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Synopsis

The University of California (UC), California State University (CSU), and California Investor-Owned Energy Utilities are collaborating in an innovative new program to retro-commission campus facilities with the assistance of permanently installed energy monitoring equipment and trending capability. This monitoring-based commissioning (MBCx) effort spans 25 campuses, with nine projects for plant systems and 37 projects for buildings. Half of the buildings include laboratory or other energy-intensive space. The program is a part of the implementation of the UC Green Building and Clean Energy Policy, the similar CSU policy, and the California Investor Owned Utility (IOU) customer funded Energy Efficiency Program.

Monitoring-Based Commissioning (MBCx) 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 recommissioning. The program emphasizes training of campus staff in commissioning techniques including monitoring and diagnostic protocols. 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 wells 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 retro commissioning practices and enhanced permanent monitoring results in a robust energy efficiency program. The monitoring supports persistence of savings for the commissioning effort, while the commissioning makes the monitoring action-oriented with energy savings the end-result.

The first project results indicate more energy use reduction than expected, making this a promising approach for California universities and indicating potential for other programs as well. The 2004-05 effort is serving as a pilot —with the identification of best practices to form the basis for an expansion of the program to a large portion of the 160 million gross square feet of floor area in the two university systems.

About the Authors

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 coordinated R&D addressing HVAC duct leakage, diagnostics for commissioning and operations, and efficient design of facilities for high-technology industries (e.g., laboratories). His most recent R&D management activity involves leadership of a team organizing beta tests, demonstrations, and other technology transfer of Public Interest Energy Research products on UC and CSU campuses.

Karl's work with UC facilities has included energy and environmental stewardship planning, standards development, and design review for the new Merced campus. He has also made substantial contributions to the development of the UC Green Building and Clean Energy Policy. He is currently focused on energy performance monitoring and benchmarking for campuses.

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 Bay Area Chapter, 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, complemented by field experience gained during six years as a building energy consultant.

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 thirty years. This work has included energy efficiency analysis of sites ranging from Manhattan high rises to nuclear power plants to food processing facilities to amusement parks. He has performed energy efficiency work on five continents. He has also participated in 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 2004-2005 and 2006-2008 UC/CSU/IOU Energy Efficiency Partnership. He has a BS and MS in Mechanical Engineering from Harvey Mudd College.

Introduction

A set of 46 monitoring-based commissioning (MBCx) projects have been initiated as a major element of the 2004-05 Energy Efficiency Partnership Program implemented by 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 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 recommissioning of campus buildings and plant systems. Monitoring can 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. Campus staff will receive 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.

Synergy Between Monitoring and Retrocommissioning

Neither monitoring capability nor retrocommissioning have often been funded by energy-efficiency incentive programs, with skepticism about cause and effect and persistence of savings inhibiting enthusiasm about investment. While commercial buildings 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 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.

Program Design Issues

Distinguishing Between MBCx and Retrofit Projects

The Partnership MBCx program defines commissioning as the adjustment, maintenance or repair of existing equipment as opposed to 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 important project component. The authors observe that the role of monitoring is often discounted, and that the confusion is exacerbated for combined projects in which 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, encouraging development of the straightforward approach. This account of the first completed projects presents all results, but focuses on the projects clearly emphasizing immediate commissioning. (Even straightforward commissioning projects were anticipated to identify retrofit projects that could eventually be implemented with other funds.)

Targeting Peak Energy Use Reduction

Both retrofit and MBCx program elements targeted peak electric demand reduction in addition to reductions in annual electricity and gas use. 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. Retrocommission 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 mis-adjustment, 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 mis-set, resulting in operation away from the optimum full-load condition. Furthermore, as new "demand-response" technologies and control strategies begin to be implemented in buildings, they will be similarly subject to performance problems and will thus benefit from retrocommissioning.

The authors argue that it is possible to target peak demand or peak electricity use reduction with MBCx efforts. Obviously it is to the universities' advantage to do so because this is the most expensive power

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 could 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.

The university campus environment is more complicated, presenting 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 thirty-three UC and CSU campuses. Finally, the campuses have historically had varying levels of success in securing resources for energy information systems (EIS), with each campus starting this program having a different capability with respect to telemetry and trending capability.

Flexibility was crucial in program guidelines 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-exiting 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. To summarize the result: the funding of campus staff effort on MBCx is allowed, but sometimes with limits on the allocated fraction of project resources. Funding of consultant effort for MBCx is also allowed, but proposals were expected to include an emphasis on training of campus staff—for ongoing commissioning activities to ensure persistence of reduced levels of energy use, or for performance of other commissioning activities on 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 up-front calculations. As a result, the actual savings are often not 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, up-front 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, and proposed projects.

The details of the program’s economic criteria are arcane and not useful for characterization of the program. Also, 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. 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 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). Prudence suggested conservative goals for projects and even more modest overall goals for this pilot program.

