How Monitoring-Based Commissioning Contributes to Energy Efficiency for Commercial Buildings

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ABSTRACT

Monitoring-based commissioning combines permanent building energy system monitoring with established retro-commissioning protocols to achieve and maintain high performance and low energy use. A major pilot program on twenty-five California university campuses is establishing the potential contribution of monitoring-based commissioning to facility energy management. A partnership of universities and investor-owned utilities created this leading-edge effort based on a decade of research and development activity, as well as the accomplishments of innovative campuses across the country.

This $5 million program funded monitoring-based commissioning for over thirty buildings, including the upgrade of permanent energy meters and other instrumentation, augmentation of energy information systems, benchmarking of building energy performance, assistance with initial commissioning efforts, and training of in-house staff. Results to date from thirteen sites significantly exceed targets: the projects reporting at the time of this writing represent 32% of total funding, while producing 66% of aggregate energy and cost savings goals for the overall program, with aggregate simple payback period of 2.3 years.

These initial results suggest that monitoring-based commissioning has great promise to deliver cost-effective energy savings for higher-education campuses and other commercial facilities. The first set of thirteen projects was successful in targeting on-peak electricity use reduction, in addition to annual electricity and natural gas savings. Enhanced monitoring capability has proven valuable in identifying, diagnosing, and quantifying measures to reduce energy use. Monitoring also provides a means to increase persistence of commissioning-related savings, although evidence of this effect needs to be documented over the longer term.

Future work will also explore the value of building energy use benchmarks in targeting cost-effective projects. Benchmarks have already proven valuable in assessing the relative level of success for projects, with respect to both the monitoring-based commissioning portfolio and projects in other programs.

Background

Statewide policies in California have led to the setting of ambitious energy efficiency goals including provisions of the California Green Building Initiative (GBI 2004), the University of California Green Building and Clean Energy Policy (UCOP 2004), and a similar policy for the California State University System. Strong goals in turn have led utilities and their customers to consider new options for delivering energy efficiency. In 2004 and 2005, the California Public Utilities Commission (CPUC) partnership model for energy efficiency funding afforded a unique opportunity to explore new ways to reduce energy use.

One innovation was the Monitoring-Based Commissioning (MBCx) program, an element of the collaboration among the University of California (UC), California State University (CSU), Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Southern California Gas (SCG). The monitoring-based commissioning approach employed by this program includes permanent upgrade of energy meters and other instrumentation, along with augmentation of energy information systems to facilitate trending and benchmarking of building energy performance. Expert commissioning assistance is focused on training in-house staff, which along with the permanent monitoring capability can increase persistence of savings.

The following account of the program and its initial results illustrates promise for the Monitoring-Based Commissioning approach, as well as providing guidance for future program implementation. Program origins and design issues are first discussed, followed by a summary description of the 2004-05 project portfolio described in more detail in a previous publication (Brown and Anderson 2006). Results from the first thirteen complete MBCx projects are presented, first compared with program goals, then with the meta-analysis of retro-commissioning projects compiled by Mills et al. 2004. Discussion includes detail regarding the value of the monitoring in diagnosing inefficiency, along with the success of the program in targeting reductions in peak electricity use. Conclusions include lessons learned for future MBCx program planning and broader implications for commercial building energy efficiency. The discussion of future directions covers opportunities for improving benchmarking practice and the long-term studies needed to confirm persistence of savings from more monitoring capability.

Origins of Monitoring-Based Commissioning

Though little about the monitoring-based commissioning approach is unique, the consistent emphasis on diagnosis and persistence of savings through monitoring is thought to be unprecedented in a program of this scale. In the 1990s, research and development on building monitoring and diagnostics included an approach employing extensive permanent energy system monitoring. This capability was shown to enable building operators to identify previously unrecognized dysfunction and energy waste (Piette et al 2000). Also in the 1990s, Texas A&M University was prominent among those pioneering the practice of building retro-commissioning, with an emphasis on monitoring for baseline determination and diagnostics (Claridge et al. 2000). Early in this decade, some early adopters on university campuses spontaneously combined these concepts in their energy management programs, establishing part of the model for development of the MBCx program (Haves et al 2005).

