The Persistence of Retro-commissioning Savings in Ten University Buildings

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ABSTRACT

A study was performed to evaluate how well energy savings persisted over time in ten university buildings that underwent retro-commissioning in 1996. Total annualized savings for all buildings in 1997 were 45(±2)% for chilled water, 67(±2)% for hot water, and 12% for electricity. Combining consumption from the most recent data year for each building showed a total savings of 39(±1)% for chilled water, 64(±2)% for heating water, and 22% for electricity. Follow-up work performed in the buildings, lighting retrofits, and building metering changes were the major issues believed to have contributed to the high level of savings persistence in later years. When persistence trends were evaluated with adjustment for these factors, average savings were found to degrade over time, and exponential models were developed to describe this degradation. The study concludes that on average energy savings after retro-commissioning will degrade over time in a way that can be modeled exponentially. Savings for heating, cooling, and non-cooling electricity use in the buildings studied declined by an average of 8%, 6% and 4% per year, respectively following commissioning without further intervention.

INTRODUCTION

Despite thorough documentation of savings achieved by retro-commissioning, little has been recorded on the long-term savings of retro-commissioning projects. While a few studies in savings persistence have been performed in the past (see Chvala et al., 1995; Vine 1992), the topic as it relates to retro-commissioning is relatively new, and the most relevant projects identified in the literature as of the beginning of 2010 involve a total of 42 buildings as noted below.

- 10 Retro-commissioned Buildings at Texas A&M University – Claridge et al. (2002, 2004), Cho (2002)
- 3 Retro-commissioned Buildings at Texas A&M University – Engan and Claridge (2007)
- 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)
- 2 Retro-commissioned Buildings from Utility Program – Eardley (2007)
- 10 Commissioned New Buildings – Friedman et al. (2002, 2003a, 2003b).

The first study to examine persistence of retro-commissioning savings in detail was the study of 10 buildings at Texas A&M, which evaluated the persistence of energy savings in ten university buildings that had undergone retro-commissioning in 1996 or 1997 (Claridge et al. 2002, 2004, Cho 2002). The documented savings in each of four years following retro-commissioning were evaluated and compared, to determine how well they had persisted. With a few exceptions, the energy savings achieved in the year following retro-commissioning were shown to have high levels of persistence.

The current paper documents a follow-up of this study. Using the same ten buildings, but with a greatly expanded period of time, the levels of persistence of original retro-commissioning benefits have been evaluated. Significant changes in consumption have been examined, and conclusions have been drawn with regard to the trends observed. The significant length of time of evaluation for each of the buildings after retro-commissioning and follow up is a major factor that differentiates the current study from the previous studies mentioned. This is also the first of these studies to attempt to quantifiably predict how retro-commissioning savings degrade over time.

The ten buildings studied are all located on the campus of Texas A&M University in College Station, TX. Each of the buildings is supplied with hot water and chilled water from a central plant. The buildings range in size from 97,920 square feet to 258,600 square feet, and include office buildings, classroom buildings, laboratories, and a volleyball arena.

METHODOLOGY

To determine savings, Option C of the International Performance Measurement & Verification Protocol (IPMVP) was used for each of the buildings, and Option D was used for some of the comparisons in more recent years for one of the buildings that underwent a major renovation. In using Option C, the normalized savings approach was utilized. Both the baseline period data and reporting period data were adjusted to a common weather year. The common year selected was the 1995 daily average weather data for College Station, TX. This provided consistency with the previous study of these buildings.

In order to adjust each year of data to the selected conditions, three- and four-parameter change-point models were developed using Emodel, a statistical toolkit. The models used average daily temperature as the independent variable, with daily hot water or chilled water consumption as the dependent variable. Once the models were generated, the average daily temperatures from the 1995 weather data were substituted to obtain normalized energy consumption data. The electricity consumption was found to have negligible dependence on weather data for the buildings studied since each of the buildings received chilled water and hot water from a central plant, the electricity consumption of which was not included in the metered building electricity consumption data. Therefore, the electricity consumption data were not normalized to a common weather year.

Once weather normalized consumption data had been obtained for all of the applicable years for which metered data were available, year by year comparisons of consumption were conducted for each of the buildings to determine to what level retro-commissioning savings had persisted. The percentage of energy savings as compared with the baseline year was calculated for chilled water, hot water, and electricity where available.

In one of the buildings, a major addition took place in 2002. The metered energy data after this year included the consumption for this addition combined with the original building. In order to quantify the effects of this added space so that the original building energy consumption could be appropriately compared with the consumption of previous years, a calibrated simulation of the building using a commercial simulation program was performed, in accordance with Option D of the IPMVP.

For all savings estimates reported, an uncertainty analysis was performed according to guidelines given in IPMVP 2007. Each savings estimate was reported as a range with a calculated precision at the stated confidence interval.

SAVINGS RESULTS

The overall trends in chilled water, hot water, and electricity savings over the period sampled for the ten buildings are shown in Figures 1, 2, and 3.

