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Review on Persistence of Commissioning Benefits in New and Existing Buildings

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Abstract:

In recent years the topic of persistence of benefits has gained more interest both for existing building retrocommissioning and new building commissioning. This topic is relatively new, and the only relevant projects identified in the literature to date involve a total of 27 retrocommissioned buildings and 10 new buildings. In retrocommissioned buildings, savings generally decreased with time.

10 buildings in Texas:

- cooling savings dropped from 44.8% to 35.1% from 1997 to 2000
- heating savings dropped from 79.7% to 49.7 % from 1998 to 2000
- retrocommissioning savings in 2000 were \$985,626/year compared with \$1,192,000 in 1998
- three fourths of the decrease was caused by component failures in two buildings

Eight buildings in California:

- peak aggregate savings occurred in years two and three
- about 1/4 of the savings disappearing in year four (year 4 data available for only four buildings)

Three buildings in Oregon:

- 89% of the electric savings but none of the gas savings in three of the Oregon buildings persisted four years later.

One building in Colorado:

- 86% of the savings persisted after seven years

In new buildings (after at least two years)

- over half of the fifty-six commissioning fixes persisted
- hardware fixes, such as moving a sensor or adding a valve, and control algorithm changes that were reprogrammed generally persisted.
- Control strategies that could easily be changed, such as occupancy schedules, reset schedules, and chiller staging tended not to persist.
- persistence is also related to operator training.

1. INTRODUCTION

In recent years the topic of persistence of benefits from commissioning has gained more interest both for existing building retrocommissioning and new building commissioning. Several studies have been performed and published examining both aspects of this topic. This review will summarize the key results of these studies. The categories presented are persistence of commissioning measures in existing buildings, persistence of commissioning measures in new buildings, strategies for improving persistence in new and existing buildings, and related reports. This topic is relatively new, and the only relevant projects identified in the literature to date involve a total of 37 buildings as noted below:

- 10 Retro Commissioned Buildings at Texas A&M University – Claridge et al. (2002, 2004)
- 8 Retro Commissioned Buildings in Sacramento, California – Bourassa et al. (2004)
- 8 Retro Commissioned Buildings in Oregon – Peterson (2005)
- 1 Retro Commissioned Building in Colorado – Selch and Bradford (2005)
- 10 Commissioned New Buildings – Friedman et al. (2002, 2003a, 2003b)

2. PERSISTENCE OF COMMISSIONING MEASURES IN EXISTING BUILDINGS

2.1 10 Buildings at Texas A&M

A study was performed in 2000 to evaluate the persistence of savings in 10 buildings on a university campus three years after the buildings participated in retrocommissioning (Turner, et al. 2001, Cho 2002, Claridge et al. 2002, 2004, Chen et al. 2002, Liu et al. 2002).. The objectives of the study were to determine quantitatively how much savings degradation occurred and the major causes of any observed degradation. The investigation did not focus on the detailed measures implemented in each building, but rather on the degree to which the measures implemented in the retrocommissioning process had been maintained, as indicated by examination of energy use data, the retrocommissioning reports, and the control settings in place on the main energy management control system.

The study was conducted in five major parts. First, buildings were selected to be studied. Second, savings calculations were performed based on energy usage data from the different periods needed. Third, field examination and commissioning follow-up was conducted on two buildings in which major savings degradation occurred. Fourth, operational and controls changes that could have contributed to changes in building performance after retrocommissioning were identified. And fifth, calibrated simulations of some of the buildings were performed to verify the effects of the identified changes on energy consumption.

A preliminary group of 20 buildings which had been commissioned in 1996 or 1997 was initially selected. An office review of information on the retrocommissioning measures implemented and available information on operating parameters before and after retrocommissioning was then conducted. Based on this review, the 10 buildings with the most complete information concerning the retrocommissioning process and energy consumption data were selected. None of the buildings in this group received capital retrofits during the period 1996-2000. Five buildings were commissioned in 1996 and the other five were finished in 1997. In each of these buildings, commissioning measures were identified by the retro commissioning provider and then implemented by the provider, after receiving the concurrence of the building owner’s representative. Since all 10 buildings were located on a university campus, they primarily consisted of classrooms, laboratories, and offices, with one volleyball arena.

The energy usage data for these buildings had been monitored and was obtained beginning with the period shortly before retrocommissioning and ending in 2000 when the study was performed. For comparison purposes, all of the energy data was normalized to a single year of weather data. Because the weather data for the year 1995 most closely approximated average weather conditions for the years studied, it was chosen as the baseline year. Energy use before and after the retrocommissioning process were compared. In this study savings from the retrocommissioning process were determined by using Option C of the International Performance Measurement and Verification Protocol (IPMVP, 2001), which determines savings using measured energy use at the whole facility level. This required that baseline models of the consumption be formulated for each major source of energy use in each building. Chilled water and hot water energy consumption were measured for each year, and three-parameter or four-parameter change-point models of cooling and heating consumption were determined as functions of ambient temperature using a modeling program.

The process of calculating the yearly savings required the development of five separate chilled water models and five hot water models for each building, one for each year, including the baseline model. The consumption and savings for each year were then normalized to 1995 weather by using the models for each year's data with the 1995 temperature data to determine the savings for each year. Electricity savings were determined without normalization since the buildings did not have chillers, and electricity consumption is not appreciably affected by ambient temperature.

