Quantifying Monitoring-Based Commissioning in Campus Buildings: Utility Partnership Program Results, Lessons Learned, and Future Potential

(Updated from: Anderson, M., Brown, K. 2006. *Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects.* San Francisco, Calif. The National Conference on Building Commissioning: April 19-21, 2006.)

Michael Anderson, Ann McCormick and Andrew Meiman
Newcomb | Anderson | McCormick

Karl Brown
California Institute for Energy and Environment

Synopsis

The University of California (UC), California State University (CSU), and California Investor-Owned Energy Utilities (IOUs) are collaborating in an innovative new program to retrocommission campus facilities with the assistance of permanently installed energy monitoring equipment and trending capability. This monitoring-based commissioning (MBCx) effort spans 25 campuses, with 9 projects for plant systems and 36 projects for buildings. Half of the buildings include laboratory or other energy intensive space. The program is part of the implementation of the UC Green Building and Clean Energy Policy, the similar CSU policy, and the California Investor Owned Utility customer-funded Energy Efficiency Program.

Monitoring-based commissioning employs remote energy system metering with trend log capability to identify previously unrecognized inefficiencies in energy system operations, facilitate the application of diagnostic protocols, document energy savings from operational improvements, and ensure persistence of savings through ongoing re-commissioning. The program emphasizes training of campus staff in commissioning techniques including diagnostic protocols and monitoring. The program is also demonstrating the potential for MBCx to identify previously unrecognized cost-effective retrofit opportunities. In addition, the monitoring equipment will provide enhanced benchmarking capability for campuses – aiding in overall energy management efforts, as well as design of new buildings and infrastructure.

Based on the success of preceding efforts on university campuses, and supported by research and development efforts, this synergy of retrocommissioning practices and enhanced permanent monitoring results in a robust energy efficiency program. The monitoring supports persistence of savings for the commissioning effort, and the commissioning makes the monitoring action-oriented, with energy savings as the end result.

Preliminary results from this effort were first reported at the NCBC conference in April 2006. This report updates those findings with a more complete set of project results. The final project results indicate more energy use reduction than targeted, making this a promising approach for California universities and indicating potential for other programs as well. The original effort in the 2004-2005 program cycle served as a pilot with the identification of best practices forming the basis for an expansion of the program in 2006-2008 to a large portion of the 160 million gross square feet of floor area in the two University systems. The UC/CSU/IOU Program's success also lead to the creation of an MBCx pilot program in the 2006-2008 California Community College Partnership.

About the Authors

Mike Anderson is a Principal at Newcomb Anderson McCormick, Inc. in San Francisco, California. He has worked exclusively in consulting for facility energy efficiency for 30 years. This work has included energy efficiency analysis of a wide range of sites, as well as cogeneration, photovoltaic, and alternate fuel construction projects. Mike is a member of ASHRAE and the Association of Energy Engineers, and is a registered engineer in five states. He is currently working on the 2006-2008 UC/CSU/IOU Energy Efficiency Partnership. He has a BS and MS in Mechanical Engineering from Harvey Mudd College.

Ann McCormick is a Principal at Newcomb Anderson McCormick, Inc. in San Francisco, California. She has worked exclusively in the field of energy engineering and renewable energy for over 20 years. Her work has ranged from evaluating energy conservation projects at commercial, industrial, and governmental facilities to the design and management of statewide energy efficiency programs. Ann is a member of ASHRAE, the California Commissioning Collaborative, and the Association of Energy Engineers, and is a registered engineer in California. She has an MS in Mechanical Engineering from the University of Wisconsin, Madison and a BS in Mechanical Engineering from Michigan State University.

Andrew Meiman is a Senior Program Manager at Newcomb Anderson McCormick, Inc. in San Francisco, California. He has nearly 15 years of experience managing complex projects and programs and has been the lead Program Manager for work with the UC/CSU/IOU Energy Efficiency Partnership. Andrew holds an MBA from the University of Virginia Darden Graduate School of Business Administration, and a BS in Aerospace Engineering from the University of Colorado at Boulder.