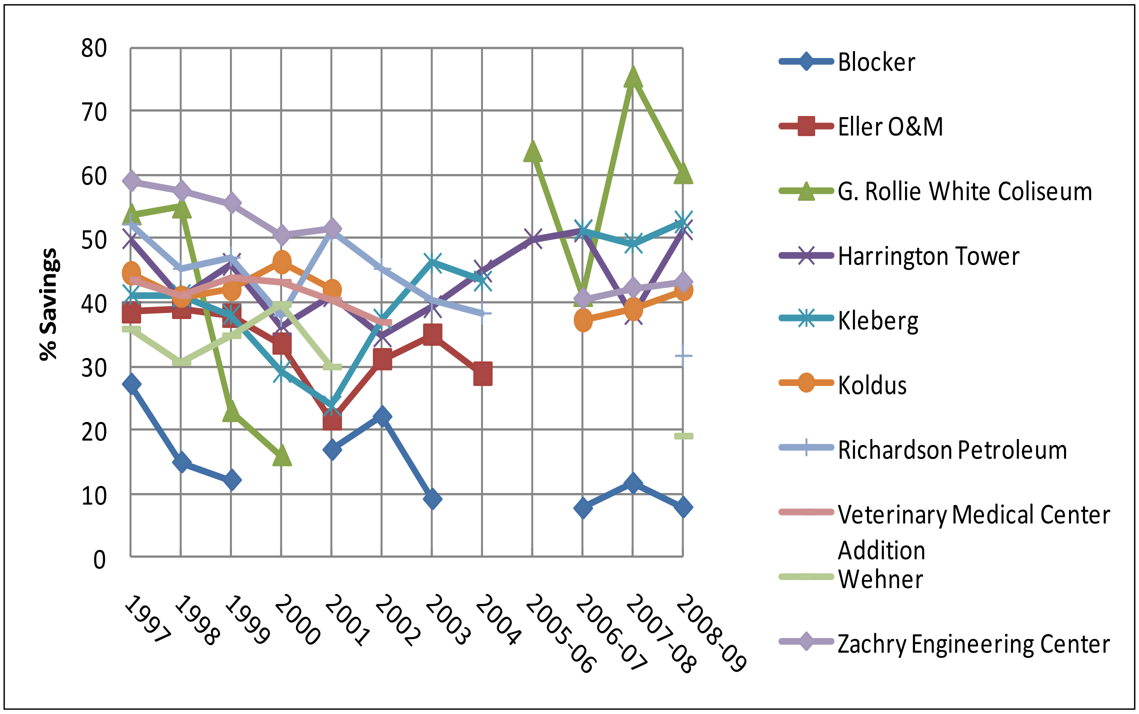

Figure 1. Chilled water savings trends over time for the ten buildings studied.

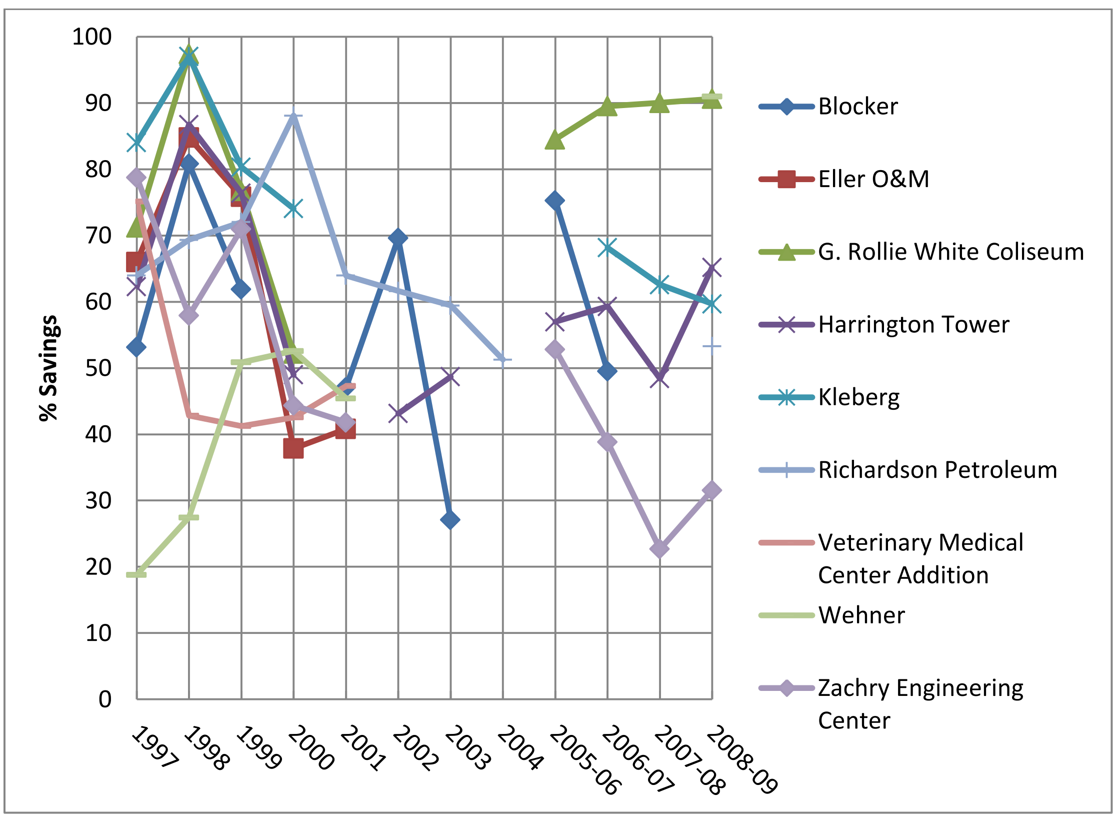

Figure 2. Hot water savings trends over time for the ten buildings studied.