Follow-up was performed on two buildings with significant savings degradation. This was done primarily through a field investigation of the buildings to determine what changes had occurred that would produce the changes. Equipment performance and EMCS control settings were examined to evaluate possible causes for degradation.

Information was then gathered on controls and operational changes that had occurred in the buildings during the period studied. This was done by examining the retrocommissioning reports and interviewing the engineers and maintenance personnel who had responsibility for each building. These interviews provided identifiable reasons for many of the changes in savings seen in the buildings.

In order to quantify the effect of each operational or control change identified, it was decided that the energy usage of the buildings would be modeled using a computer simulation program. The rough simulations would then be calibrated until they provided accurate representations of the actual energy use. These simulations would then demonstrate how much of an effect each control or operational change had on the building energy use.

Results

All ten buildings showed significantly reduced chilled water and hot water energy consumption after retrocommissioning; the savings subsequently decreased somewhat with time in most buildings. Eight buildings had larger HW savings in 1998 than in 1997 as a consequence of hot water loop optimization conducted in 1997 and final retrocommissioning actions. Overall the electricity consumption remained fairly constant, with three buildings showing small increases in consumption (negative savings). The average electricity savings for the 10 buildings from 1997 to 2000 were 10.8%. Fig. 1 and Fig. 2 below show the chilled water and hot water savings trends for the years following the building retrocommissioning.

Overall, chilled water savings for the three years following retrocommissioning averaged 39.3% of the pre-commissioning baseline. Eight of the buildings showed good persistence of savings for chilled water (less than 15 % change during the 3-4 years after retrocommissioning), while the other two displayed significant degradation. The Blocker building had 19% degradation, and the G. R. White Coliseum had a dramatic savings degradation of 38%.

Hot water consumption was reduced significantly in the years following retrocommissioning, but the savings fluctuated widely from year to year. Savings increased from 1997 to 1998 in most buildings due to optimization in the hot water loop in 1997 and some ongoing retrocommissioning work. The 10 buildings averaged hot water savings of 65.0 % after retrocommissioning.

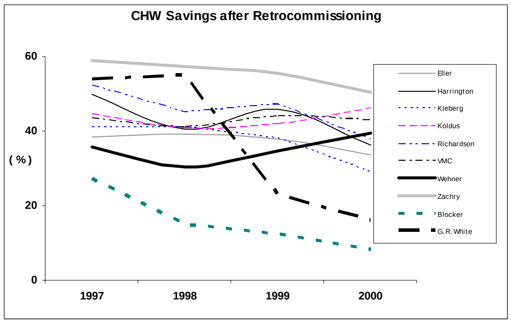


Fig. 1 Chilled water savings persistence after retrocommissioning (Turner et al. 2001).

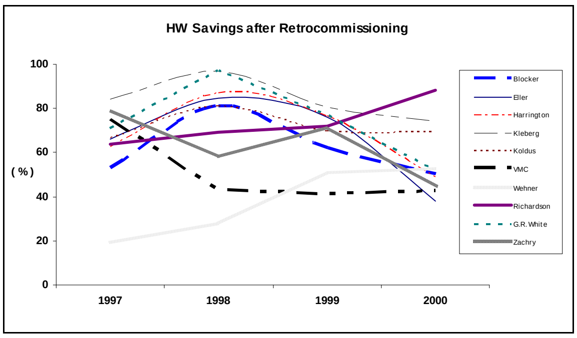


Fig. 2 Hot water savings persistence after retrocommissioning (Turner et al. 2001).

Based on the historic campus energy costs of \$4.67/MMBtu for chilled water, \$4.75/MMBtu for hot water, and \$0.02788/KWh for electricity, the cumulative savings from retrocommissioning in these 10 buildings were \$4,439,000 for the period 1997 - 2000. Only three buildings had year 2000 savings greater than 1998 savings, and the increase in two of these was about 2% of baseline consumption which is well within the range of normal year-to-year variation. The savings of the other buildings decreased.

Table 1 summarizes the savings history of this group of 10 buildings. The savings in 1998 following initial retro commissioning corresponded to average energy cost savings of 39% for the 10 buildings. Savings decreased to 32.3% over the next two years – still a highly significant level of savings.

Tab. 1 Summary of Savings in 10 Buildings Retrocommissioned at Texas A&M

	Baseline Use($/yr)	1998 Cx Savings ($/yr)	Savings 2 Yrs Later($/yr)
10 Buildings	$3,049,487	$1,192,000 (39.1%)	$984,516(32.3%)
8 Buildings	$2,195,307	$723,376 (32.9%)	$666,108 (30.3%)
2 Buildings	$854,180	$468,624 (55%)	$314,408(37%)

Investigation showed that two of the buildings, G. Rollie White Coliseum and Kleberg, accounted for 3/4 of the total savings degradation, and both had experienced major equipment and controls malfunctions which were the primary causes of their degradation. Following correction of these problems, savings were restored to earlier levels. In the remaining eight buildings, savings changes were rather small, declining from 32.9% to 30.3% in aggregate.