Karl Brown is the Deputy Director of the California Institute for Energy Efficiency, a part of the University of California Office of the President. His work includes planning and management of end-use energy R&D, as well as energy planning, policy development, and program coordination for UC facilities. Karl has been active in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standards and Technical Committees, the Association of Energy Engineers, the Advanced Lighting Advisory Committee, the Laboratories for the 21st Century Pilot Partnership Program, and the UC/CSU/IOU 2004-2005 Energy Efficiency Partnership. He has a BS and an MS in Mechanical Engineering from UC Berkeley.

Introduction

A set of 45 monitoring-based commissioning (MBCx) projects have been implemented as a major element of the Energy Efficiency Partnership Program (the Partnership) implemented by the University of California, California State University, Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Southern California Gas (SCG). The program is funded by California utility customers and administered under the auspices of the California Public Utilities Commission.

In this program, a combination of permanently installed energy system monitoring equipment with enhanced trending capability supports retrocommissioning and ongoing re-commissioning of campus buildings and plant systems. Monitoring helps facilitate the application of diagnostic protocols, identify previously unrecognized inefficiencies in building and plant system operations, and measure and document energy savings from resulting operational improvements. Additionally, campus staff received supplemental training to facilitate long-term efforts to ensure persistence of savings.

History of Monitoring-Based Commissioning

In the 1990s, Texas A&M University was prominent among those pioneering retrocommissioning practices in buildings. Their approach includes an emphasis on monitoring for baseline determination and diagnostics (Claridge et al. 2000). The value of extensive permanent energy system monitoring was established by research on the potential for building operators to identify dysfunction and modes of energy waste on an ongoing basis (Piette et al, 2000).

More recently, some university campuses have combined these concepts in their energy management programs, establishing prototypes for the development of the current MBCx program (Haves et al. 2005). An example is the University of California at Santa Barbara (UCSB), where extensive trending of monitored data, retrocommissioning, and retrofits partially identified through monitoring have led to a substantial reduction in campus-wide energy use (Motegi et al 2003).

Program Description

Over $5 million in 2004-05 funding was made available for MBCx, with a separate large retrofit element and a small training and education element rounding out the UC/CSU/IOU Energy Efficiency Partnership Program. For the 2006-2008 Program, energy savings goals and incentive funding have increased significantly and the amount available for MBCx has increased correspondingly.

Synergy between Monitoring and Retro-Commissioning

Energy efficiency incentive programs have rarely funded either monitoring capability or retrocommissioning. Skepticism about cause and effect as well as questions concerning persistence of savings can inhibit investment. While commercial building retrocommissioning has been shown to be highly cost effective (Mills et al. 2004), degradation of energy use reduction following initial success has been readily observed (Bourassa, Piette and Motegi 2004).

The MBCx program element received favorable consideration in recent California utility programs because a synergy between these two aspects of the approach overcame the conventional perceptions about the limitations of each. The inclusion of permanent monitoring capability provides a means to intrinsically verify and ensure the persistence of savings achieved through retrocommissioning. Retrocommissioning makes the integrated monitoring-based approach "actionable" and results-oriented, dispelling the perception that measurement (alone) does not reduce energy use. Monitoring increases the overall potential for reducing energy use by identifying more opportunities for both immediate retrocommissioning and for eventual retrofit pending the availability of funds.

The value of the monitoring and trending capability in the commissioning process has been verified by this program (Brown, Anderson, and Harris, 2006).

Program Design Issues

Distinguishing between MBCx and Retrofit Projects

The Partnership's MBCx program defines commissioning as the adjustment, maintenance or repair of existing equipment; as opposed to the upgrade of equipment, which is considered "retrofit" for this overall program design. Obviously mixed or "combined" projects are conceivable, often with synergy that maximizes reduction in energy use or improves project cost effectiveness for that building. In the long term our development of MBCx will fully pursue this synergy.

In the short term, the acceptance of MBCx depends on the perception that monitoring is essential in achieving reduction in energy use and is therefore fundable as an important project component. The authors observe that the role of monitoring is often discounted, and that the confusion is exacerbated for combined projects where the retrofit components may be perceived as responsible for all of the energy use reduction.

The first solicitation of projects for this program sought a large fraction of commissioning-only projects (with no retrofit components) to encourage development of the more straightforward approach. This account of the completed projects presents all results, but focuses on the projects clearly emphasizing immediate commissioning. Even these straightforward commissioning projects were anticipated to identify retrofit projects that could eventually be implemented with other funds.

