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An Evaluation of Savings and Measure Persistence from Retrocommissioning of Large Commercial Buildings

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ABSTRACT

Commercial building retrocommissioning activity has increased in recent years. LBNL recently conducted a study of 8 participants in Sacramento Municipal Utility District's (SMUD) retrocommissioning program. We evaluated the persistence of energy savings and measure implementation, in an effort to identify and understand factors that affect the longevity of retrocommissioning benefits.

The LBNL analysis looked at whole-building energy and the retrocommissioning measure implementation status, incorporating elements from previous work by Texas A&M University and Portland Energy Conservation Inc. When possible, adjustments due to newly discovered major end uses, occupancy patterns and 2001 energy crisis responses were included in the whole-building energy analysis. The measure implementation analysis categorized each recommended measure and tracked the measures to their current operational status. Results showed a 59% implementation rate of recommended measures.

The whole-building energy analysis showed an aggregate electricity savings of approximately 10.5% in the second post-retrocommissioning year, diminishing to approximately 8% in the fourth year. Results also showed the 2001 energy crisis played a significant role in the post-retrocommissioning energy use at the candidate sites. When natural gas consumption was included in the analysis, savings were reduced slightly, showing the importance in considering interactive effects between cooling and heating systems. The cost effectiveness of retrocommissioning was very attractive at the sites studied. However, funding for retrocommissioning activities is still very constrained.

Introduction

Commissioning of existing buildings is an increasingly important tool for building owners and operators. Large commercial buildings have many energy consuming systems that will degrade or fail without preventative maintenance and attention. The retrocommissioning process is fast emerging as a cost-effective method to fine tune or correct problems, often resulting in energy and cost savings. Although retrocommissioning is becoming popular, the question of how long the benefits will endure over time is not well understood.

Retrocommissioning can be defined as follows:

> *Commissioning of existing buildings or "retrocommissioning," is a systematic process applied to existing buildings for identifying and implementing operational and maintenance improvements and for ensuring their continued performance over time. Although retrocommissioning may include recommendations for capital improvements, the primary focus is on using O&M tune-up activities and diagnostic testing to optimize the building systems. Retrocommissioning is not a substitute for major repair work. Repairing major problems is a must before retrocommissioning*

can be fully completed (ODOE, March 2001).

The Sacramento Municipal Utility District (SMUD) is a public-power electric utility serving over 500,000 customers. The SMUD retrocommissioning program is designed to reduce overall building energy consumption through low-cost operational improvements and on-site training of building operators. A secondary goal is to guide the customer toward more far-reaching improvements that may become evident in the course of commissioning. Such improvements may include capital intensive energy efficiency retrofits, more advanced operator interface and software, and replacement of the entire controls system and associated equipment (Parks et al., 2003).

Obtaining an estimate of the energy savings persistence is difficult due to continually dynamic load and occupancy events. Building operators often make modifications to control setpoints in response to ongoing occupant calls. Over time, the changes might affect the implemented retrocommissioning measures. Additionally, calibration drift of systems and components can occur over time. Equally difficult is characterizing the persistence of the retrocommissioning measure settings. In many cases access to the actual control settings are difficult and involve arcane programming code. Equally often, paper records or the operator's memory are the sole resource. More understanding of the effect of system loads, building occupancy, and control setpoint changes will help retrocommissioning attain more market acceptance.

This paper discusses a recent study of retrocommissioning persistence, conducted by LBNL for SMUD (Bourassa et al, 2004). The objective of this study was to examine a selection of buildings that participated in SMUD's retrocommissioning program and estimate the persistence of energy savings and measure implementation. The paper is organized in five sections. The remainder of the Introduction describes previous related work, the Methodology section provides an overview of the data analysis. Next, the Results and Discussion sections summarizes key findings. Finally, a Summary section provides conclusions.