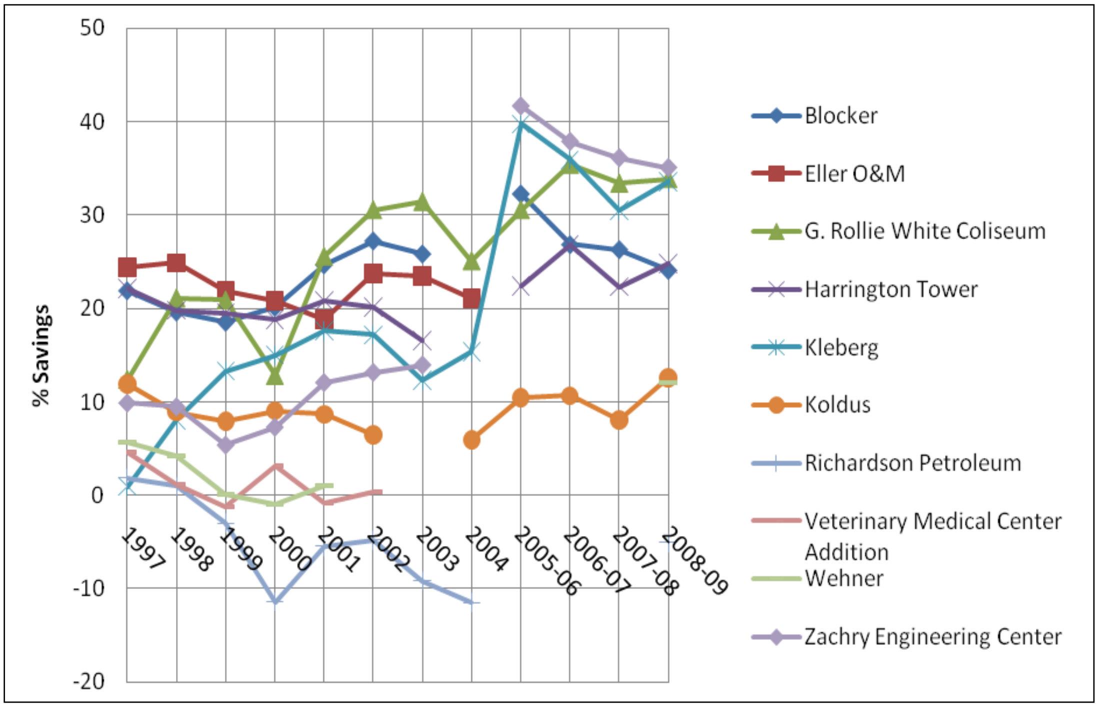

Figure 3. Electricity savings trends over time for the ten buildings studied.

The hot water data for Koldus displayed highly negative savings in recent years. After analysis, it was determined that the data from previous years had been unreliable, making comparisons of hot water energy savings for this building untenable. These data were excluded from the results.

Table 1 gives percentages for the total savings achieved for all ten buildings during the first year after retro-commissioning (1997), then again using the total of the consumption data for each building in its most recent available data year. For chilled water, the most recent year for each building is 2008-09, except for Eller (2004) and VMCA (2002). For hot water, the most recent year for each building is 2008-09, except for Blocker (2006-07), Eller (2001), and VMCA (2001). The hot water data for Koldus were completely excluded due to the meter problems. For electricity, the most recent year for each building is 2008-09, except for Eller (2004) and VMCA (2002).

Using this metric, it is apparent that most of the savings present in 1997 for chilled water and hot water persisted through the most recent year of available data. For electricity, the amount of cumulative savings dramatically increased.

To look at this more closely, Table 2 is a summary of the chilled water, hot water, and electricity savings percentages for each of the ten buildings in the year just following the first round of retro-commissioning, in the year when maximum savings were observed, and in the most recent year that reliable metered data were available for the building.

Table 3 shows the average savings by year for the buildings with valid metered data, and Figure 4 presents them graphically.

Table 1. Total cumulative savings percentage in 1997 and in most recent data year (90% confidence interval).

Year	CHW	HW	Electricity
1997	45(±2)%	67(±2)%	12%
Most recent data year	39(±1)%	64(±2)%	22%

Table 2. Savings comparison for ten buildings in first year, maximum year, and most recent year.

Building	Utility	Savings 1997 (%)	Max Savings Achieved (%)	Max Savings Year	Savings Most Recent Year (%)	Most Recent Year
Blocker	CHW	27	27	1997	8	2008-09
	HW	53	81	1998	50	2006-07
	Elec	22	32	2006-07	24	2008-09
Eller	CHW	38	39	1998	29	2004
	HW	66	85	1998	41	2001
	Elec	24	25	1998	21	2004
G. Rollie White	CHW	54	75	2007-08	60	2008-09
	HW	71	97	1998	91	2008-09
	Elec	12	35	2006-07	34	2008-09
Harrington Tower	CHW	50	51	2006-07	51	2008-09
	HW	62	87	1998	65	2008-09
	Elec	22	27	2006-07	25	2008-09
Kleberg	CHW	41	53	2008-09	53	2008-09
	HW	84	97	1998	60	2008-09
	Elec	1	40	2005-06	34	2008-09
Koldus	CHW	45	46	2000	42	2008-09
	HW	NA	NA	NA	NA	NA
	Elec	12	13	2008-09	13	2008-09
Richardson	CHW	52	52	1997	32	2008-09
	HW	64	88	2000	53	2008-09
	Elec	2	2	1997	-5	2008-09
VMCA	CHW	43	44	1999	37	2002
	HW	75	75	1997	47	2001
	Elec	5	5	1997	0	2002
Wehner	CHW	36	40	2000	19	2008-09
	HW	19	88	2008-09	91	2008-09
	Elec	6	12	2008-09	12	2008-09
Zachry	CHW	59	59	1997	43	2008-09
	HW	79	79	1997	32	2008-09
	Elec	10	42	2005-06	35	2008-09