Targeting Peak Energy Use Reduction

In addition to reductions in annual electricity and gas use, both the retrofit and MBCx program elements targeted peak electric demand reduction. This was despite the fact that the ability of retrocommissioning efforts to impact maximum demand or even peak period energy use is controversial. Conventional wisdom is that retrocommissioning focuses on ensuring that systems are throttled back during periods of part-load, with most of the impact on off-peak use. However, the authors observe that there are several common modes of full-load operation that waste significant amounts of energy.

First, HVAC systems employing reheat for temperature and humidity control are prone to slip out of adjustment, resulting in both excess cooling and reheat under peak cooling conditions. Retrocommissioning can reduce peak power draw in these circumstances. Second, it is common for variable frequency drive controls to fail to throttle over-sized fan or pumps back to actual maximum conditions, either through maladjustment, or because the frequency variation is not enabled at all. Third, it is common for set points in chilled water/air handler systems to be set incorrectly, resulting in operation away from the optimum full-load condition. Furthermore, as new demand response technologies and control strategies are implemented in buildings, they will be similarly subject to performance problems and will thus benefit from retrocommissioning.

This program has confirmed the peak use reduction opportunity from commissioning (Brown, Anderson, and Harris. 2006). Obviously it is to the universities' advantage to do so because this is the most expensive power. Most projects significantly reduced peak electricity use through commissioning, including a variety of measures. Monitoring and trending often led to the identification and implementation of the commissioning measures impacting peak use.

Whole Building vs. Sub-System Monitoring

Basic diagnostic and verification capability has historically started with trending of whole-building energy inputs. Some of the pioneering efforts previously discussed often went far beyond whole-building energy monitoring, employing extensive sub-system monitoring for diagnostic efforts.

For stand-alone buildings, the monitoring protocol for MBCx can be simple: upgrade building electric and gas meters for interval outputs, add trending capability through an Energy Information System (EIS) or Energy Management and Control System (EMCS), and add sub-metering capability as resources allow.

However, the university campus environment is more complicated and presents several challenges for program design. First, campuses are typically master-metered by the utility, with building-level metering dependent on campus resources and often not present. Second, campuses often have plant systems providing chilled water and hot water and/or steam to buildings through district distribution systems. More energy flows need to be monitored to get the desired whole-building information. Third, these plant configurations vary widely, with virtually every practical permutation present in the set of 33 UC and CSU campuses. Finally, the campuses have historically had varying levels of success in securing resources for energy information systems, resulting in each campus starting this program with their own unique telemetry and trending capabilities.

Creating flexible program guidelines was crucial for monitoring upgrades. To summarize, virtually any augmentation to a building or campus monitoring system was eligible for funding, as long as it contributed to campus ability to trend energy use or other energy performance indicators for the building or system slated for commissioning. One firm requirement is that any building in the program must end up with the ability to trend interval data for all energy flows into that building (electricity, fuel, chilled water, hot water, and/or steam), either through pre-existing capability or through upgrades funded by this program.

In-House vs. Contracted Commissioning Resources

Long-running commissioning community debate about the appropriateness of in-house or external (”third-party”) resources manifested itself in the development of the MBCx program. Briefly, the result was that the funding of campus staff effort on MBCx was allowed, with the caveat that limits were placed on the allocated fraction of project resources. The funding of consultant efforts for MBCx was also allowed, but included an emphasis on training campus staff on ongoing commissioning activities to ensure persistence of reduced levels of energy use, and enable campus staff to perform other commissioning activities on the campus.

Verification of Savings: The Implications of a Monitored Approach

For traditional retrofit programs, determination of savings is largely based on accepted engineering assumptions made during the project proposal process. Justified or not, this confers a high degree of perceived certainty in the projected savings. Empirical observation is used to verify installation and some assumptions, but accounting of savings often reverts back to the initial calculations. As a result, the actual savings are often not precisely known.

MBCx projects allow a higher degree of savings verification through monitoring, with an increased ability to empirically confirm reductions in energy use being inherent in the nature of the program. On the other hand, preliminary savings numbers are just targets, as the exact level of savings that will be achieved for any given project is uncertain until after implementation. Savings are best targeted on the portfolio level, with a high degree of certainty about the overall savings achieved for a group of projects.