All but one of the group of eight buildings had experienced at least some changes in EMCS control settings. To verify the impact of the EMCS changes on energy consumption, the calibrated simulation process was performed on the four buildings with the most complete data sets. Simulation was conducted for a pre-commissioning period, a post-commissioning period soon after retrocommissioning and for the year 2000 for each building. It was found that the changes in consumption observed following retrocommissioning in these buildings were consistent with those due to the identified controls changes, with an RMS difference of only 1.1%. Control changes accounted for the savings increase observed in the Wehner Building as well as the decreases observed in the other three buildings. This suggests that the changes in savings these four were almost entirely due to the control changes.

Based on the results of this study of 10 buildings, it was concluded that

- Basic retrocommissioning measures are quite stable
- Savings should be monitored to determine the need for follow-up
- Steps should be taken to inform operators of the impact of planned/implemented control changes

2.2 8 Buildings in SMUD Program in Sacramento

In 2003, a study was performed by Bourassa et al. (2004) on eight buildings which had undergone retrocommissioning through the Sacramento Municipal Utility District (SMUD) retrocommissioning program. The objective of the study was to determine the extent to which retrocommissioning measures were implemented, and the magnitude and persistence of energy savings achieved. Another objective was to see if the two primary goals of the SMUD retrocommissioning program had been met: reduced overall annual building energy consumption, and improved energy efficiency awareness and focus in the customer. The eight buildings selected for the study consisted of six office buildings, one laboratory, and one hospital. Four of the buildings participated in retrocommissioning in 1999, and the other four in 2000. In this program, the retrocommissioning provider worked with the building operators to develop the recommended measures. The measures selected for adoption were subsequently implemented by the building staff and/or contractors over a period of up to two years.

2.2.1Energy Analysis

The energy savings obtained in the years following retrocommissioning were determined and compared. In order to be able to compare energy savings in the different buildings over the years examined, baseline energy consumption was established for each building based on pre-retrocommissioning energy use. Electricity use data were collected from monthly utility bills for each building. Four buildings also had metered data recorded at 15 minute intervals. Gaps in utility bills were filled from site records or regression analysis.

The energy consumption data were normalized to a common weather year and to a common billing cycle of 30.5 days. The savings were calculated using spreadsheets, based on the normalized data, which allowed for a simpler and more robust statistical comparison. Another set of savings was also calculated, based on the retrocommissioning report predictions. Adjustments were made for a capital retrofit in one of the buildings. The cost of retrocommissioning was also estimated for each of the buildings, based on three categories: SMUD's retrocommissioning costs, the site's retrocommissioning costs, and the retrocommissioning measure implementation costs. Based on the estimated costs and savings, simple payback periods for retrocommissioning at each of the sites were calculated and compared.

The electrical savings observed for each building over the years following retrocommissioning are shown below in Fig 3.

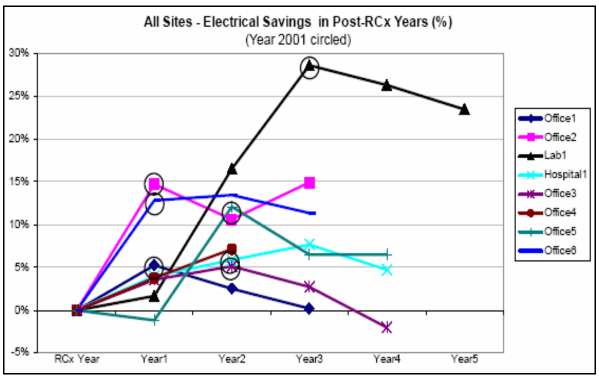


Fig 3. Electrical savings following retrocommissioning for each of the buildings (Bourassa et al. 2004).

The aggregate savings for the sites for each year after retrocommissioining are given in MWh/yr are shown in Fig 4. The buildings are grouped together according to the number of years of data available after retrocommissioning. Note that the "three year" line in the figure includes the data from the "four year" line plus data from three additional buildings, while the "two year" line simply adds data from one more building. Comparison with the data in Figure 3 suggests that the peak in year 3 may be largely due to the one building whose savings peaked in year 3.

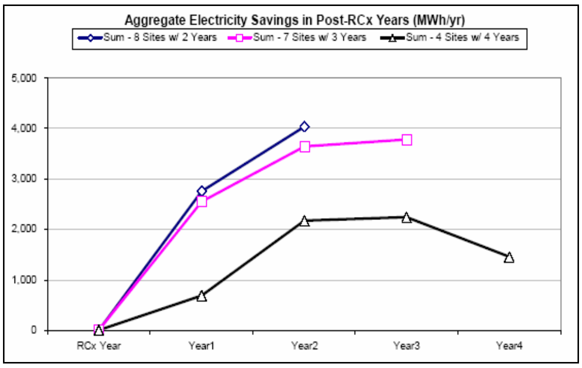


Fig 4. Plot of aggregate post-retrocommissioning electricity savings (Bourassa et al. 2004).

These plots demonstrate the observed trend in energy savings for the commissioned buildings. During the first two years the savings generally increased. This was expected because of the length of time needed for the retrocommissioning measures to be implemented. In the third year the savings began to level off, and the fourth year generally showed a declination in the electricity savings. A comparison with the predicted savings estimated in the retrocommissioning reports revealed that on average these reports underestimated the savings by 27.5%.

The average electricity savings for all the sites over all the years was 7.3% per year. Natural gas usage was only able to be obtained for four of the buildings. The savings for natural gas were considerably lower, but since Sacramento is dominated by cooling needs, the lower natural gas savings only reduced the average total energy savings in these four buildings to 6.1% per year.