Previous Commissioning Persistence Studies

Two previous and relevant studies have examined persistence of savings from (retro) commissioning improvements obtained through the implementation of operation & maintenance tune-up measures. The first study by Texas A&M was a quantitative examination of the persistence of savings in existing buildings. They evaluated whole-building energy use data for several years after commissioning (Turner et al., 2001). Texas A&M refers to existing building commissioning as Continuous Commissioning, but it is quite similar to the retrocommissioning of the SMUD program. This research showed that 3 to 4 years after commissioning, about 80% of the energy savings were still present in the 10 buildings studied. The study included an examination of the status of each of the measures originally included in the retrocommissioning intervention. Several control measure fixes were defeated. Building operators were shown to not have any feedback regarding the energy consumption impacts of their actions and were unaware of changes in building performance.

The second study by PECI, looked at the persistence of savings in new building commissioning and focused on control system changes (Friedman et al., 2002 & 2003). The PECI study used a qualitative approach based on interviews and site visits conducted for new buildings that had recently been commissioned. Individual "Commissioning fixes" were tracked and evaluated. Fifty-five commissioning fixes were studied, and the large majority of the measures persisted. However, 14 of the 55 fixes, or about one fourth, did not persist.

Methodology

The study started with a background review of persistence work and development of a project plan. Next, the sites were identified and data were collected. Somewhat overlapping with data collection was the data analysis phase, where persistence levels were estimated. Finally, the development of recommendations and the project final report were assembled.

Site Selection

SMUD provided LBNL with 12 BAS (Building Automation Systems) retrocommissioning reports as well as SMUD's Evaluation reports for the Year 1999 and 2000 Retrocommissioning Program participants. The Evaluation reports are SMUD's official record of the measures thought to be implemented.

The selected sites included six office buildings, one hospital and one laboratory. Two of the sites, Office1 and Office3, have significant computer data center loads. One site visit and multiple telephone interviews with each contact person were conducted.

Table 1: Summary of selected sites

Site	RCx Program Year	Approximate Floor Area (ft^2)	Construction Year
Office1	1999	352,000	unknown
Hospital1	1999	267,000	1996
Office5	1999	150,000	1995
Lab1	1999	94,000	1997
Office6	2000	308,400	1965 (Renov. 1999)
Office2	2000	383,200	1984
Office3	2000	400,000	1991
Office4	2000	324,000	1990

Energy Analysis

This study incorporated elements from the two relevant studies discussed in the introduction. The energy analysis process was conducted in three phases: analysis of local weather history, the production of weather normalized energy consumption data and the comparison of consumption history against a pre-retrocommissioning baseline year. Attempts to include adjustments for the 2001 energy crisis and other confounding occupancy patterns were done, but the available data limited the success of this effort.

Weather data for Sacramento, CA were obtained from the Average Daily Temperature Archive website (U of Dayton, 1999). A regression model was applied to each year of 1997 to 2003 data, producing a "normal" weather year of average monthly dry bulb temperatures. Monthly electricity billing history was obtained for all eight sites. We had at least two years of post-retrocommissioning data at each site. Five sites had at least one year of pre-retrocommissioning data and three had no data earlier than the retrocommissioning baseline year. At one site, 15-minute interval data from a web-based energy information system were used to provide some end use metering. Monthly natural gas billing history were obtained for only four sites.

Data Normalization

All the energy use data were normalized to the average weather year and a common billing period of 30.5 days using EModel (Kissock et al., 1995). This is similar to the methodology used by Texas A&M (Claridge, et. al., 2003), with the exception that this study used the calculated average weather year instead of the "best fit" actual weather data for each site (determined by commissioning year). One key assumption in the analysis was that changes in annual energy use from the baseline year were considered to be a result of the retrocommissioning. However, some adjustments were made for large load changes due to major capital improvements or occupancy changes that could be quantified. The savings estimates were calculated using the normalized consumption data as well as the retrocommissioning report savings predictions. Both sets of savings (columns C & D in Table 4) were calculated against the same normalized baseline.

The savings predictions were done measure-by-measure in the retrocommissioning report. Two of the retrocommissioning reports, Lab1 and Hospital1, included a 20% interactive effects discount for multiple measure implementations. The other six reports did not discuss the issue of interactive effects.