Examples of campus initiatives. The University of California at Santa Barbara (UCSB) has achieved a remarkable reduction in campus-wide energy use through extensive trending of monitored data, retro-commissioning, and retrofits partially identified through monitoring (Motegi et al 2003). UCSB leadership in campus energy monitoring extends to a public website displaying campus load, along with simple trending tools (UCSB 2006). The new UC campus at Merced has incorporated extensive energy system monitoring into the energy management and control system for the entire main site. This capability is facilitating initial commissioning, as well as ongoing commissioning of campus energy systems (Brown 2002).

The UC/CSU/Investor-Owned Utility Program for Monitoring-Based Commissioning

As a part of the UC/CSU partnership application for 2004-05, the University of California proposed a program element to fund permanent energy system monitoring equipment along with retro-commissioning efforts. This was complemented by a retrofit element of equal magnitude, as well as a training and education element with only around 5% of the total funding but equal long-term importance. Total program funding was $15 million for two years, to include 33 campuses in the two university systems.

The monitoring-based commissioning approach employed by this program includes upgrade of permanent energy meters and other instrumentation, augmentation of energy information systems, benchmarking of building energy performance, assistance with initial commissioning efforts, and training of in-house staff. Though the methodology is not unique, the deployment of this general approach in a program at this scale is thought to be unprecedented. The following discussion of program design illuminates the many concepts, issues, and questions that come into play when emphasizing the role of monitoring in building commissioning and ongoing operations. Resolution of all these issues is beyond the scope of this paper, with the subsequent discussion of initial results providing just a starting place for more extensive investigation.

Synergy between monitoring and retro-commissioning. Energy-efficiency incentive programs have rarely funded monitoring capability or retro-commissioning due to skepticism about cause and effect issues and persistence of savings following initial success with retro-commissioning (Bourassa, Piette and Motegi 2004).

The UC/CSU proposal received favorable consideration because a synergy between these two aspects - retro-commissioning combined with permanent enhancements in monitoring - overcame the conventional perceptions about each. Including permanent monitoring capability provides a means to verify and ensure the persistence of savings achieved through retro-commissioning. Retro-commissioning makes the integrated monitoring-based commissioning approach “actionable”, dispelling the perception that measurement alone does not reduce energy use.

Monitoring to verify savings. For traditional retrofit programs, savings are generally estimated as part of the project proposal, based on accepted engineering assumptions. Justified or not, this confers a high degree of perceived certainty on the projected savings. Empirical observation is used to verify installation and some of the prior assumptions, but the authors observe that accounting of savings often reverts to the up-front calculations.

MBCx projects allow a higher degree of savings verification through enhanced monitoring: an increased ability to empirically confirm energy savings is inherent in the nature of the program design. For the MBCx program, up-front savings numbers are just targets, rather than specific predictions, as the exact level of savings that will be obtained at any given site depends on what is discovered and can be corrected during the commissioning process. Savings will be more reliable on the portfolio level, with a higher degree of certainty in predicting the overall savings achievable by a group of projects.

Program theory: monitoring increases savings opportunities. Monitoring expands the potential for reducing energy use in two ways. First, monitoring complements conventional functional testing protocols in the identification of wasteful dysfunction in building systems. The UC/CSU/IOU program uses both methods. Second, savings opportunities are often constrained to measures for which savings can be calculated using accepted engineering assumptions. Opportunities that are difficult to predict in advance and require measurement to assess or verify the energy savings have gotten less attention.

Goals for peak energy use reduction. The UC/CSU/IOU program provides some good examples of the ability of retro-commissioning efforts to impact maximum demand and peak-period electricity use. The 2004-05 MBCx program has goals for "peak electric demand" reduction, but the definition of "peak electric demand" is actually based the average levels of peak-period electricity (CPUC 2003). Thus we track peak-period kWh toward program goals, and use maximum 15-minute demand observations only for benchmarking purposes.

Distinguishing between MBCx and retrofit projects. This program defines commissioning as the adjustment, maintenance or repair of existing equipment; as opposed to equipment upgrades, which are considered to be "retrofit". Obviously, "combined" projects are conceivable, often with synergy that maximizes reduction in energy use or improves project cost effectiveness. In the long term our development of MBCx will fully pursue this synergy. In the short term, establishing the concept of MBCx requires that we have a portfolio including many straightforward projects that unambiguously establish the potential for MBCx alone.