The payback periods for the retrocommissioning projects all proved to be attractive, with the longest period being 2.3 years.

2.2.2 Measure Persistence Analysis

A series of interviews and site visits were used to determine the persistence in the retrocommissioning measures recommended. The eight retrocommissioning reports recommended a total of 81 corrective measures, of which 48 were implemented. Of these 48, it was found that 81% had persisted, in that they were still in effect at the time of the study. It was discovered that four of the measures had been abandoned completely, all of which were air distribution component recommendations. Five of the measures had undergone evolution by the building engineers because the original measures had not resolved the problems.

Surveys were given at the sites to determine attitudes regarding the retrocommissioning process, as well as its benefits. All of the sites reported that retrocommissioning was a worthy process. Four of the sites listed training as the primary non-energy benefit from retrocommissioning. The most cited downside to retrocommissioning was the time intensive nature of the process. All of the sites came out of the retrocommissioning process with ideas on how to retain the commissioning benefits over time, the most common solutions being preventative maintenance plans. All of the sites would undertake retrocommissioning again, but only two had potential internal funding.

2.2.3 Conclusions

Some important retrocommissioning process factors that this study identified were:

• The commissioning authority is most effective when he is both an expert and a teacher.

• Building engineers prefer to evolve the settings on a recommendation that doesn't work, rather than revert to the previous condition.

• Retrocommissioning appears to raise energy efficiency awareness

• Retrocommissioning funds are constrained within building management budgets

The energy analysis results showed:

• Analyses should not emphasize first-year savings because savings typically take two to three years to fully manifest.

• Energy savings persist to four years or more, although some degradation begins in the third year.

• The retrocommissioning energy savings predictions were reasonably accurate.

• Building managers lack tools for tracking energy performance.

• Retrocommissioning cost pay back was shorter than the apparent savings persistence.

• Retrocommissioning focused mostly on electricity savings and some natural gas trade offs in the savings occurred.

On the whole, the SMUD retrocommissioning program's two broad goals were met at the eight sites. Aggregate post-retrocommissioning savings were strong, peaking at approximately 4,420 MWh and the program helped educate site staff about energy efficiency and the role operations and maintenance plays.

2.3. Oregon Case Study

A study performed in Oregon in 2004 examined eight Intel buildings that had been retrocommissioned in 1999 and 2000 (Peterson 2005). The buildings were located on the Intel Jones Farm and Hawthorn Farms campuses. The retrocommissioning for these buildings was performed by Kaplan Engineering and PECI through funding from Portland General Electric (PGE). At the time retrocommissioning occurred, it was estimated that electricity savings of nearly 3.5 million kWh annually would result from the low cost energy efficiency measures (EEMs) proposed. The purpose of this study was to examine the energy usage of the buildings to determine what percentage of the original savings was still being achieved four years later. At the same time, it was desired to determine how many of the EEMs proposed were still being utilized.

Three of the buildings studied were located on the Hawthorn Farms Campus, and were designated

HF1, 2, and 3. The buildings combined for a total of 640,000 square feet, and were served by a central chiller and boiler plant. HF1 had DDC control interfaced with pneumatic actuators, and the other two buildings were upgraded to DDC control in 2000. The remaining five buildings studied were located on the Jones Farm Campus, and were designated by JF. They combined for a total of 1.4 million square feet, with over 40 major air handling systems served by two central chiller plants and two hot water boiler plants. Most of the spaces on both campuses were served by variable air volume (VAV) systems.

Three reports generated at the time of retrocommissioning were examined to determine what measures had been implemented. The current status of these measures was determined through random sampling, with functional testing or trending being used as appropriate. For HF1, the terminal reheat units were serviced at the time of retrocommissioning to ensure proper damper motion. At the time of this study, random sampling discovered no noticeable damper movement from full cooling to full heating in 60% of the units. The savings for this measure did not persist, probably due to the aging pneumatic system. For HF 1, 2, and 3, retrocommissioning had modified outside air intake controls to allow for the economizing cycle to function. At the time of the study, random sampling revealed this measure to still be functioning. For the HF chillers, retrocommissioning had lowered the condenser water set point from 75 F to 70 F, while raising the chilled water set point from 42 F to 45 F. This measure was also found to be in operation at the time of this study.

For the JF buildings, air handling units and terminal boxes were scheduled at the time of retrocommissioning to reflect occupancy patterns, scheduling unoccupied hours as 6 PM to 6 AM on weekdays and all day on weekends. At the time of this study, JF3 was evaluated, and the control was found to be working fairly well, with only a couple of override issues. Additional savings opportunities for the JF buildings were also identified in this study, including air flow and scheduling opportunities and control overrides that needed adjustment. For the HF chillers, the leaving condenser water set point was lowered from 80 F to 67 F at the time of retrocommissioning. The current study found the set point to be at 71 F, still significantly lower than the original.

Overall at the Hawthorn Farms campus the ECMs were found to have been maintained, with the exception of the terminal unit reheat optimization in HF1. Of the original projected savings in the three buildings at Hawthorn Farms, 89% of the electric savings and 0% of the natural gas savings were still being achieved at the time of this study. In the five buildings at Jones Farm, the results were more mixed and less quantifiable. The recommended scheduling changes were still programmed at a high level, but it appeared that numerous control overrides at a zone or box level had been made. Some overrides may have been due to changes in space use (such as conversion to a lab), but in many instances conference and training rooms were maintaining occupied modes around the clock. The trending done on some of the variable speed air handlers showed little difference between day and nighttime airflow suggesting that terminal box scheduling was not having an impact on overall airflow.