The Table 4 results are based on the average annual electricity savings, calculated as the mean difference of each post-retrocommissioning year's electricity consumption against the baseline year. The energy cost savings calculation used the average utility rates provided by the retrocommissioning report. All the sites have electric rates with demand charges, but they are not blended in the average electricity rate we used.

During the interviews, retrocommissioning and retrofit implementation costs were also gathered. The costs fell into three categories: SMUD's retrocommissioning costs, the Site's retrocommissioning costs and the Site's measure implementation costs. The cost to SMUD at each site was $25,000. The Site's retrocommissioning costs were defined as any costs the site absorbed to accommodate the commissioning team's field work. (e.g., billed time to generate BAS trends, building engineer escorts, etc.) The measure implementation costs include the material and time costs as estimated by the site's chief engineer.

A simple cost effectiveness study of the retrocommissioning program was done by calculating simple paybacks for the sum of the costs using the average annual electricity savings. Paybacks were calculated for the retrocommissioning report predictions and from the normalized consumption data. The results are presented in Table 9.

Measure Persistence Analysis

The measure persistence analysis used site visits and interviews to determine the current status of the implemented retrocommissioning recommendations. A three phase interview method was used to improve accuracy. The first phase consisted of a questionnaire provided prior to the initial site visit. At the site visit, if access to the BAS was available, the associated measure settings were checked. The second phase involved telephone interviews in which all the measure implementation questions were rephrased and posed again. The third phase was yet another round of telephone interviews, as well as email correspondence, focusing on the discrepancies between the first two phases and any other newly implemented measures.

In an effort to track measure persistence trends, we developed a measure categorization code. Each retrocommissioning measure was assigned a code that represented the component type and the type of intervention strategy. The categories are listed in Table 2. For example, a recommendation to modify the supply air reset schedule of an air handler was assigned the code A-CR1.

After the current measure status was determined, we identified each implemented measure as being in one of three persistence states: 1) persisting as implemented, 2) not persisting as implemented or 3) evolved from the originally implemented settings. The third category for measures that are 'evolved' was added to capture measures that were tried, but were eventually changed to something fundamentally different than the original settings. The results of the implemented measure survey are presented in Table 3.

Results

The eight retrocommissioning reports recommended a total of 81 corrective measures and 48 were implemented. Air distribution related measures were the most popular with 43% of the component count. Cooling plant related measures are next with 26% of the count. The distribution of recommended strategies is even, with start/stop controls having a slight edge. Only one of the ten recommended start/stop measures was not implemented.

Table 2: Count of Implemented & Not Implemented Measure Categories

Measure Categories			Code Letters	Implemented Tally	Not Implemented Tally
Component	Cooling plant		C	13	8
	Heating plant		H	5	4
	Air distribution		A	22	13
	Lighting		L	7	5
	Plug Loads		R	0	1
	Whole Buidling		W	1	0
Strategies	Design, Installation	Change equipment	DI1	4	6
		Install controller	DI2	7	4
	Control	Reset	CR1	4	6
		Sart/Stop	CR2	9	1
		Scheduling	CR3	6	2
		Modify setpoint	CR4	7	3
		Calibration	CR5	5	5
	O&M	Manual operation	OM1	3	2
		Maintenance	OM2	3	3

Measure persistence among the implemented recommendations appears to be good, with 81% identified as still persisting with the system settings that were recommended. The current persistence state of the implemented measures are listed in Table 3. Only four measures were identified as being abandoned completely and as such are non persisting. All four of the non persisting measures were control recommendations for air distribution components.