Other program design issues. The relative emphasis on in-house vs. contracted resources and whole-building vs. sub-system monitoring is briefly covered in a previous account of the program (Brown and Anderson 2006). The timing of permanent monitoring capability and the occasional need for interim use of short-term means is a program design issue beyond the scope of this paper.

The portfolio of 2004-05 projects. In the pilot program, monitoring-based commissioning was funded for thirty-seven building projects and 9 plant systems. Half of the building projects contain energy-intensive laboratory space with 100% outside air loads operating 24/7. The floor area included in the building projects totals 7 million square feet (gross), representing over 4% of the total 160 million square feet of floor area in the two university systems.

The $5.2 million of partnership funding was supplemented by approximately $0.5 million in campus resources, although a full accounting of overall program costs awaits the further documentation of all projects. Due to energy prices that vary by campus, and arcane program economic criteria that vary by utility service area, it is difficult to make precise or consistent comparison of energy cost savings across all the projects. To simplify the discussion of overall program economics, we assign the same representative energy prices to all projects. Energy prices representative of a large campus, but without transmission level service or other special pricing have been applied to all projects and to the program as a whole in Table 1[1]. This results in a reference simple payback period for the overall program of around five years.

Given the prototypical nature of this program, this modest overall target is prudent. However, a shorter payback period for MBCx measures is both widely desired and achievable. Individual projects often pursed more aggressive targets, averaging 50% higher than a prorated share of the whole program goal. These aggressive projects explain why the portfolio average

[1] The prices used are close to the PG&E E-20P rate applicable to a few projects in the sample.

payback period is substantially shorter at around three an one-half years. More detail on the project portfolio has been reported previously (Brown and Anderson 2006).

Initial Results

At this writing, thirteen of the thirty-seven building projects have provided full reports documenting their MBCx efforts and results. For these projects, representing 32% of the total program funding, all affordable commissioning measures were implemented and actual savings observed. Several other building projects have reported achieving savings through a combination of commissioning and substantial retrofit measures. Still others have reported truncated efforts where affordable commissioning efforts are not being carried-out because of a decision to pursue retrofit solutions or other reasons. One complete plant project has reported. Including these projects results in a data set comprising 49% of the total program funding. Projects that have as yet only reported estimated savings from identified commissioning measures are not included in this analysis. Summary results and economic information is presented in Table 1.

Reporting Guidelines

Project results herein are as self-reported by campuses, often with the assistance of engineering consultants. Program guidelines call for building baseline energy use levels to be updated using the existing or added monitoring capabilities, with reports of energy use reduction to be based on post-measure observations and monitoring[2]. There is an emphasis on consistency of analysis between "before" and "after" conditions. Project reports are scrutinized for internal consistency and compliance with program guidelines. A separate "EM&V" analysis will be reported independently of these results, with indications that it may be based more heavily on engineering estimates of savings.

Energy Savings and Cost-effectiveness Relative to Program Targets and Economic Criteria

One way of summarizing the overall achievement of this first group of building MBCx projects is to compare their cumulative energy savings (as a percentage of the cumulative target) with their cumulative project funding (again as a percentage of total program funding)[3]. As a group, the thirteen completed building MBCx projects have achieved 46% of the portfolio and 66% of program goals with only 32% of the funding. In other words, this initial set of projects is contributing more than its share of energy use reduction, putting the partial program totals far

[2] Limitations on baseline and post-measure monitoring periods require some use of calibrated models to annualize results. Monitoring periods are per unique project circumstances.
[3] Comparing the observed savings relative to targets for each project is not very useful outside the context of the program, because of the arcane methods used to set the targets.

Table 1: UC/CSU/IOU Partnership MBCx Project Results Summary (1)