Table 3. Average savings by year for buildings with valid metered data.

Year	CHW		HW		Electricity	
	Savings	# of bldgs.	Savings	# of bldgs.	Savings	# of bldgs.
1997	45%	10	64%	9	12%	10
1998	41%	10	72%	9	12%	10
1999	38%	10	67%	9	10%	10
2000	37%	9	55%	8	9%	10
2001	35%	9	48%	6	12%	10
2002	35%	6	58%	3	15%	9
2003	34%	5	45%	3	16%	7
2004	39%	4	51%	1	11%	5
2005-06	57%	2	67%	4	30%	6
2006-07	38%	6	61%	5	29%	6
2007-08	43%	6	56%	4	26%	6
2008-09	38%	8	65%	6	21%	8

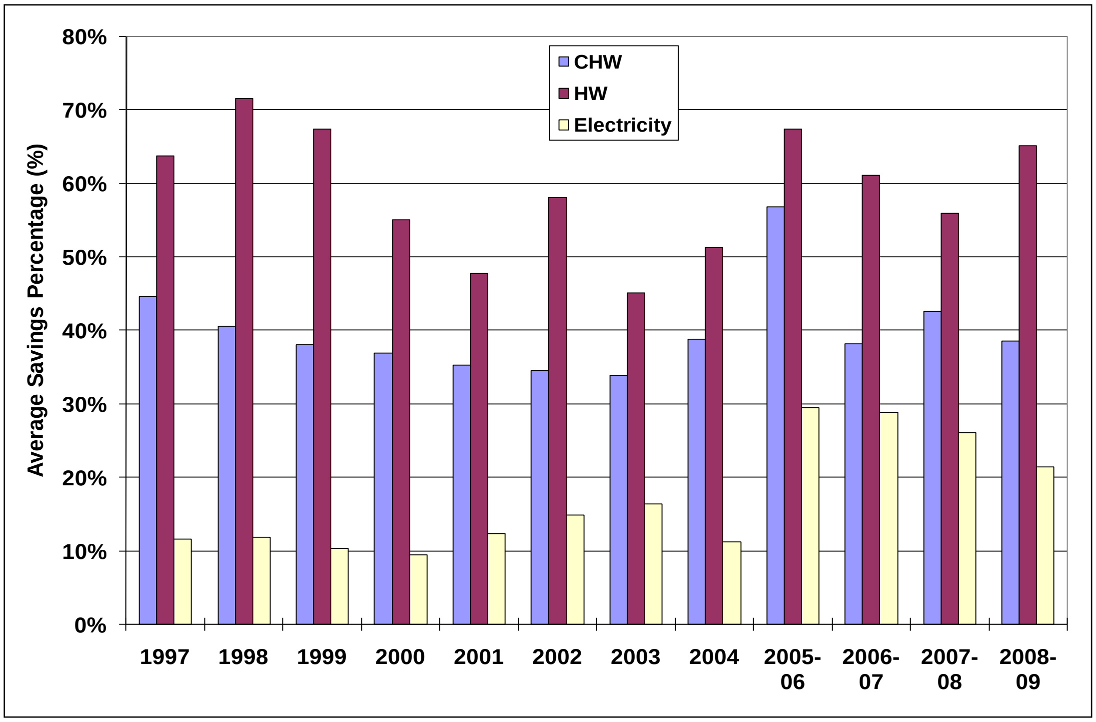

Figure 4. Average savings by utility by year for buildings with valid metered data.

The average chilled water savings for each year display a trend of slight degradation over several years, followed by a small rise in 2004, then a large rise in 2005-2006. Further degradation then occurs. The average hot water savings display at least three periods of degradation followed by increase. The average electricity savings demonstrate degradation and increase, followed by a large increase in 2005-2006, and then further degradation. The year 2005-2006 marked the first year after the new metering system was installed, as well as major lighting retrofits in several of the buildings, and a significant difference in average savings is noticeable for all three utilities over the previous year.

Table 4 shows the cumulative savings for each year for the buildings, and Figure 5 then shows these values graphically.

Table 4. Cumulative savings by year for buildings with valid metered data.