Of the eight buildings retrocomissioned in Oregon in 1999 and 2000 quantitative findings were reported for three and qualitative findings for the other group of five buildings. For the three buildings on the Hawthorn Farms campus, totaling 60,000 m^2 in floor area,

89% of the original electric savings were achieved in 2004

0% of the natural gas savings were achieved in 2004

For the five buildings on the Jones Farm campus with 130,000 m^2 of floor area, the results were mixed and less quantifiable. It was found that

Scheduling changes were still programmed at a high level, but

Numerous control overrides at a zone or box level had been made

2.4 Office Building in Colorado

A study completed in 2005 evaluated the persistence of recommissioning savings in a large office building in Colorado (Selch and Bradford 2005). Of the studies of this kind done to date, this study appears to have chosen the largest window of time over which to look at persistence. The office building was recommissioned in 1995, which resulted in verified savings of 14% in electrical demand, 25% in electrical use, and 74% in gas use. In 2003, the building was again recommissioned, at which time the status of the energy conservation measures implemented in the initial recommissioning effort was evaluated.

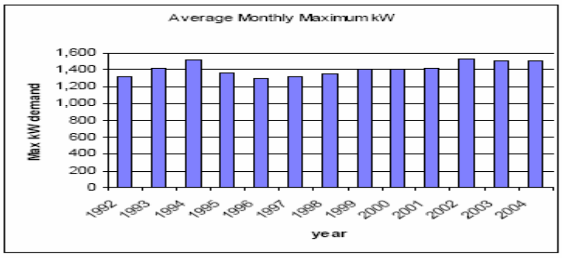
The computation of savings was done in two ways. The overall energy use of the building for each year was obtained from utility bills. These data were then normalized to account for factors such as weather differences, changing occupancy patterns in the building, and added construction in the building. In this way the yearly energy use could be accurately compared to the baseline, pre-commissioned energy use. The other savings calculation method was an individual measure evaluation. Specific measures that impacted individual HVAC system components were examined. To perform the calculations, Options B & C of the International Performance Measurement and Verification Protocol (IPMVP 2001) were employed, Option B being used for individual measure evaluation, and Option C for whole building usage comparison.

Tab. summarizes the results of the individual measures evaluation. The savings from the 2003 recommissioning effort are compared with the 1996 savings. The column for 2003 shows the savings percent for that year as well as the percentage persistence of the savings for each energy type.

Tab.2 Savings persistence summary.

	1996 Savings	2003 Savings
Electricity	20%(1,600,000 kWh)	17% (1,330,000 kWh)(83% Persistence)
Demand	14%(219 kW)	12% (188 kW) (86% ersistence)
Gas	74%	74%(Complete persistence)

As noted in the table, it was calculated that 86% of the electrical demand savings had persisted, while 83% of the electrical use savings had persisted. There had been complete persistence of the large natural gas savings. The results of the whole building energy use comparison appear in Fig. 5 and Fig. 6. The left chart in each figure represents the raw values, while the right chart displays adjusted, normalized values.



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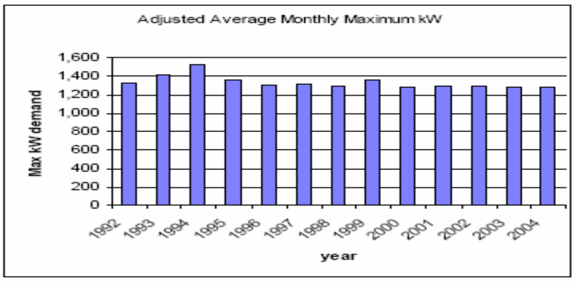
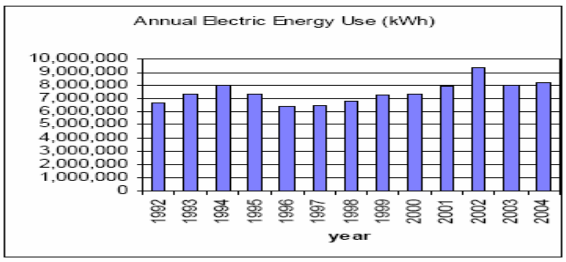


(b)

Fig. 5. Annual electrical demand, raw and adjusted (Selch and Bradford 2005).



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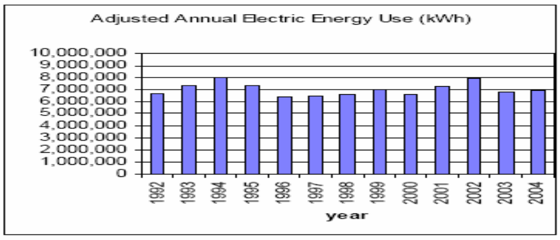

(b)

Fig. 6. Annual electrical use, raw and adjusted (Selch and Bradford 2005).

The annual demand and consumption values that were adjusted to account for changing conditions indicated that the savings achieved from recommissioning had largely persisted. This was concluded with greater confidence due to the corroboration of the independent measure analysis.