Table 3: Summary of persistence status for Implemented Measures

	Office1	Office2	Lab1	Hopsital1	Office3	Office4	Office5	Office6
Measure Category Codes	C-CR2(y)	A-CR4(y)	W-OM1(y)	A-CR3(e)	A-CR5(y)	A-CR5(y)	A-DI1(y)	A-CR2(y)
	C-CR2(y)	L-DI2(y)	A-DI2(y)	A-CR4(y)	A-CR1(n)	H-CR2(y)	A-OM2(y)	H-CR2(y)
	H-CR2(y)	C-DI1(y)	A-DI2(y)	A-CR3(y)	C-CR2(n)	A-CR5(n)	A-CR1(n)	C-CR2(e)
	A-CR4(y)		A-CR4(y)	A-CR3(y)		H-CR3(y)	A-OM2(y)	C-DI1(y)
	A-CR5(y)			C-CR4(y)		C-DI2(y)	A-OM2(e)	C-CR4(y)
	L-CR3(y)			C-CR4(y)			A-DI2(y)	C-CR1(e)
				C-DI1(y)			H-CR2(y)	A-CR5(y)
				L-OM1(y)				C-CR1(e)
				L-OM1(y)				
				L-CR3(y)				
				L-DI2(y)				
				L-DI2(y)				
Category & Status ID (y = Persists, n = Not-Persisting, e = Evolved)								

Five implemented measures did not solve the identified problems to the building engineers satisfaction and they chose to evolve the measures to find a better solution. Three are control settings on a cooling plant, and the other two are air distribution measures.

Energy Analysis Results

The energy savings analysis shows an average of 7.3% (4.9% median) electricity savings per year across all eight sites. The retrocommissioning reports predicted an average electricity savings of 5.6% per year (4.0% median) for all eight sites.

Table 4: Predicted & Post-RCx Measured Average Annual Electricity Savings

Predicted & Post-RCx Measured Average Annual Electricity Savings	A	B	C	D	B/A
	Predicted (MWh/yr)	Post-RCx (MWh/yr)	Predicted	Post-RCx	Post-RCx vs Predicted
Office1	380	190	7.3%	3.6%	0.50
Office2	490	360	7.5%	5.5%	0.73
Lab1	520	620	16.1%	19.3%	1.19
Hospital1	460	430	4.7%	4.4%	0.93
Office3 *	90	300	1.0%	3.4%	3.33
Office4	120	290	2.2%	5.4%	2.42
Office5	170	220	3.4%	4.3%	1.29
Office6	140	610	2.9%	12.5%	4.36
All Sites	2,360	3,010	5.6% (4.0)	7.3% (4.9)	1.28

* Limited RCx report data (Median values in brackets.)

Column A and B of Table 4 compares the difference between predicted and measured retrocommissioning electricity savings. Savings prediction was on average about 28% conservative versus the measured post-retrocommissioning savings. Only two sites had predictions that were larger that the post-retrocommissioning energy savings. The retrocommissioning reports predicted an average annual savings of 2,360 MWh per year and the measured energy use reductions are estimated at approximately 3,300 MWh. The median difference between predicted and measured was 78.0%. The range of predictions is wide. At Office1, energy savings were half as large as the retrocommissioning prediction. Office3 and Office6 were greatly under-predicted.

Table 5: All Sites - Summary of Electricity Savings by Year

Baselines are shaded		1998	1999	2000	2001	2002	2003
Office1 *	% Savings		**0%**		5%	2%	0%
	EUI **		**33.7**		32.7	33.2	34.6
	MWh/yr		**0**		270	130	10
Office2	% Savings			**0%**	15%	11%	15%
	EUI			**17.2**	14.7	15.4	14.7
	MWh/yr			**0**	970	700	990
Lab1	% Savings	**0%**	2%	16%	29%	26%	24%
	EUI	**33.9**	33.4	28.4	24.2	25.0	26.0
	MWh/yr	**0**	50	530	910	840	750
Hospital1	% Savings		**0%**	4%	6%	8%	5%
	EUI		**37.4**	35.9	35.2	34.5	35.6
	MWh/yr		**0**	390	590	770	470
Office3	% Savings		**0%**	4%	5%	3%	-2%
	EUI		**21.7**	21.0	20.6	21.1	22.2
	MWh/yr		**0**	310	440	230	-180
Office4	% Savings				**0%**	4%	7%
	EUI				**16.4**	15.8	15.3
	MWh/yr				**0**	200	380
Office5	% Savings		**0%**	-1%	12%	6%	6%
	EUI		**14.7**	14.8	12.9	13.7	13.7
	MWh/yr		**0**	-60	620	330	330
Office6	% Savings			**0%**	13%	13%	11%
	EUI			**15.7**	13.6	13.5	13.9
	MWh/yr			**0**	620	650	550
All Sites - Total MWh			**0**	**1,170**	**4,420**	**3,850**	**3,300**