Year	CHW		HW		Electricity	
	Savings	# of bldgs.	Savings	# of bldgs.	Savings	# of bldgs.
1997	45%	10	67%	9	12%	10
1998	42%	10	80%	9	12%	10
1999	40%	10	72%	9	10%	10
2000	37%	9	63%	8	11%	10
2001	35%	9	50%	6	13%	10
2002	35%	6	60%	3	15%	9
2003	37%	5	49%	3	17%	7
2004	39%	4	51%	1	13%	5
2005-06	58%	2	81%	4	34%	6
2006-07	40%	6	68%	5	31%	6
2007-08	43%	6	65%	4	28%	6
2008-09	40%	8	67%	6	25%	8

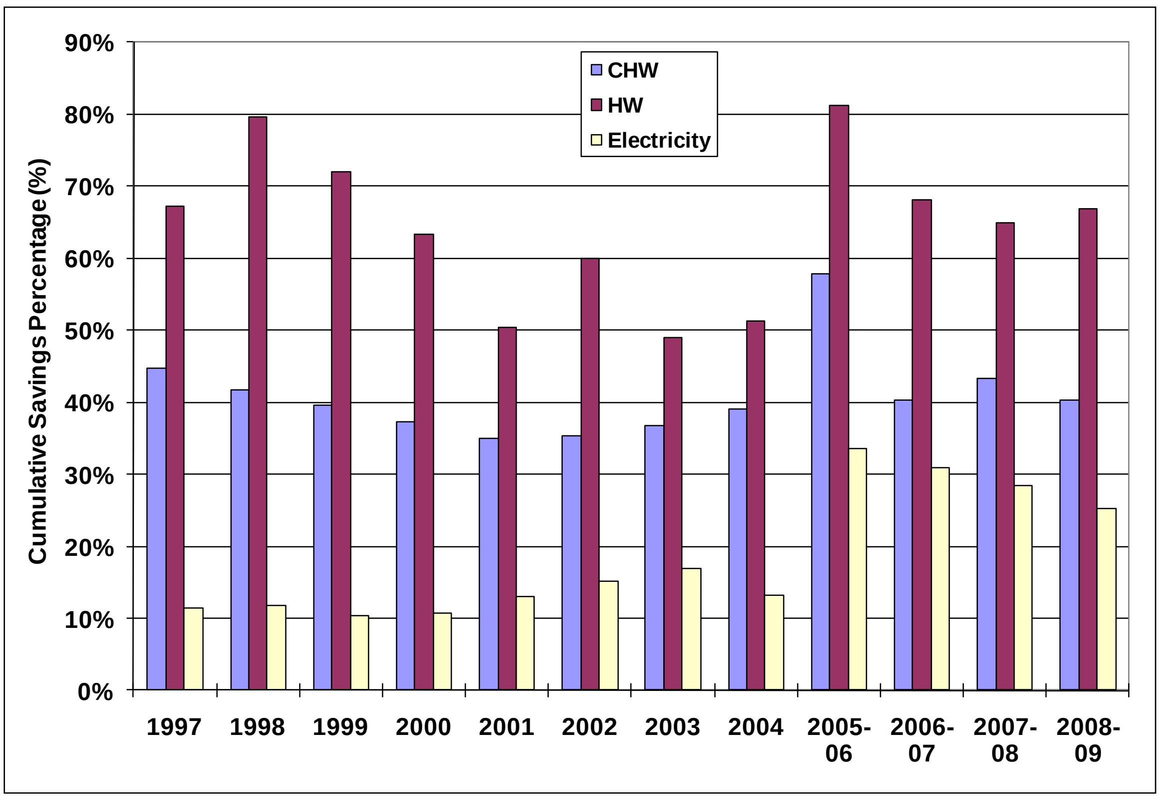

Figure 5. Cumulative savings by utility by year for buildings with valid metered data.

The trends for cumulative savings by year are very similar to those seen in the average savings trends. The large increase in savings is also noted for all three utilities in 2005-2006.

FOLLOW UP WORK PERFORMED AND MAJOR CHANGES

In the years following the initial rounds of retro-commissioning, most of the buildings had some follow-up work performed. Five of the buildings had a second round of retro-commissioning performed three or more years after the first round. Three of the other buildings had significant investigation performed after major comfort complaints were received or savings degradation was noted. For two of these, Kleberg and G. Rollie White, the follow up work corrected serious maintenance and controls issues and resulted in improved savings. For G. Rollie White, a simple control error had the heating and cooling setpoints reversed for 13 single-zone AHUs, resulting in simultaneous heating and cooling as the units attempted to cool to 68˚F while heating to 74˚F. This issue was corrected along with several others, and better savings resulted.

Six of the buildings had new metering installed for chilled water, hot water, and electricity in 2005 or 2006. Six of the buildings had a major lighting retrofit performed in 2006, and three others had one in 2008.

Sometime between 2001 and 2006, a large mainframe computer was removed from Zachry, which appeared to have been a major factor in electricity reduction thereafter.

As mentioned, Wehner had a major addition constructed in 2002. Calibrated simulation was needed to allow energy comparisons before and after the addition was finished, since its energy consumption was included in the same set of building meters.

ADJUSTED SAVINGS

The data were redistributed based on when significant follow up retro-commissioning work was performed, or when metering changes occurred or other changes to the building that would be expected to impact energy usage. In these cases, the year of data following the change or follow up was assigned as year zero, and years following were years one, two, etc. The year 1997 was also assigned as year zero for every building, since it represented the data just after retro-commissioning. This meant that for most buildings there was more than one data set per year after retro-commissioning. This shortened the overall time after retro-commissioning that would be evaluated for persistence, but greatly increased the data in the first few years after retro-commissioning or major follow up.