The study reported that a large majority of the energy savings measures implemented in the original recommissioning effort had persisted, as had their resultant energy savings. This was in spite of changing conditions in the building, including a complete change in operation staff. It was concluded that ECMs of this nature can persist for at least eight years even with limited support from operators and staff. However, it was noted that continued, on-going support to the building staff as part of the original recommissioning effort probably would have resulted in complete persistence of the savings achieved.

3. PERSISTENCE OF COMMISSIONING MEASURES IN NEW BUILDINGS

3.1 PeciPier Study

In the summer of 2002, a study was completed that had begun in the fall of 2001 under a California Energy Commission Public Interest Energy Research (PIER) project (Friedman et al. 2002, 2003). The purpose of the study was to examine ten buildings that were commissioned at building start-up in order to address the persistence of benefits from the commissioning process. This study drew qualitative conclusions about the persistence of new building commissioning, focusing on three issues: how well the benefits of commissioning persisted, the reasons for declining performance, and the methods that can be used to improve the persistence of benefits achieved through commissioning. A quantitative assessment of persistence by measure ("this measure has an expected persistence of X years") was outside the scope of this project, since a large number of buildings would have been required to determine the figures for each measure.

To evaluate the persistence of commissioning benefits on new buildings, the buildings first had to be selected. To qualify for the study, the facility needed to have been commissioned as a new building or major retrofit between two and eight years prior to the study. Due to the difficulty in finding such buildings with adequate commissioning documentation in California, five buildings were selected in the Pacific Northwest, and five more in California. It was not feasible to limit the study to buildings that followed the full commissioning process, from pre-design through final acceptance and post-occupancy, as described in ASHRAE Guideline 1 (ASHRAE, 1996). The most completely commissioned and documented buildings were sought, but these typically did not include design-phase commissioning.

For each building, three to eight items were identified that were documented to have been fixed during commissioning. The changes and repairs made during commissioning generally fell into three categories: hardware, control system, and documentation improvements. Due to the focus on energy savings measures in the study, the hardware and control system changes with the greatest energy implications were of highest interest, as well as measures dealing with comfort and reliability. The amount of documentation available for each measure was also a driving force in measure selection. It was necessary to only evaluate those measures that had actually been implemented and documented. Routine maintenance issues or measures deemed static once corrected (such as equipment disconnected from the power supply) were not looked at. With the limited amount of time and funding for the study, it was necessary to focus on measures whose current status could easily be compared to the as-commissioned status and which would affect energy consumption. Because of the bias in selecting these measures, and the underestimation of savings persistence due to the limited number of measures considered, the results of the study were presented qualitatively.

For purposes of the study, it was decided that if the measure resulted in better performance than the pre-commissioning condition, then the measure was said to have persisted, even if it had been adapted to meet real operating conditions of the building. In some cases the persistence of a measure was somewhat subjective.

The people with the most knowledge about the control system at each site were interviewed. Some sites were identified for site visits, and for the others a second interview was conducted to discuss the current status of the commissioning measures. Six of the buildings were visited, during which the persistence of the selected commissioning measures was investigated, and the work environment and resources available to the operations staff were evaluated.

3.2Results

It was found that the process of finding qualified buildings for the study in California was difficult. As mentioned above, qualified buildings were located more easily in Oregon, most likely because of the longer history of new building commissioning in the Pacific Northwest. California had numerous existing buildings involved in retrocommissioning projects, but new buildings having undergone commissioning at least two years earlier were sparse. For many of the commissioned buildings considered for the study, commissioning reports had not been written, so the information that could have been used by operations personnel to more efficiently operate the building essentially was lost. Often times in lieu of a report, the commissioning activities would simply be placed on a “punch list” for maintenance personnel to work on, who, when they had completed them usually did not document the changes. In other buildings the reports had been written, but were not readily available to the operations staff, having been filed away in storage and not easily accessible. In many cases where documentation did exist, it was not clear when or if the commissioning measures had been implemented, as they were noted as “recommendations” or “pending.” These issues led to the conclusion that the term “commissioning” had been applied to a variety of different activities, including troubleshooting items and checklists, indicating a lack of consistency in the way the term was being applied.

Tab. 1 below summarizes the commissioning measures studied and their level of persistence. A light gray square indicates that the measure persisted, while a black square indicates that the measure did not persist. A square split in half horizontally indicates that more than one measure was investigated in the category.

Tab. 1. Persistence of equipment and controls fixed during commissioning (Friedman et al. 2003).

BUILDING (year commissioned)		DOCUMENTS			CENTRAL PLANT				AIR HANDLING AND DISTRIBUTION								PREFUNCTIONAL TEST					OTHER		
		Commissioning report on site	Commissioning report used	Control sequences available	Chiller control	Cooling tower control	Boiler control	Hydronic control	Economizer control algorithm	Discharge air temperature reset	Simultaneous heating and cooling	VFD modulation	Dessicant cooling	Duct static pressure	Space temperature control	Terminal units	Piping and fitting problems	Valve modification	Wiring and instrumentation	Sensor placement or addition	Sensor error or failure	Scheduling	Skylight louver operation	Occupancy sensor
California	Lab and Office 1 (1995)	no	-	yes																				
California	Office Building 1 (1996)	no	-	yes																				
California	Office Building 2 (1996)	no	-	no																				
California	Office Building 3 (1994)	yes	yes	no																				
California	Office Buidling 4 (1994)	no	-																					
Pacific Northwest	Office Building 5 (1997)	no	-	yes																				
Pacific Northwest	Medical Facility 1 (1998)	yes	yes	yes																				
Pacific Northwest	Medical Facility 2 (1998)	yes	yes	yes																				
Pacific Northwest	Lab and Office 2 (1997)	no	-	yes																				
Pacific Northwest	Lab and Office 3 (2000)	no	-	no																				