Project ID	Reduction in Energy Use				Annual Cost Savings	Total Project Funding	Simple Payback on Funding (years)
	Total Electricity (kWh/year)	Peak Electricity (kWh/year) (2)	Demand (kW) (2)	Natural Gas (therms/year)	(3)	(4)	
Results for Complete Building MBCx Projects Reporting To-Date							
2005.01	197,679	13,743	23	40,591	$62,420	$67,500	1.1
2005.02	496,619	11,262	18	43,497	$94,848	$114,140	1.2
2005.03	454,586	23,751	39	0	$49,021	$83,500	1.7
2005.04	720,038	50,899	84	76,987	$156,626	$270,000	1.7
2005.06	36,754	2,555	4	9,406	$13,465	$25,500	1.9
2005.08	302,529	18,013	30	15,836	$48,796	$110,000	2.3
2005.13	714,430	25,274	42	0	$75,234	$184,900	2.5
2005.10	758,644	75,864	125	11,787	$99,031	$244,950	2.5
2005.15	343,412	44,726	73	11,221	$52,271	$192,163	3.7
2005.12	250,009	17,010	28	5,233	$32,785	$152,601	4.7
2004.16	76,670	7,806	13	661	$9,499	$49,300	5.2
2005.14	129,394	6,182	10	11,186	$25,053	$143,000	5.7
2005.17	4,354	343	1	3,587	$4,074	$27,700	6.8
Subtotal	**4,485,168**	**297,428**	**488**	**229,992**	**$723,123**	**$1,665,254**	**2.3**
	48% of Portfolio Target 61% of Program Target		**48% of Portfolio Target** 53% of Program Target	**40% of Portfolio Target** 76% of Program Target	**46% of Portfolio Target** 66% of Program Target	**32% of Funding**	
Results for All Projects Reporting To-Date							
Total	**6,262,973**		**643**	**364,346**	**$1,044,673**	**$2,572,904**	**2.5**
	67% of Program Target 85% of Program Target		**63% of Program Target** 70% of Program Target	**63% of Program Target** 120% of Program Target	**66% of Program Target** 95% of Program Target	**49% of Program Funding**	
MBCx Target and Funding Totals							
Portfolio Program (5)	**9,346,082** 7,387,726		**1017** **919**	**579,793** 302,560	**$1,576,337** $1,097,300	**$5,233,944**	**3.3** **4.8**

(1) Results updated from Brown and Anderson 2006.
(2) The program definition of peak demand savings is based on peak kWh, averaged over the peak period. Hours in the peak period vary between service territories. These results have been normalized to the CPUC definition of the peak period covering 609 hour per year.
(3) Using uniform representative price assumptions: $0.10 per non-peak kWh, $0.25 per peak kWh and $1.00 per therm.
(4) Total project cost accounting is pending, with average total costs tracking within 10% of funding. Total estimated cost is 5.7 million.
(5) On average, individual projects set goals that are almost 50% higher than their prorated share of the program goals based on funding.

ahead of goals. If we add to this analysis the projects that combined commissioning and retrofit, along with the completed plant projects, and projects that were truncated, the promising general trend does not change, with 66% of portfolio targets and 95% of program targets already achieved by a subset of projects that have used only 49% of the funding.

Five of the thirteen complete building MBCx projects have a simple payback period less than two years, far lower than the overall program target of five years. These projects represent the model for future refinement of the program. Reliability of the energy use reduction is high because of the monitoring-based valuation inherent in the program protocol. Persistence of the savings is anticipated to be high because the permanent monitoring capability left in place by the projects and the training provided to the in-house personnel.

Five other projects had simple payback periods under five years, exceeding the overall program targets. Though considered successes from the standpoint of this program, it will be desirable in the future to improve cost-effectiveness even more. The remaining three completed building MBCx projects did not meet their targets. The UC/CSU/IOU program hopes to employ benchmarking, "best practice" analysis, and other methods to reduce the number of under-performing projects even more in the future.

Success in reducing peak electricity use. Substantial decreases in peak period energy use were documented through MBCx efforts, with the relative level of reduction varying by project. This program followed CPUC protocols for documentation of peak savings (CPUC 2003), averaging kWh reduction over the hours in the peak period to obtain a number for kW savings. However, the measures implemented would often be expected to reduce the maximum 15-minute demand observed for the building as well. Informal reporting of reduction in maximum 15-minute demand often confirmed this.

The Role of Monitoring in Identifying Opportunities for Energy Use Reduction

The program premise for MBCx predicts that enhanced monitoring and trending can contribute to the identification, diagnosis, and quantification of building energy waste. Initial results confirm this potential, with monitoring playing a key role in the substantial levels of energy use eliminated by projects. In this initial set of projects, monitoring and trending generally contributed to the diagnosis of control problems—broadly categorized as mis-tuned control loops, improper set points, flow balance problems, broken actuators, and scheduling problems. This section offers several examples, although a more complete accounting is beyond the scope of this paper and will await the planned best practices report from the program.