* Estimated Baseline from 1998 - 2000 data. ** Energy Use Intensity (kWh/sf^2 yr)

Table 5 shows the calculated post-retrocommissioning energy savings and Energy Use Intensities (EUI) for each year. The annual totals show that these sites produced a peak electricity savings of approximately 4,420 MWh in 2001.

Figure 1 shows the percent energy saved at each site, this time with a retrocommissioning year progression instead of calendar year. Seven of the sites had 2001 in post-retrocommissioning years, as indicated with circles on Figure 1. At five sites, 2001 was the peak post-retrocommissioning electricity savings year with savings reducing afterwards. The 2001 peaks are very likely due to extra-ordinary energy saving activities by sites during the energy crisis.

Figure 2 shows the energy saved when the data is summed by years after the retrocommissioning baseline. Each curve represents an aggregate group of sites with the same amount of post-retrocommissioning consumption data. All the sites show increasing energy savings during years one and two. This is expected because the recommended measures are implemented over time. After year 2, the trend appears to plateau before savings begin to degrade in the fourth year. The values for Figure 2 are listed in Table 6.

Figure 1: All Sites - Electrical Energy Savings in Post-RCx years (%)

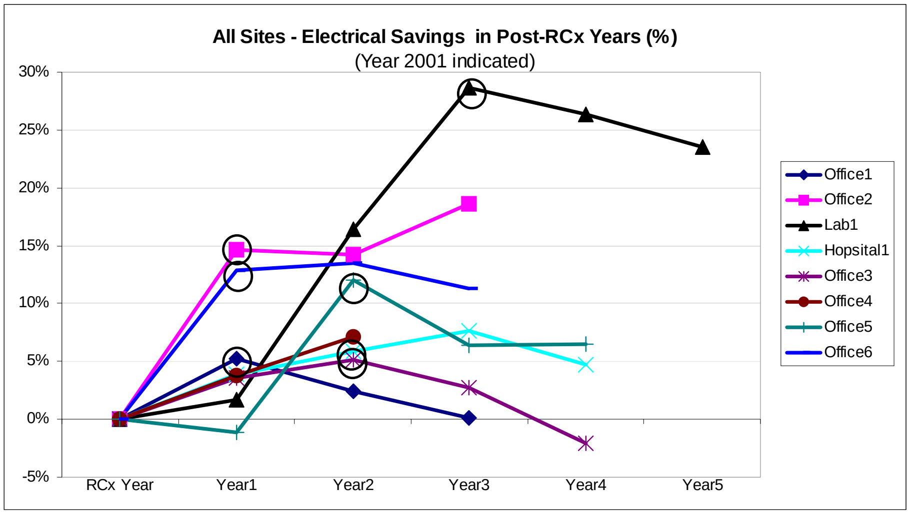

Figure 2: Plot of Aggregate Post-retrocommissioning Electricity Savings

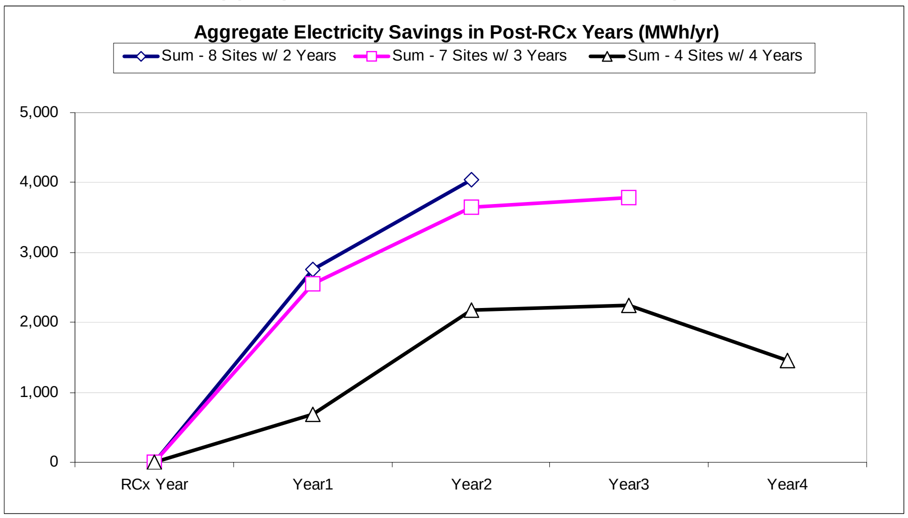

Table 6: Electricity Savings in Post-commissioning Years (MWh/yr)

(2001 years are shaded)	RCx Year	Year1	Year2	Year3	Year4	Year5
Office1	0	270	130	10		
Office2	0	970	700	990		
Lab1	0	50.0	530	910	840	750
Hospital1	0	390	590	770	470	
Office3	0	310	440	230	-180	
Office4	0	200	380			
Office5	0	-60	620	330	330	
Office6	0	620	650	550		
Sum - 8 Sites w/ 2 Years	0	2750	4040			
Sum - 7 Sites w/ 3 Years	0	2550	3660	3790		
Sum - 4 Sites w/ 4 Years	0	690	2180	2240	1460	

At the four sites with natural gas data (Table 7), the average electrical savings was 7.0% of the building's total electricity usage, but the natural gas consumption showed a smaller savings of 2.9% (3.3% median). Since the cooling season dominates energy use in