Across the ten buildings studied, patterns about the types of commissioning fixes that persisted emerged. For the fifty-six commissioning fixes selected, well over half of the measures persisted. It was not surprising that hardware fixes, such as moving a sensor or adding a valve, persisted. Furthermore, when control algorithm changes were reprogrammed, these fixes often persisted, especially when comfort was not compromised. Many design phase fixes may have persisted in a similar way, but these were not able to be studied since only one building was commissioned in the design phase.

The types of measures that tended *not* to persist were the control strategies that could easily be changed, such as occupancy schedules, reset schedules, and chiller staging. Four out of six occupancy schedules did not persist. Chiller control strategies did not persist in three out of four cases, most likely due to the complex nature of control in chilled water systems. The study of sensor issues was limited to major sensor problems that were corrected during commissioning, such as sensor failure or excessively faulty readings. With this selection bias applied, two out of five sensor repairs did not persist.

Among the commissioning measures implemented, a few cases involved technologies that were new or different from normal practice. Due to lack of documentation, these measures were not included in this study, but it was observed during the investigation that these measures generally did not persist. This was attributed to a lack of operator training for the technologies.

3.4 Discussion

The study suggested three possible reasons for lack of persistence among some measures. The first was limited operator support and high operator turnover rates. Operators often did not receive the training necessary or they did not have sufficient time or guidance for assessing energy use, and the training given new operators who came in after the commissioning was usually inadequate. The second reason involved poor information transfer from the commissioning process. For nearly every case studied, the commissioning report was either difficult to locate, or was not even located on site, which reduced the ability of building operators to review commissioning measures implemented. The third reason for lack of persistence was a lack of systems to help track performance. Operators spent most of their time responding to complaints and troubleshooting problems, leaving little time to focus on assessing system efficiency. Aside from this, lack of information and knowledge impeded the efficiency assessment by building operators.

The persistence of commissioning benefits was found to be highly dependent on the working environment for building engineers and maintenance staff. A working environment that was supportive of persistence included adequate operator training, dedicated operations staff with the time to study and optimize building operation, and an administrative focus on building performance and energy costs. Trained operators were found to be knowledgeable about how the systems should run and, with adequate time and motivation to study the system operation, these operators evaluated and improved building performance. In five buildings, operators participated in the commissioning process and came away with a good understanding of their systems. In addition, good system documentation in the form of a system manual served as a troubleshooting resource for operators at two buildings. It was noted that administrative staff can help enable a supportive working environment by placing high priority on energy efficient systems and operator training. Only a few of the buildings studied seemed to operate in this environment, and the measures investigated at these facilities had the highest rate of persistence.

Some of the measures simply persisted by default – no maintenance being required to keep them operational. If comfort issues were not a factor, or the measure involved programming buried deep within code, the measures tended to persist.

The study recommended four methods for improving persistence. First, operators should be provided with training and support. Especially with high operator turnover, adequate training is needed for benefits to persist, and a working environment with energy efficiency as a high priority is also beneficial. Second, a complete systems manual should be provided at the end of the commissioning process. This will serve as a reference for building operators, and will allow the systems knowledge gained from the commissioning process to be available over the long term. Third, building performance should be tracked. New building commissioning efforts should help to implement mechanisms for performance tracking, including what information to track, how often to check it, and the magnitude of deviations to address. Fourth, commissioning should begin in the design phase to prevent nagging design problems. Changes made on paper before construction has begun tend to be more cost effective and have higher levels of persistence.

The study concluded with a recommendation that more in-depth, quantitative studies be performed to investigate the life of commissioning measures and carry out cost-benefit analyses for new building commissioning. It was further recommended that a manual of guidelines for improving persistence be developed to give guidance and direction to building operators with regard to energy efficiency.

4. RELATED REPORTS

A report was compiled in 2004 that evaluated the cost effectiveness of commissioning in new and existing buildings (Mills et al. 2004, 2005). The largest study of its kind to date, it examined the results of commissioning for 224 buildings across 21 states. Among the existing buildings commissioned, a median payback period for commissioning was reported to be 0.7 years. For new buildings, this value was found to be 4.8 years. Both of these figures excluded non-energy benefits, which would increase the savings experienced.

While persistence of savings was not the primary focus of the study, it was examined briefly since it plays a role in determining overall savings. Fig. 7 shows the persistence of savings results for 20 of the buildings in the study, with a four year period following commissioning in each building. The savings are indexed by a comparison of the year’s consumption to the pre-commissioning baseline consumption. The savings are compared by category: electricity, fuel, chilled water, and steam/hot water.