When the years following major follow up work or building changes are treated the same as and grouped together with the years following initial retro-commissioning, more consistent data patterns begin to emerge. Table 5 shows the average savings adjusted for years with major changes or follow up. In Figure 6, the savings percentage points are plotted for the years after retro-commissioning or follow up that had at least five data sets. Those years with less than five data sets were excluded, as it was felt that they may have insufficient data points to accurately represent a trend. This allowed exponential curves to be fitted to the data to further describe the decay of savings noted in the average.

Table 6 shows the cumulative savings adjusted for years with major changes or follow up, and Figure 7 presents them graphically.

Table 5. Average savings by year, years adjusted for major changes.

Years after RC or Follow Up	**CHW**		**HW**		**Electricity**	
	Savings	**# of data years**	**Savings**	**# of data years**	**Savings**	**# of data years**
0	43%	18	67%	26	16%	24
1	41%	19	65%	16	18%	20
2	40%	17	56%	12	15%	19
3	38%	14	51%	9	15%	16
4	33%	8	56%	2	13%	8
5	31%	4	38%	2	17%	5
6	28%	3			20%	4
7	37%	2			21%	1

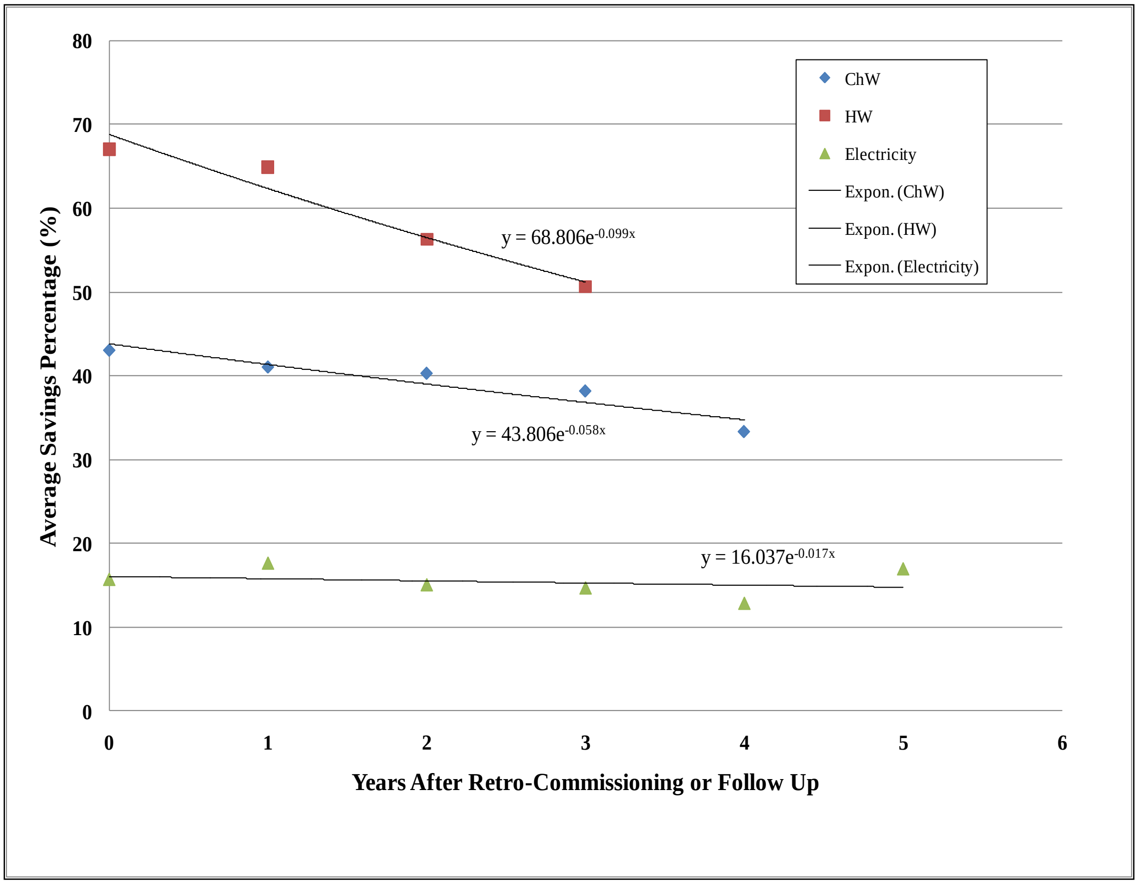

Figure 6. Average savings by utility versus number of years after major change.

Table 6. Cumulative savings by year, years adjusted for major changes.

Years after RC or Follow Up	CHW		HW		Electricity	
	Savings	# of data years	Savings	# of data years	Savings	# of data years
0	43%	18	72%	26	18%	24
1	42%	19	70%	16	18%	20
2	41%	17	64%	12	16%	19
3	39%	14	57%	9	17%	16
4	33%	8	58%	2	13%	8
5	32%	4	37%	2	17%	5
6	27%	3			20%	4
7	34%	2			21%	1