The 2004-05 UC/CSU/IOU Monitoring-Based Commissioning Portfolio

The overall statistics for the 2004-05 portfolio are presented in Table 1. The wide range in project budget levels reflects the flexibility in the program as well as the diversity of campus buildings, plant systems, existing infrastructure, and proposed projects.

Energy prices vary significantly between campus sites, making comparison among projects or the evaluation of a subset of projects difficult. To overcome this complication, the authors have used nominal energy pricing to provide a general picture of portfolio economics. For the nominal pricing, a simplified energy pricing structure is employed, with sufficient detail to capture major differences among projects, while roughly averaging rates for the wide range of service types, service territories, and other circumstances. The analysis is transparent, with readers encouraged to apply their own price structure to evaluate the engineering results in their own context.

With some exceptions and some variation among utility service territories, projects were generally expected to support an amount corresponding to, or somewhat exceeding, their share of the overall program energy use reduction targets, with targeted savings generally proportional to incentive funding provided. Thus the expected simple payback period for any one project is likely to be close to the portfolio average of 4 years. A shorter payback period for MBCx efforts is both widely desired and achievable (Mills et al. 2004). The portfolio targets represent the sum of the proposed project targets, which significantly exceed the overall program targets (see Table 3). As a pilot program, the Partnership set conservative goals for projects and even more modest overall goals for this program element.

Table 1: UC/CSU/IOU Energy Efficiency Partnership MBCx Portfolio Summary

	All Projects Including Plant and District Systems	**Building Projects Only**
Participating Campuses	22 (8 of 10 UC, 14 of 23 CSU)	
Projects	45	36 (19 with Lab Space)
Gross Floor Area	(1)	6.0 Million
Funding Provided by Program	$5.2 Million	$4.0 Million
Total Anticipated Cost	$5.7 Million	$4.3 Million
Range of Project Funding	$20,444 - $270,000	$25,500 – $270,000
Range of Funding	N/A	$0.30 - $1.75 per gross sq. ft.
Range of Total Anticipated Cost	$20,444 - $380,667	$25,500 - $380,667
Range of Cost per Unit Area	N/A	$0.30 - $1.75 per gross sq. ft.
Electricity Use Reduction Target (3)	9,100,000 kWh per year	(2)
Demand Reduction Target (3, 4)	1.02 Megawatts	(2)
Corresponding Electricity Use Reduction During Summer On-Peak Period (3)	620,000 kWh per year	
Nat. Gas Use Reduction Target (3)	530,000 therms per year	(2)
Nominal Value of Saved Energy (3, 5) @ $1.00/therm, $0.10/non-peak kWh, $0.25/peak kWh	$1.84 million per year	
Nominal Simple Payback Period for Funding	2.2 years	(2)
Nominal Simple Payback Period for Anticipated Costs	2.3 years	(2)

(1) Accounting of floor area served by central plant or district systems pending confirmation of all project documentation.
(2) Some campuses proposed combined building and plant system projects, and did not separately target savings.
(3) Portfolio targets are the sum of the proposed project targets. These are substantially higher than the overall program goals.
(4) The program definition of peak demand savings is based on peak kWh, averaged over the peak period.
(5) Nominal values based on simplified price structure with approximate average of rates across service types for normalization of project results.

Details for the Initial Set of Projects

Characteristics of the projects are presented in Table 2. All are laboratory or other building projects, with plant and district projects proving to be more complex to organize. For the purpose of this analysis a building is considered a "laboratory" building if it has fume hoods and/or a significant amount of space requiring 100% outside air 24/7. Program flexibility and diversity in project proposals are evident, with significant variation in the cost per unit area, monitoring augmentation needs and costs, and commissioning measures implemented. The Partnership Program funded approximately 95% of the total cost of implementation of all building projects, with the rest provided by the campuses.