Extended trend analysis revealed subtle problems—like the influence of return air on the improperly placed outside air sensor in project 2005.15. In contrast, shorter-term observations uncovered unintended nighttime operation of air handlers, chillers, boilers, and lighting in project 2005.12. The prevalence of nighttime operation was not apparent from monthly electric and gas meter readings, but was obvious when whole-building meters were tied into the campus EMCS for trending.

Trend analysis was a key to diagnosing poorly tuned control loops—one of the most common problems observed. Alternating heating and cooling on thirty-minute cycles was observed in project 2005.02. This is an interesting variation on the simultaneous heating and cooling problem common in reheat systems (and also evident in several of the projects). In project 2005.10, monitoring identified significant instability in the control of supply air temperatures in two air handlers by a direct digital control system. The trend data showed that both heating and cooling valves were cycling resulting in up to 10 F variations in supply air temperature. This cyclic variation in supply air temperature made it difficult to control space temperatures, in addition to causing unnecessary heating and cooling. Peak period electricity use reduction was often achieved in these scenarios.

Trend data revealed stuck actuators almost as often as cycling. A chilled water valve stuck fully open was diagnosed in project 2005.16, the resulting commissioning led to reduction of simultaneous heating and cooling during both peak and off-peak conditions. The ubiquitous broken economizer was also frequently identified by analyzing trends. One example was project 2005.13, with resultant reduction in both peak and total electricity use. Pre-functional testing initially identified a malfunctioning economizer in project 2005.08, but subsequent trend analysis also showed that the initial repairs had not achieved full control functionality. This led to further commissioning to restore its intended operation.

Variation in monitoring suites. The MBCx program allowed flexibility in project design, including monitoring suites that were often customized and unique to the needs of specific sites. Project 2005.06 took the interesting approach of installing temperature sensors in multiple rooms in the building, and linking these back to an energy management system. These sensors were in parallel with the existing pneumatic thermostats, part of a control system that allowed no remote monitoring of space temperatures, VAV box airflow or reheat valve position.

Trend analysis showed large variations in temperatures among various rooms. For example, one room might be 79ºF while another similar room was 70ºF. The commissioning actions included thermostat calibration and/or repair of inoperative air damper actuator or reheat valves for roughly 80% of the zones, leading to significant reduction in heating, cooling, and fan energy use as well as increased comfort. Discomfort calls in the building had previously led to the chiller being manually started during some hours when comfort could have been maintained without chilled water. This MBCx project led to a shift in retrofit priorities from a new chiller to digital controls, based on monitoring that showed the annual load on the chiller was lower than expected and was likely to be lower still after repairing the zone controls.

Immediate results from use of monitoring. In May 2005 the in-house MBCx team for project 2005.03 evaluated trend data from the first air handler, taking just two days to identify supply air and chilled water temperatures outside of the expected performance range. The team investigated and found that chilled water from the central plant was not being drawn into the building loop. As a result, the building air handlers were delivering air at an elevated temperature, causing them to operate at high speeds to meet the cooling load.

In June 2005 the team modified the set points on the loop pressure control and the variable frequency (VFD) controller, resulting in a proper air handler supply air temperature and an appropriately high chilled water temperature returning to the campus loop. The metering system showed a reduction in the building electric load and an increase in the building chilled water load. That increased load on the chiller plant was calculated to offset about 20% of the fan savings. The increased chiller electricity use occurs at night because the campus uses a thermal energy storage system at the central plant.

In this example, analysis of trended building data led directly to reduced peak period energy use and increased comfort. For this project, a single major monitoring finding led to the majority of energy savings for one of the most cost-effective projects in the program. Could this problem have conceivably been identified through other means?—Probably. Was it recognized before the MBCx project?—No.

Energy Savings and Cost Effectiveness Relative to Other Commissioning Efforts

Success relative to the conservative internal program goals does not provide a complete picture for assessing the potential contributions of the monitoring-based commissioning approach. It is also desirable to analyze the results relative to other commissioning programs. A recent meta-analysis of commissioning projects provides a good data set for comparison (Mills et al 2004). A brief review of this data set with some additional analysis is provided in Table 2.

