MBCx phase in order to verify the implemented measures are working as intended.
- The implementers must also realize that the MBCx whole building approach is not appropriate for all buildings, such as the buildings that undergo frequent changes in various non-program-related energy improvements such as equipment retrofit, addition and elimination of building loads, and changes in the building usage patterns. These changes may have an impact on the energy consumption that can't be specifically isolated through the whole building approach. Thus, the implementers need to keep track of the various changes that the buildings undergo during the MBCx project and make sure to isolate these effects from the MBCx impacts using an appropriate calculation methodology.

Summary and Conclusions

Our evaluation on MBCx projects confirmed our belief that all buildings are different, and no two buildings with similar characteristics and usage exhibit the similar behavior. Furthermore, there are many variables that impact building energy usage such as occupancy profiles, load characteristics, time of use, etc., and two similar buildings at a college campus may likely exhibit different energy consumption based on the predominance of any of these variables. Therefore, energy consumption characteristics of a building may not be replicated in similar other buildings on the college campus. Lastly, even the buildings with little or no process loads are often not appropriate candidates for using a particular regression-based MBCx protocol. We conclude that using a theoretically appropriate methodology is not necessarily sufficient to demonstrate the savings for the MBCx project; other factors must also be considered, such as collecting adequate data at appropriate time intervals, identifying all relevant independent variables, documenting the system performance, and establishing appropriate baselines. These additional factors should be fundamental requirements for this program. Each project is unique and should be evaluated based on its own system configuration, building characteristics, behavior of loads and operations. The majority of the MBCx sites, in general, and college campuses in particular, provide ample opportunity to generate and store historical data that can be used during project implementation and during the subsequent project impact evaluation.

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