Table 2: UC/CSU/IOU Monitoring-Based Commissioning Project Detail

Project ID[1]	Building Function	Funded Unit Cost ($/gsf)	Meter Cost, If Available (% of total)	Addition or Upgrade to Building Metering	Major Cx Action(s)
2005.01	Laboratory & Classrooms	$ 0.60	15%	Calibration CHW & HW Btu	VAV Fume Hoods: Control Adjustments Sequence of Operation
2005.02	Laboratory & Classrooms	$ 1.13	46%	Calibration Subsystems: VFD Power Air Pressure/Flow	VAV Fume Hoods: Control Adjustment Valve Repair
2005.03	Library	$ 0.39	20%	Power Natural Gas EIS Front End	CHW System: Flow Balance Setpoint Adjustment
2005.04	Laboratory	$ 1.53	63%	Subsystems: Chilled Water Steam Heating/Dom HW	VFD Control Adjustments Chiller Control Setpoints Piping Reconfiguration Vent. Rate Adjustment
2005.05	Offices	$ 1.22	58%	EMCS Interface	Combination Project Controls Upgrade
2005.06	Non-Laboratory, Modern, Small	$ 0.67	41%	Subsystems: Chiller Power CHW Btu Boiler Btu	Controls: Sequence of Operations Setpoint Adjustment Calibration
2005.07	Laboratory & Classrooms	$ 1.06	N/A	Subsystem: Fan Power	Combination Project Air Handlers: VFD Installation Reconfiguration
2005.08	Laboratory & Classrooms	$ 0.79	49%	EMCS Interface	Sensor Calibration Valve Repair Economizer Repair Control Adjustment
2005.09	Classrooms & Offices	$ 1.26	55%	Power	Economizer Repair Control Adjustment
2005.10	Laboratory & Classrooms	$ 1.15	47%	Subsystem: Fan Power	Sensor Calibration Valve Repair
2005.11	Laboratory & Classrooms	$ 1.44	N/A	Subsystem: Fan Power	Exhaust Fan Control Upgrade
2005.12	Offices, Classrooms, Dormitories	$ 0.51	N/A	Power Natural Gas	Sensor Calibration Damper & Valve Repair

Project ID[1]	Building Function	Funded Unit Cost ($/gsf)	Meter Cost, If Available (% of total)	Addition or Upgrade to Building Metering	Major Cx Action(s)
2005.13	Library	$ 0.38	N/A	Power Chilled Water Steam	Lighting Controls Repair Damper & Valve Repair Economizer Optimization Sensor Calibration
2005.14	Laboratory, Modern, Large	$ 0.95	21%	Power Hot Water Chiller Power & CHW Btu	Economizer Optimization Sensor Calibration Control Adjustment
2005.15	Library	$ 0.56	37%	Steam Btu CHW Btu	Damper & Valve Repair Sensor Calibration VFD Control Adjustments
2005.16	Laboratory Building, Modern, Small	$ 1.02	20%	Power Natural Gas	Sensor Calibration Valve Repair
2005.17	Laboratory, Modern, Small	$ 1.54	36%	Power Natural Gas	Sensor Calibration Replacement of Evaporative Cooler Coils
2005.18	Non-Laboratory, Modern, Large	$ 1.24	47%	Subsystems: Fan & Pump Power Chiller & Cooling Tower Power	Re-enable Economizer Control Adjustment
2005.19	Non-Laboratory, Modern, Large	$ 1.13	48%	Subsystems: Fan & Pump Power Chiller & Cooling Tower Power	Control & Setpoint Adjustments Valve Repair
2005.20	Library & Classrooms	$ 0.35	20%	Power Natural Gas	Boiler Control Adjustment Economizer Optimization
2005.21	Non-Laboratory, Modern, Large	$ 0.62	26%	CHW & HW Btu EMCS Interface	Economizer Repair Sensor Calibration, Relocation, & Installation Controls Adjustment
2005.22	Laboratory, Modern, Large	$ 0.59	19%	CHW & HW Btu EMCS Interface	Scheduling Adjustment Valve Repair Sensor Calibration & Controls Adjustment
2005.23	Laboratory & Classrooms	$ 1.06	44%	Power CHW & HW Btu	Valve & Damper Repair VAV Fume Hoods: Control Adjustments