The commissioning projects compiled for the meta-analysis have an average savings value of 16% of the building baseline source energy with the median project at 13%. The sub-analysis by energy type shows the expected trend toward higher percent savings of plant produced energy (chilled water, hot water, and steam) and fuel, relative to electricity. This is understood to be an indication of the greater effect of commissioning on heating ventilation and air conditioning (HVAC) systems relative to lighting or other building systems. If commissioning typically has a greater effect on HVAC systems, then the percentage savings would be expected to be higher for sites in more severe climates with proportionately greater HVAC use as a fraction of the building total.

A sample including just California, Oregon, and Washington projects (excluding more severe climate sites) gives a result consistent with this observation. The west coast sites have an average savings of 9% of the building baseline source energy, with the median project at 8%. The savings fraction of a sample also including colder climates from Rocky Mountain states falls between the west cost sample and the entire data set including the humid eastern states.

The statistics for the initial UC/CSU/IOU Monitoring-Based Commissioning Program compare well with the meta-analysis. The savings by fuel type are in the same range with the full meta-analysis, except for plant-produced energy. The total source energy savings fraction of the average project, the median project, and the aggregate total are all at 10%. This is lower than the total meta-analysis, and slightly higher than the west coast cohort. Though a promising result, the potential value-added of monitoring toward achieving savings cannot be confirmed by this limited data set. Projects in the meta-analysis often employ monitoring-based diagnosis as well. Many other potentially confounding variables are present in the analysis, including the level of previous energy management in the buildings

The analysis of peak electricity use reduction for the MBCx data set is distinctly different from the meta-analysis in that most MBCx sites targeted peak electricity use and all reported achieving significant reduction, while only three meta-analysis sites reported peak reduction.

Relative cost-effectiveness is harder to analyze because of observed variations in both energy prices and project cost accounting. However, at face value, simple payback period for the MBCx data set is comparable to the west coast cohort of the meta-analysis. It is notable that MBCx projects spent an average of 40% of their budget on monitoring and energy information system upgrades. This was intended to increase the persistence of achieved savings, as well as increase the level of initial savings. In addition, an undetermined fraction of commissioning costs went toward training and other measures to enable facility staff to use the monitoring enhancements to keep the commissioned systems operating well with low energy use.

Table 2: UC/CSU/IOU Partnership MBCx Project Portfolio Statistical Summary

	UC/CSU/IOU Partnership First Completed MBCx Projects N=13	**2004 Cx Meta Analysis (Mills et al 2004)**	**2004 Cx Meta Analysis (Mills et al 2004) CA/OR/WA Only (1)**
	Median / Project Average / Aggregate (2)	Median / Project Avg.	Median / Project Avg.
Electricity	8% / 8% / 9%	9% / 11% (N=46)	
Peak Electricity	6% / 6% / 6% (3)	2% / 7% (N= 3)	
Fuel	8% / 10% / 12% (N=6)	6% / 13% (N=19)	
Chilled Water	13% / (4) / 12% (N=6)		
Hot Water/Steam	12% / 20% / 16% (N=7) (5)		
Total Thermal		36% / 37% (N=16)	
(6) Total Source Energy	10% / 10% / 10%	13% / 16% (N=46)	8% / 9% (N=24))
(7) Total Site Energy	10% / 12% / 11%	15% / 19% (N=46)	8% / 9% (N=24)
Simple Payback Period	2.5 / 3.1 / 2.3 (8,9)	1.0 / 2.1 (N=98) (8)	1.5 / 2.7 (N=36) (10)

(1) Excludes projects in more severe climates. Slightly higher savings fraction and slightly longer payback period observed for sample excluding only humid climates (e.g. Texas), where more energy use and control complexity is employed for humidity control.
(2) Project Average = Average of Project Value, Aggregate = Total Savings/Total Baseline.
(3)The UC/CSU/IOU program definition of peak demand reduction is based on total peak period kWh, averaged over the period. Hours in the peak period vary among service territories. These results have been normalized to the CPUC definition of the peak period covering 609 hour per year. All MBCx projects report peak reduction.
(4) One project resulted in a large shift energy use from the building to the plant, rendering the average of values meaningless.
(5) 5 of 7 MBCx projects report savings. All 7 projects counted to calculate median and averages.
(6) Basis: 9,215 Source Btu/kWh (Cal-Arch 2006). Meta-sample analysis on source energy basis is new, not in Mills et al 2004.
(7) Use of site energy totalization can introduce a bias relative to any other valuation of energy—toward over-reporting Cx savings. This is because site energy under-values electricity, for which there is normally a lower percent Cx savings. Cx is normally more effective for HVAC, which uses proportionately more fuel, chilled water, etc.
(8) Using uniform representative price assumptions: $0.10 per non-peak kWh, $0.25 per peak kWh and $1.00 per therm.
(9) Basis: Project funding, with average total costs tracking within 10% of funding.
(10) New analysis of meta sample using standardized energy prices and inflation-corrected commissioning costs, without non-energy impacts (2003$).