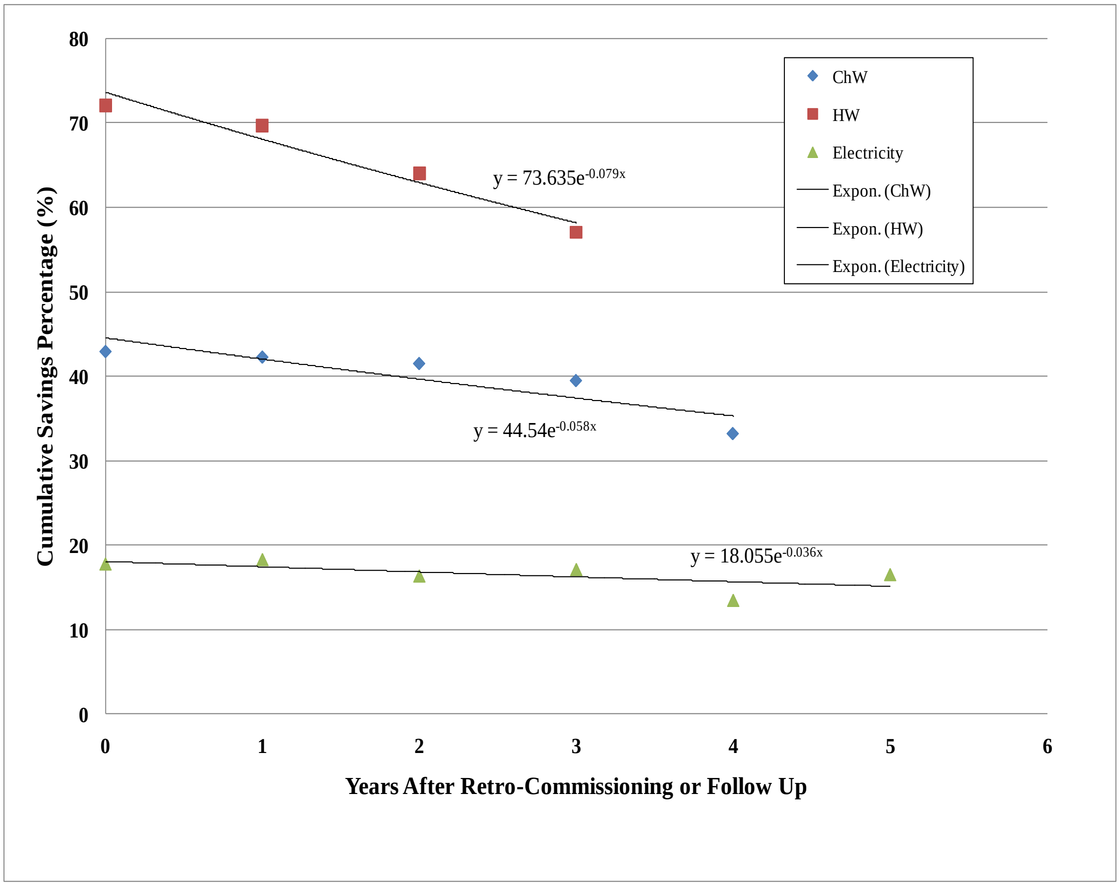

Figure 7. Cumulative savings by utility versus number of years after major change.

The cumulative savings with follow up years also treated as year zero demonstrated degradation trends very similar to those seen in the average savings graph treated in the same manner. Exponential curves were also fitted to the data points, with only those years with at least five valid data sets being included.

All of this information together shows that cumulative and average savings up to 11 years after the initial retro-commissioning still maintained levels close to, or even higher than initial savings. However, taking into consideration the follow up work that occurred in many of the buildings, the metering changes that occurred, the lighting retrofits and other major changes, the picture emerges that initial savings after a major event do degrade with time, in a way that can be modeled exponentially. Savings for heating, cooling, and non-cooling electricity use in the buildings studied declined by an average of 8%, 6% and 4% per year, respectively following commissioning without further intervention.

CONCLUSIONS

From this study, some conclusions can be drawn about retro-commissioning savings persistence. In two of the buildings (G. Rollie White and Kleberg), major mechanical problems and significant control parameter changes led to dramatic reductions in savings in years after retro-commissioning. However, these increases were noticed by energy management personnel, and follow-up retro-commissioning work was able to be performed, after which savings improved significantly. From these examples it can be concluded that continuous monitoring and comparison of energy consumption in a facility is critical for identifying when follow up work might be needed due to unexpected changes in consumption.

This study found two of the buildings, the Eller O&M building and the Veterinary Medical Center Addition, which did not have any follow up retro-commissioning work performed after the initial round of retro-commissioning, at least during the years when valid metered data were available (the Eller

O&M underwent retro-commissioning again in 2008, but no metered data were available after 2004). These two buildings experienced little degradation in chilled water or electricity savings, but both had some degradation in hot water savings.

The remaining eight buildings had some sort of retro-commissioning follow up work performed after the initial round of retro-commissioning. For some, this was just selected follow up that was a result of comfort complaints or unusual energy patterns, but for several of the buildings full rounds of retro-commissioning were performed again, sometimes even a third time. These appeared to be effective insofar as recommended measures were implemented, though they appear to have had less effect than the initial round of retro-commissioning, since much of the savings potential had already been recovered the first time. The implementation of recommended measures during this time was also not as complete as in the initial retro-commissioning.

From this set of buildings evaluated over a lengthy period of time, it can be concluded that even without retro-commissioning follow up work, some buildings will demonstrate a reasonably good level of savings persistence, while others will degrade significantly. As a whole, however, it can be concluded that on average savings will degrade over time after retro-commissioning or follow up work is performed. Savings for heating, cooling, and non-cooling electricity use in the buildings studied declined by an average of 8%, 6% and 4% per year, respectively following commissioning without further intervention.