Project ID[1]	Building Function	Funded Unit Cost ($/gsf)	Meter Cost, If Available (% of total)	Addition or Upgrade to Building Metering	Major Cx Action(s)
2005.24	Laboratory, Modern, Large	$ 1.07	54%	Power CHW & Steam Btu Condensate Return & Air CFM	VSD Installation Controls Upgrade New HVAC Equipment
2005.25	Library	$ 0.32	47%	Subsystem Power CHW & HW Flow	Controls Upgrade & Optimization
2005.26	Classrooms and Offices	$ 1.19	63%	EMCS Interface CHW & HW Btu	VSD Installation Economizer Repair Sequence of Operation
2005.27	Laboratory & Classrooms	$ 1.75	0%	CHW & HW Btu	VAV Fume Hoods: Valve Replacement Control Adjustments
2005.28	Library	$ 0.30	33%	Hot Water Btu EMCS Interface	Controls Upgrade Sequence of Operation Valve & Damper Repair
2005.29	Classrooms	$ 0.50	45%	Hot Water Btu EMCS Interface	Controls Upgrade Sequence of Operation Valve & Damper Repair

1 Three buildings showed no energy savings. Some of this budget may have been shifted to other buildings. Four buildings have not yet reported results. The savings for these seven buildings is assumed to be zero for this table. These projects are not included in this Table.

Results

Results for the first building projects are summarized in Table 3. This analysis separates the cohorts for MBCx projects and for "Combined" (indicating a major retrofit component) projects, with straightforward MBCx projects considered to be a greater indication of the program potential. Projects are ranked by simple payback period within each cohort. Project payback ranking is by funding level, which on average is 95% of the total project cost.

Table 3: UC/CSU/IOU Partnership MBCx Project Result Summary (Buildings)

ID	Observed Reduction in Energy Use				Representative Annual Cost Savings[2]	Total Project Funding	Nominal Simple Payback (yrs)
	Total Electricity (kWh/yr)	Peak Electricity (kWh/yr)[1]	Demand (kW)	Natural Gas (th/yr)			
Results for Straightforward MBCx Projects							
2005.22	526,183	0	0	59,699	$112,317	$75,000	0.7
2005.19	663,184	42,135	69	83,456	$156,095	$131,550	0.8
2005.01	238,571	13,743	23	36,584	$62,502	$67,500	1.1
2005.02	496,619	13,981	18	43,497	$95,256	$14,140	1.2
2005.10	1,348,620	151,969	250	11,787	$169,444	$244,950	1.4
2005.03	454,586	30,186	39	0	$49,987	$83,500	1.7
2005.04	720,038	64,689	84	76,987	$158,694	$270,000	1.7
2005.06	36,754	2,555	4	9,406	$13,465	$25,500	1.9
2005.08	302,579	15,441	30	15,836	$48,410	$110,000	2.3
2005.09	245,010	45,215	74	28,621	$59,904	$144,000	2.4
2005.13	714,430	32,121	42	0	$76,261	$184,900	2.4
2005.21	225,098	13,344	17	5,594	$30,105	$75,000	2.5
2005.18	462,472	0	0	5,462	$51,710	$135,550	2.6
2005.23	170,000	0	0	17,900	$34,900	$113,500	3.3
2005.15	343,412	55,522	73	11,221	$53,890	$192,163	3.6
2005.12	250,009	17,010	28	5,233	$32,785	$152,601	4.7
2005.16	76,670	9,921	13	661	$9,816	$49,300	5.0
2005.14	129,394	7,857	10	11,186	$25,304	$143,000	5.7
2005.17	4,354	436	1	3,587	$4,088	$27,700	6.8
2005.20	128,552	2,596	3	5,354	$18,599	$127,500	6.9
2005.11	164,893	11,449	19	0	$18,207	$128,300	7.0
Subtotal	**7,701,428**	**530,171**	**797**	**432,070**	**$1,281,739**	**$2,595,654**	**2.0**
	124% of Portfolio Target		121% of Portfolio Target	132% of Portfolio Target	135% of Portfolio Target	64% of Portfolio Funding	