Analysis of cost-effectiveness for MBCx may also differ from the meta-analysis sites because all potential savings are not yet identified or captured for MBCx projects. Management of the funding program required all projects to report a "snapshot" of savings achieved by an arbitrary program end date[4]. The program premise predicts that an ongoing commissioning process will employ the enhanced monitoring to not only maintain the initial energy use reductions, but also diagnose and harvest additional savings over time.

The program emphasis on baseline benchmark information allowed determination of the fraction of baseline use eliminated by commissioning for each project. Benchmarking also facilitated review of results for internal consistency and compliance with program guidelines.

[4] 30 June 2006 for the 2004-05 program cycle.

Conclusions and Future Directions

Implications for Future UC/CSU/IOU Partnership Program Planning

Monitoring-based commissioning (MBCx) is on track to exceed its goals for 2004-05 and has the potential to further increase average savings levels and cost-effectiveness as the program continues to evolve. Both the overall 2006-08 program as a whole, and individual projects, can consider setting energy savings goals that are higher than the targets for 2004-05. With many well-documented successes from 2004-05, campus building projects should continue to be a major part of the MBCx portfolio. Assessment of savings and cost-effectiveness of plant-level campus projects must await more results from 2004-05.

MBCx projects produced substantial reductions in peak electricity use in 2004-05, providing confidence for targeting peak reductions in 2006-08. Improved monitoring and trending capabilities played a major role in identifying and quantifying savings opportunities, as well as providing tools to improve persistence of savings.

While the overall MBCx portfolio performed well, there was a wide range of return on investment, with several projects not worth replicating based on their marginal cost-effectiveness. More selective screening can help increase the number of projects with short payback periods. Building benchmarking and best practice guidelines can be tried as screening tools. Benchmarking options range from simple whole-building energy indices to more sophisticated tools that consider weather and other factors.

The Contribution of Monitoring-Based Commissioning

This paper has taken a first step toward assessing the potential contribution of monitoring-based commissioning to energy management at higher-education campuses and other commercial facilities. The percent of energy saved in the initial MBCx projects is comparable to a 2004 meta-analysis of retro-commissioning projects in similar climates. Of particular interest to is the consistent success of MBCx in identifying, and achieving peak electricity savings. Quantitative results are supported by records of commissioning measures that reduce peak kW demand as well as peak period kWh.

If the majority of MBCx projects in the 2004-05 UC/CSU/IOU program approach the performance of those projects reporting to date, then monitoring-based commissioning is poised to make a substantial contribution to meeting the policy goals of UC and CSU, the utility program targets set by the California Public Utilities Commission, and the longer-term goals of the California Green Building Initiative (which calls for an overall reduction of 20% in California's commercial sector energy use in ten years). UC and CSU campus energy managers and administrators are equally enthusiastic about both MBCx and retrofit approaches, also seeing the potential for synergistic combined projects. We believe that system wide implementation of monitoring-based commissioning could roughly double the energy savings resource for UC and CSU in a cost-effective manner, and with increased assurance of energy savings persistence.

Beyond the UC and CSU systems, these results are most applicable to private institutions of higher education and to community colleges. The pilot MBCx program findings may also be applicable to health-care facilities, other public and private laboratory-intensive buildings, K-12 schools, and other institutional buildings. Results may have more limited applicability to large private office buildings and may be least applicable to small private office and retail buildings.

Future Investigation

With a larger project data set on the horizon, it will be easier to identify best practices that can facilitate project identification and development. Benchmarking can be further exploited, with the aim of finding the most effective predictive parameters. The comparative impact of whole-building vs. sub-system metering can be explored, contributing to more refined monitoring scenarios. Experience with more building types will provide further insights into the overall impact of the MBCx approach. Perhaps most important, long-term studies can establish the degree to which monitoring can enhance the persistence of savings.

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