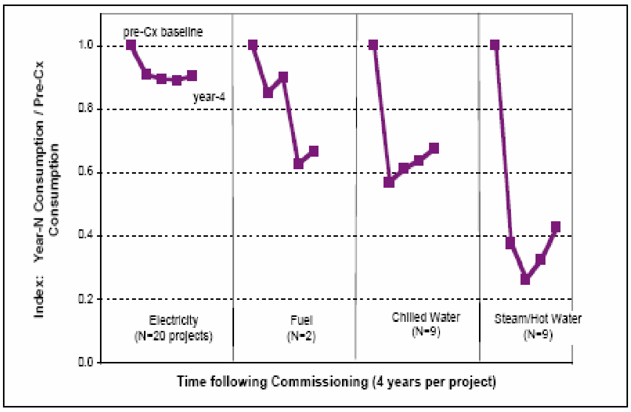

Fig. 7 Emergence and persistence of energy savings (weather normalized) (Mills et al. 2004).

An important factor noted in the report was the fact that in many cases of commissioning, the recommended measures were implemented gradually, indicating that the first year after commissioning was not the best year for calculating savings. On the other hand, it was also observed that some of the savings subsequently decreased somewhat due to changing building conditions, operations, or aging. As seen in the figure, the maximum value for savings was reached and subsequently savings began to degrade. This effect was smallest for electricity, but much more noticeable for chilled and hot water and steam.

With regard to persistence of commissioning benefits, the report concluded that tracking energy consumption for evidence of significant consumption increases is the most important means of determining the need for follow-up commissioning, and that while controls changes by building operators account for a portion of savings degradation, hidden component failures are perhaps the greatest culprit in persistence problems.

5. METHODOLOGIES FOR DETERMINING PERSISTENCE OF COMMISSIONING MEASURES AND ENERGY BENEFITS OF COMMISSIONING

The retrocommissioning studies that provided a quantitative evaluation of the persistence of energy benefits of commissioning used multiple approaches to evaluating the persistence of energy benefits.

The study of 10 Texas buildings (Turner et al 2001) used a variation on Option C of the IPMVP that normalized for weather differences between years by selecting a "normal" year of weather data in the sequence available that most closely met long term norms. A suitable three-parameter or four-parameter regression model of the baseline year was created along with models of the performance of the building in each year evaluated.

Then the annual consumption for each year was determined by running the appropriate model with the appropriate year of weather data. The study of eight SMUD buildings (Bourassa et al. 2004) used the same methodology, except that they used a long term average weather year instead of selecting one of the available years of weather data. The Colorado study (Selch and Bradford 2005) used a different approach, evaluating savings persistence with IPMVP Option C with baseline adjustments and IPMVP "Option B" was used to determine savings for specific measures in operation. The Oregon study did not specify how savings were evaluated.

The study of eight buildings in Oregon (Peterson 2005) and the Colorado building (Selch and Bradford 2005) used different approaches. These studies examined each of the measures that had been implemented and determined whether the measures were still in place and functioning. Peterson (3) found that in three of the buildings, she could quantify the savings associated with measures that had been disabled after four years. It was found that numerous measures implemented in the other five buildings were still in place, but there were also numerous overrides and changes that had occurred as well. It was not possible to quantify the degree of persistence in these buildings. Selch and Bradford (2005) found that they were able to quantify the savings associated with measures that had been disabled.

The study of 10 new buildings that had been commissioned in Oregon and Washington (Friedman et al 2002) used a methodology that quantified the number of measures that were still in place, but it did not seem appropriate to try to quantify the energy savings associated with these measures. The four retrocommissioning studies all discussed the measures found to be still operating and those that had been changed. The Texas study used calibrated simulation to evaluate measures that had been changed. The other studies were not explicit in the methods used to evaluate the impact of measure changes.

6. SUMMARY AND CONCLUSIONS

The results of studies from five projects related to commissioning, either in new or existing buildings, have been discussed, with the major conclusions

component failures occurred. For the eight buildings in California, peak aggregate savings occurred in years two and three with about 1/4 of the savings disappearing in year four for the four buildings for which that much data was available. 89% of the electric savings and none of the gas savings in three of the Oregon buildings persisted four years later. The persistence in the other five Oregon buildings was not quantified. The building in Colorado was still saving 86+% as much after seven years as after the initial retrocommissioning.

For the new buildings, well over half of the fifty-six commissioning fixes persisted. Hardware fixes, such as moving a sensor or adding a valve, and control algorithm changes that were reprogrammed generally persisted. Control strategies that could easily be changed, such as occupancy schedules, reset schedules, and chiller staging tended not to persist. It was also found that the extent to which persistence occurs is also related to operator training.

As is evident, the number of buildings studied in all of the papers described here represents a very small portion of commercial buildings that have undergone commissioning or retrocommissioning. Much more research is needed to verify the conclusions made in these studies, as well as to continue to provide practical solutions to building

drawn from each. These studies represent the extent of research that has been performed with regard to the persistence of commissioning benefits over time.

The savings in the buildings that were retrocommissioned generally showed some degradation with time, with specific findings as detailed below. For the ten buildings studied at Texas A&M, the cooling energy savings obtained from retrocommissioning degraded from 44.8% to 35.1% during the period from 1997 to 2000. The heating energy savings decreased 79.7% in 1998 to 49.7 % in year 2000. In spite of these decreases, cost savings from retrocommissioning in these 10 buildings were still $985,626/year compared with original savings of $1,192,884/year. As noted, 3/4 of the decrease was in two buildings in which

owners and operators as to how to best maintain commissioning savings, and how these methods may be better integrated in the commissioning process.

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