ID	Observed Reduction in Energy Use				Representative Annual Cost Savings[2]	Total Project Funding	Nominal Simple Payback (yrs)
	Total Electricity (kWh/yr)	Peak Electricity (kWh/yr)[1]	Demand (kW)	Natural Gas (th/yr)			
Results for Combined Projects							
2005.28	0	0	0	105,150	$105,150	$120,000	1.1
2005.29	0	0	0	129,000	$129,000	$150,000	1.2
2005.07	943,452	0	0	0	$94,345	$155,850	1.7
2005.24	337,510	0	0	83,365	$117,116	$214,444	1.8
2005.27	659,964	0	0	9,907	$75,903	$160,000	2.1
2005.05	139,030	2,404	3	0	$14,264	$70,000	4.9
2005.26	155,969	0	0	0	$15,597	$96,100	6.2
2005.25	40,986	0	0	0	$4,099	$85,000	20.7
Results for All Projects[4]							
	9,978,339	**532,575**	**800**	**759,492**	**$1,837,212**	**$4,064,048**	**2.2**
	160% of Portfolio Target		121% of Portfolio Target	232% of Portfolio Target	193% of Portfolio Target	100% of Portfolio Funding	
	135% of Program Target		87% of Program Target	251% of Program Target	176% of Program Target	72% of Program Funding	
MBCx Target and Funding Totals for Buildings							
Portfolio	**6,229,899**		**661**	**326,807**	**$949,797**	**$4,064,048**	**4.3**
MBCx Target and Funding Totals for Buildings Plus Nine Central Plants							
Program	**7,387,726**		**919**	**302,560**	**$1,041,333**	**$5,650,570**	**5.4**

[1] The program definition of peak demand savings is based on peak kWh, averaged over the peak period. Hours in the peak period vary somewhat across utility service territories.

[2] Nominal price assumptions for normalization of results: $1.00 per therm, $0.10 per non-peak kWh, $0.25 per peak kWh.

[3] Three buildings showed no energy savings. Some of this budget may have been shifted to other buildings on the same campus. Four buildings have not yet reported final results. The savings for these seven buildings is assumed to be zero for this table. The cost for these seven buildings is included in the "Results for All Projects" row.

Portfolio Performance

The achievement of this group of projects is illustrated by the nominal simple payback period at less than half of that expected for the portfolio as a whole. Energy use reduction is approximately double the average expected for a given amount of funding.

The referenced ACEEE Summer Study paper compares this MBCx Program with a meta-analysis of other commissioning programs (Brown, Anderson, and Harris 2006, Mills et al. 2004). The savings and payback periods are comparable to the programs described in the meta-analysis. The majority of the savings in the MBCx Program are based on actual measured energy use reductions, which may give them a higher accuracy than energy savings derived strictly from the more typical engineering estimates. In addition, the metering, monitoring and training incorporated in the MBCx Program are expected to significantly improve persistence, relative to conventional retrocommissioning processes.

Individual Project Performance

While the overall portfolio performance is strong, there is a wide range of return on investment for individual projects. Approximately one-third of the projects represent the short-payback periods that the approach is anticipated to regularly generate. Another third performed better than the program target, but still left some room for improvement. Roughly one-third of the projects either had long payback periods that may not be worth replicating, or produced insignificant energy savings. More selective screening can be introduced to increase the number of short payback-period projects.

It was the intent of this program that energy savings be documented through measurements over sample time periods with projections made on an annual basis. More than half of the projects documented savings using this approach. Some of the projects appear to have used a calibrated simulation model that was matched to building energy use profiles, either before or after implementation of measures. In these cases the savings were calculated through changes made to the calibrated model, but the actual energy savings were not measured directly. In the remaining cases energy savings were calculated using conventional analysis techniques, similar to the calculations used in a conventional customized utility incentive program.

In future cycles of this program, actual measurement of savings will be emphasized further. New guidelines have been created for baseline and post implementation measurement periods.

Conclusions and Next Steps

Based on the 2004-05 projects, the monitoring-based commissioning pilot exceeded expectations with regard to energy use reduction. The continuation of this element in the 2006-08 UC/CSU/IOU Partnership Program is well justified. Additionally, the California Community Colleges have embarked on their own MBCx pilot in the 2006-2008 CCC Partnership Program, which is employing the techniques pioneered at UC and CSU campuses to their advantage. Other programs should consider this approach to expand opportunities for energy savings.