Therefore, follow up retro-commissioning work is a good idea in order to maintain savings levels. Through this follow up work, maintenance problems contributing to savings degradation can be identified, and building usage changes can be optimally dealt with for maximum efficiency. Improving retro-commissioning knowledge and technology also opens the door to improving savings levels beyond what was originally achieved, such as in the cases of implementing demand based reset schedules over those just based on outside air temperature.

The frequency with which retro-commissioning follow up should be performed in a facility largely depends on the facility. Its level of maintenance is a good indicator of how often follow up might be needed. Also, major changes in usage generally present appropriate opportunities for follow up. The best method for determining when follow up is needed is through energy monitoring, to identify unusual consumption patterns. This study also provided some exponential fit curves modeling average savings degradation over a five to seven year period. While every facility is different, these models have the potential to be useful in helping a facility owner determine how often to pursue retro-commissioning follow up, since degradation levels could be predicted.

More work is needed in order to determine how to apply the findings from this study to future commissioning projects. Something that may be considered for future work would be to consolidate the findings from all of the work done thus far on persistence of commissioning and retro-commissioning savings, including the current study, and determine if a general exponential decay model can be determined that would describe the degradation in savings that could be expected over time. As more data become available regarding persistence of savings, this model could become more and more useful for assisting building owners in determining the frequency with which retro-commissioning should be performed.

REFERENCES

Bourassa, N.J., M.A. Piette, N. Motegi. 2004. Evaluation of persistence of savings from SMUD Retro-commissioning Program - Final Report. Lawrence Berkeley National Laboratory, LBNL-54984.

Cho, Sool Yeon. 2002. The persistence of savings obtained from commissioning of existing buildings. M.S. Thesis, Mechanical Engineering Department, Texas A&M University, ESL-TR-02-05-01, 347 pp.

Chvala, W.D., Jr. 1995. Persistence of energy savings of lighting retrofit technologies at the Forrestal Building. Report prepared for the U.S. Department of Energy Federal Energy Management Program, 38 pp.

Claridge, D.E., W.D. Turner, M. Liu, S. Deng, G. Wei, C. Culp, H. Chen and S.Y. Cho. 2002. Is commissioning once enough? Solutions for Energy Security & Facility Management Challenges: Proc. of the 25th WEEC 29-36.

Claridge, D.E., W.D. Turner, M. Liu, S. Deng, G. Wei, C. Culp, H. Chen and S.Y. Cho. 2004. Is commissioning once enough? Energy Engineering 101(4):7-19.

Eardley, Mike. 2007. Persistence tracking in a retro-commissioning program. Proceedings of the 2007 National Conference on Building Commissioning.

Engan, Kenneth. 2007. A comparison of commissioning savings determination methodologies and the persistence of commissioning savings in three buildings. M.S. Thesis. Mechanical Engineering Department, Texas A&M University.

Friedman, H., A. Potter, T. Haasl and D. Claridge. 2002. Persistence of benefits from new building commissioning. Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings 3.129 – 3.140.

Friedman, H., A. Potter, T. Haasl, D. Claridge and S. Cho. 2003. Persistence of benefits from new building commissioning. Proc. of 11th National Conference on Building Commissioning 15 pp.

Friedman, H., A. Potter, T. Haasl, and D. Claridge. 2003. Report on strategies for improving persistence of commissioning benefits - final report. 47 pp.

Haberl, J. and S. Cho. 2004. Literature review of uncertainty of analysis methods (inverse model toolkit). Report to the Texas Commission on Environmental Quality. ESL-TR-04-10-03.

IPMVP 2007. IPMVP Committee. *International performance measurement & verification protocol: concepts and options for determining energy and water savings*, Vol. 1, April 2007, Efficiency Valuation Organization, EVO 10000-1.2007, 123 pp.

Kissock, J.K. 1993. A methodology to measure energy savings in commercial buildings. Ph.D. Dissertation, Mechanical Engineering Department, Texas A&M University, College Station, TX, December.

Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl and M. Piette. 2004. The cost-effectiveness of commercial buildings commissioning: A meta-analysis of energy and non-energy impacts in existing buildings and new construction in the United States. LBNL-56637.

Mills, E., N. Bourassa, M.A. Piette, H. Friedman, T. Haasl, T. Powell and D. Claridge. 2005. The Cost-effectiveness of commissioning new and existing commercial buildings: Lessons from 224 buildings. Proceedings of the 2005 National Conference on Building Commissioning.

Mills, Evan. 2009. Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions. Report prepared for California Energy Commission Public Interest Energy Research (PIER). 59 pp.

Peterson, Janice. 2005. Evaluation of retro-commissioning results after four years: A case study. Proceedings of the 2005 National Conference on Building Commissioning.

Ruch, D. and D. Claridge. 1992. A four-parameter change-point model for predicting energy consumption in commercial buildings. *ASME Journal of Solar Energy Engineering*, Vol. 114, No. 2, pp. 77 -83.

Selch, M. and J. Bradford. 2005. Recommissioning energy savings persistence. Proceedings of the 2005 National Conference on Building Commissioning.

Vine, Edward L. 1992. Persistence of Energy Savings: What Do We Know And How Can It Be Ensured? Energy 17(11):1073-1084.