Sacramento, the natural gas consumption reduced the whole building energy savings to an average 6.6% (5.4% median) at these four sites (Column H, Table 7).

Table 7: Average Annual Whole Building Savings (Electricity & Natural Gas)

	A Eltricity Savings (%r)	B Natural Gas Savings (Therms)	C Natural Gas Savings (%)	D Baseline Natual Gas (Therms)	E Baseline WB Energy (MBtu/yr)	F Baseline WB EUI - Source (kBtu/ft2 yr)	G WB EUI savings - Source (kBtu/ft2 yr)	H WB EUI savings - Source (%)
Office2	5.5%	8,950	15.7%	57,100	28,300	174	11.1	6.4%
Hospital1	4.4%	4,990	1.8%	277,100	60,800	444	16.7	3.8%
Office4	5.4%	-3,370	-10.7%	31,500	3,000	161	7.2	4.5%
Office6	12.5%	2,690	4.8%	55,700	21,900	162	19.0	11.7%
All Sites	7.0%	13,260	2.9%	421,400	114,000			6.6%

Overall, the inclusion of natural gas data reduced whole building energy savings slightly, but did not significantly change the savings profile.

Cost-Effectiveness Analysis

Table 9 summarizes the retrocommissioning costs and paybacks for each site. All of the implementation costs were moderate, with a total implementation cost of $61,650 for the 48 recommended measures. This total cost excludes a capital-intensive recommendation, at Office 2, to install new chillers. Office 3 kept costs down by doing the work under an existing service contract. All the paybacks are attractive. Floor area normalized costs ranged from $0.06 to $0.28. Compared to traditional energy audits, these costs run the full range, from opportunity assessment to investment grade audit prices.

Table 9: Retrocommissioning costs & Simple Paybacks

	A RCx Study Costs *	B Measure Implementation Costs	C Post-RCx Savings ($)	(A+B)/C Simple Payback
Office1	$28,000	$1,710	$13,000	2.3
Office2	$26,500	$20,500	$27,900	1.7
Lab1	$26,000	$12,370	$40,100	1.0
Hospital1	$28,300	$11,180	$30,900	1.3
Office3	$25,400	$150	$22,400	1.1
Office4	$26,817	$8,380	$22,600	1.6
Office5	$26,817	$4,350	$15,800	2.0
Office6	$26,700	$3,000	$48,600	0.6
All Sites	$214,533	$61,650	$221,200	1.2

* CxA cost $25k, balance incured by site

The simple paybacks were calculated as though the $25,000 commissioning contractor costs were incurred by the sites. Since this cost was provided by SMUD, the actual return on investment to the sites is much shorter, with all the paybacks being less than half a year.