Monitoring-based commissioning can reduce peak electricity demand. Measures that were effective on-peak included adjustment of chilled water control set points, resulting in fan power reduction and a substantial net decrease in demand and energy use. Fan power reduction also resulted from retrocommissioning of variable air volume systems. Measures were often enabled by empirical determination of actual operating conditions through the monitoring capability reinforced by MBCx projects. We anticipate that permanent monitoring and trending will facilitate persistence of these reductions.

Though the overall portfolio performance is good and the fraction of modestly performing projects is tolerable, program efforts will immediately be focused on establishing additional methods for project selection, intended to further reduce the number of marginal projects. Such effort is most needed for non-lab projects, as lab projects more often yield very good results with the fundamental program design. Benchmarking data is being analyzed from the pilot portfolio of projects. Correlation of this with project results and best practice evaluation is expected to yield valuable information for continued program planning and development.

Acknowledgements and Disclaimer

The UC/CSU/IOU Energy Efficiency Partnership MBCx Team oversaw the execution of the 2004-2005 program, with the diverse perspective and experience necessary for success provided by Mark Bramfitt (PG&E), Len Pettis and Aaron Klemm (CSU Chancellor's Office), Maric Munn (UC Office of the President), Paul Kyllo (SCE), Tony Pierce (SCE), Randall Higa (SCG), Guy Hansen (SDG&E), Keith Marchando (Sonoma State University), and Jim Dewey (UC Santa Barbara).

Consultants providing exemplary coordination for the program include Richard Sterrett (Alternative Energy Systems Consulting), Anna Levitt (Newcomb Anderson McCormick), and Ziyad Awad (Awad & Singer). Other support for program development came from Phil Welker, Kristin Heinemeier, Dave Sellers, Bill Koran, and Tudi Haasl of PECI; Martha Brook of the California Energy Commission and Public Interest Energy Research Program; Philip Haves, Paul Mathew, Evan Mills, and Dave Watson of the Lawrence Berkeley National Laboratory; and Cathy Higgins of the New Buildings Institute.

References

Brown, K. and Anderson, M.K.J. 2006. *Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects.* San Francisco, Calif. The National Conference on Building Commissioning: April 19-21, 2006.

Brown, K., Anderson, M.K.J., and Harris, J. 2006. *How Monitoring-Based Commissioning Contributes to Energy Efficiency for Commercial Buildings.* Asilomar, Calif. American Council for an Energy-Efficient Economy Summer Study. Available at http://ciee.ucop.edu.

Bourassa, N.J., M.A. Piette, N. Motegi. 2004. *Evaluation of Persistence of Savings from SMUD Retrocommissioning Program - Final Report*. LBNL-54984. Berkeley, Calif. Lawrence Berkeley National Laboratory.

Claridge, D.E., Culp, C.H., Liu, M., Deng, S., Turner, W.D. and Haberl, J.S. 2000. "Campus-Wide Continuous Commissioning^{SM} of University Buildings", In *Proceedings of the 2000 ACEEE Summer Study of Energy Efficiency in Buildings.* 3:101-112. Washington, D.C.: American Council for an Energy-Efficient Economy.

Haves, P., D. Watson, N. Bourassa, and R. Hitchcock. 2005. *UC/CSU/IOU Monitoring-Based Commissioning Program: Case Studies and Needs Assessment.* Working Draft LBNL-57039. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Matson, N., and M. A. Piette. 2005. "Cal-Arch Building Energy Reference Tool." Available online: http://poet.lbl.gov/cal-arch/glossary.html#site. Berkeley, Calif., Lawrence Berkeley National Laboratory.

Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette. 2004. *The Cost-Effectiveness of Commercial-Buildings Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States.* LBNL-56637. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Motegi, N., M. A. Piette, S. Kinney, and J. Dewey. 2003. "Case Studies of Energy Information Systems and Related Technology: Operational Practices, Costs and Benefits." In *Proceedings of the International Conference for Enhanced Building Operations*. Berkeley, Calif. 13-15 October 2003.

Piette, M.A., S.T. Khalsa, and P. Haves. 2000. "Use of an Information Monitoring and Diagnostic System to Improve Building Operations." In *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings.* 7:101-112. Washington, D.C.: American Council for an Energy-Efficient Economy.