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

	All Projects Including Plant and District Systems	**Building Projects Only**
Participating Campuses	25 (9 of 10 UC, 16 of 23 CSU)	
Projects	46	37 (19 with Lab Space)
Gross Floor Area	(1)	7.0 million
Funding Provided by Program	$5.2 million	$4.3 million
Total Anticipated Cost	$5.7 million	$4.6 million
Range of Project Funding	$20,444 - $270,000	$25,500 – $270,000
Range of Funding	N/A	$0.21 - $1.54 per gross sq. ft.
Range of Total Anticipated Cost	$20,444 - $290,000	$25,500 - $270,000
Range of Cost per Unit Area	N/A	$0.21 - $1.54 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 $0.08616/non-peak kWh $0.17232/peak kWh	$1.37 million per year	
Nominal Simple Payback Period for Funding	3.8 years	(2)
Nominal Simple Payback Period for Anticipated Costs	4.2 years	(2)

(1) Accounting of floor area served by central plant or district systems pending documentation of all projects.
(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) Simplified price structure with rough average of rates across service types for normalization of project results.

Details for the Initial Set of Projects

Characteristics of the first eight projects to report results 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.

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

ID	Building Type	Total Project Cost ($/gsf)	Meter Cost (% of total)	Addition or Upgrade to Building Metering	Major Cx Action(s)
2005.01	Lab	$0.60	15%	Calibration CHW "Btu" HW "Btu"	VAV Fume Hoods: Control Adjustment Sequence of Operation
2005.02	Lab	$1.13	46%	Calibration Subsystems: VFD Power Air Pressure/Flow	VAV Fume Hoods: Control Adjustment Valve Repair
2005.03	Non-Lab	$0.36	30%	Power Natural Gas EIS Front End	CHW System: Flow Balance Setpoint Adjustment
2005.04	Lab	$1.53	58%	Subsystems: Chilled Water Steam Heat/Dom HW	VFD Control Adjustment Chiller Control Setpoints Piping Reconfiguration Vent. Rate Adjustment
2005.05	Non-Lab	$1.21	61%	EMCS Interface	(Combination Project) Controls Upgrade
2005.06	Lab	$0.66	41%	Subsystems: Chiller Power CHW "Btu" Boiler "Btu"	Controls: Sequence of Operations Setpoint Adjustment Calibration
2005.07	Lab	$0.62	61%	Subsystem: Fan Power	(Combination Project) Air Handlers: VFD Installation Reconfiguration
2005.08	Non-Lab	$0.79	49%	EMCS Interface	Sensor Calibration Valve Repair Economizer Repair Control Adjustment

Results

Results for the first eight projects reporting 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.

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

	Observed Reduction in Energy Use				**Nominal Annual Cost Savings**	**Total Project Funding**	**Nominal Simple Payback**
ID	**Total Electricity (kWh/year)**	**Peak Electricity (kWh/year) (1)**	**Demand (kW) (1)**	**Natural Gas (therms /year)**	**(2)**	**(3)**	**(years)**
Results for MBCx Projects Reporting To-date							
2005.02	355,292	1,451	2	76,245	$106,982	$114,000	1.1
2005.01	*197,679* (4)	*13,743* (4)	*23* (4)	*40,591* (4)	*$58,807* (4)	$67,500	*1.1* (4)
2005.03	454,586	30,186	39		$41,768	$77,000	1.8
2005.04	720,038	64,689	84	76,987	$144,599	$270,000	1.9
2005.06	36,754	2,555	4	9,406	$12,793	$25,500	2.0
2005.08	177,789	12,218	20		$16,371	$110,000	6.7
Subtotal	**1,942,138**	**124,842**	**171**	**203,229**	**$381,320**	**$664,000**	**1.7**
	21% of Portfolio Target		**17% of Portfolio Target**	**38% of Portfolio Target**	**28% of Portfolio**	**13% of Funding**	
Results for Combined Projects Reporting To-Date							
2005.07	943,452	83,360	108		$88,470	$91,100	1.0
2005.05	139,030	2,404	3		$12,186	$70,000	5.7
Results for All Projects Reporting To-Date							
Total	**3,024,620**	**210,606**	**282**	**203,229**	**$481,976**	**$825,100**	**1.7**
	33% of Portfolio Target 41% of Program		**28% of Portfolio Target** 31% of Program	**38% of Portfolio Target** 68% of Program	**35% of Portfolio** 49% of Program	**16% of Funding**	
MBCx Target and Funding Totals							
Portfolio	**9,100,000**	**620,000**	**1,020**	**530,000**	**$1,370,000**	**$5,200,000**	**3.8**
Program	7,400,000	510,000	920	300,000	$980,000		

(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 service territories.
(2) Nominal price assumptions for normalization of results: $1.00 per therm, $0.08616 per non-peak kWh, $0.17232 per peak kWh.
(3) For this set of projects, project funding equals total cost.
(4) Preliminary results.

Partial Portfolio Performance

The achievement of this initial 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 roughly double the average expected for a given amount of funding.

Individual Project Performance

Most projects perform very well, with a few non-lab projects providing marginal results. This reflects well on the experience-based but untested methods used to select the initial set of projects, as well as the overall promise of the program approach.

Conclusions and Next Steps

Based on the 2004-05 projects reporting in as of this writing, the monitoring-based commissioning pilot is exceeding expectations with regard to energy use reduction. The continuation of this element in the 2006-08 Partnership Program is well justified. 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 include 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. Both of these measures were 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 fraction of modestly performing projects is small, 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 consistently 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.

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