Discussion

Recommended measures were implemented at a rate of 59% (48 out 81 measures). In 19 cases the recommendations were rejected due to a conflicting opinion about the retrocommissioning analysis or prohibitive cost. In 14 cases, the operations personnel said they would revisit or already have plans to implement the measures in the future. In at least 2 cases, erroneous assumptions were made and the recommendations should not have been offered.

Seven sites reported that the retrocommissioning process inspired innovative analysis of their systems and they attempted to find more retrocommissioning style improvements.

Four sites, Office2, Lab1, Hospital1 and Office6 listed training as the primary non-energy benefit from retrocommissioning. The Table 5 results show that these four sites have good energy savings and persistence. Conversely, Office 3 reported no training value and it has the least persistent energy savings. The most cited downside to retrocommissioning was the time intensive nature of the process.

The energy analysis showed that the retrocommissioning projects at the sites were cost-effective, even those with low implementation rates. The persistence results in Figure 2 and the payback periods in Table 9, showed that the simple paybacks were well within the time frame of apparent energy savings.

At some of the sites, other confounding factors such as changes in occupancy or major end use loads were evaluated. At Office4 a whole floor (approx. 32,000 ft^2) was vacant for more than a year and a load discount was calculated using the previous year's energy use intensity. At Office2 they installed two new variable speed chillers, a capital intensive recommendation from their retrocommissioning report. We compensated for the effect of the new chillers with 15-minute interval data that had sub metered the pre- and post -retrofit chillers.

In view of the strong cost-effectiveness of the retrocommissioning at these sites, it seems odd that six of the sites reported that they still do not have any budget for retrocommissioning. This contrasts sharply with their response that they would undertake retrocommissioning again. A more rigorous study of retrocommissioning cost-effectiveness with a larger data set could be used to present a more convincing case to building owners.

Summary

The persistence of retrocommissioning benefits, both non-energy and energy-related, are affected by the retrocommissioning process. Especially important is the conduct of the commissioning team during field work. Commissioning agents are most effective when they are both an expert and a teacher. When done right, the retrocommissioning effort should increase awareness of energy efficiency and building diagnostics among the building operations staff.

The energy analysis indicates that the post-retrocommissioning energy savings appear to begin degradation four years after retrocommissioning. However, this data set is confounded by the 2001 energy crisis.

On the whole, the retrocommissioning predictions for energy savings appear slightly conservative. The retrocommissioning reports under predicted energy savings at the eight sites by approximately 28%.

The focus at these sites was on electricity. The natural gas data shows trade offs between electricity and natural gas consumption. From the customer's perspective, cost savings might have been improved if greater consideration of cooling and heating interactive effects occurred.

All of the cost paybacks were very good. Good efforts on the part of building operators to keep implementation costs down and the high savings in post-retrocommissioning years produced a good return on investment. The complete costs of retrocommissioning easily could have been absorbed into the building owner's internal budgets.

Most of the sites lacked tools for tracking their energy performance. Only 3 of the building operations staff had access to building performance monitoring tools such as electronic utility bill tracking or energy information systems with analysis capabilities.

Future Directions

Additional research is needed to examine whether the trends identified concerning the persistence of savings from retrocommissioning that occurred in this project are similar at other sites. The findings from this project are similar to the findings from previous research suggesting that most of the savings persist beyond three years. Longer multi-year studies are needed to examine five year savings rates and beyond. Techniques are needed to isolate the effects of confounding events, such as the 2001 energy crisis. Additional research is also needed to develop tools and methods to allow building engineers and operators to obtain feedback on savings associated with retrocommissioning. Diagnostics tools and continuous performance monitoring systems are needed to assist in such tracking.

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