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High Performance Commercial Building Systems

Persistence of Savings Obtained from Continuous Commissioning SM

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

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Synopsis

The persistence project is a study which investigates the savings in energy consumption of ten buildings that were commissioned between 1996 and 1997 by the Continuous Commissioning (CC^{SM}) group at the Energy Systems Laboratory (ESL) at Texas A&M University. All buildings selected for the study are on the Texas A&M campus, and none received major capital retrofits. This study determined how much energy and dollars the commissioned buildings have saved and how persistently the savings have been maintained after CC activities were completed.

The savings results have been calculated from hourly monitored thermal and electrical data by using E-Model, a program for data processing, graphing, and modeling energy consumption data. The models before CC were used as the baseline. As a whole, chilled water and electric savings have degraded a little over time, and hot water savings are about the same. Factors that affect energy use such as Energy Management Control System (EMCS) settings, are discussed in this paper. The EMCS settings are presented as pre-CC, post-CC, and current control schemes. In the overall study, chilled water savings have been degraded in the rate of 2.67% per year, electric savings decreased 0.67% per year, and hot water savings have stayed about the same since CC. Savings results averaged during the last four years are 40% for chilled water, 62% for hot water, and 11% for electricity. The total savings for the 10 buildings are $4,255,000. For all 10 buildings, as a whole, savings obtained from Continuous Commissioning have generally persisted since the Continuous Commissioning was completed.

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Introduction

The investigation of the persistence of savings obtained from Continuous Commissioning (CC^{SM}) was initiated to see if the buildings, which have been commissioned at least three years, are still being operated as commissioned. The approach used was to review the CC reports, determine the EMCS settings from the commissioning, determine the current EMCS settings from the controls system and then visit the buildings to verify the current building operation. If any controls were in manual operation, that was also noted.

Continuous Commissioning was started in 1993 by the Energy Systems Laboratory (ESL) and was initially funded by the Texas LoanSTAR program. CC began on the Texas A&M University campus during the summer of 1996. The implementation of CC on the Texas A&M campus and overall results of this program have been reported elsewhere (Claridge et al. 2000a and 2000b). The ESL had nine months of baseline energy consumption data from a building energy information system prior to the onset of commissioning. Ten buildings commissioned in 1996 and 1997 were investigated in this study to determine persistence. These 10 buildings had fairly complete building energy data, from which the annual savings could be determined.

On the Texas A&M University campus, like many campuses, there are a number of different groups with responsibility for maintaining the buildings. Area maintenance has the day-to-day responsibility for maintaining occupant comfort. The Energy Office has overall responsibility for the controls system and handles most of the central controls settings. The campus EMCS is a Siemens Apogee^{TM} system, and Siemens technicians have access to the buildings' controls systems, while working under the Energy Office. The ESL engineers and technicians work with all these entities during the CC process and also assist with troubleshooting comfort problems in buildings. All groups thus have access to all the buildings in this study and have contributed to the results of the original CC effort.

Typical Continuous Commissioning measures include sensor calibration, implementation of hot deck and cold deck temperature reset, static pressure resets, control of outside air, use of economizer cycles, air and water balances, and changes in terminal box airflow settings. The focus of this investigation is not on these detailed field histories of each building but rather on the main energy management control system (EMCS) for pre, post, and existing control settings and on the CC reports.

Energy use data from energy monitoring equipment were used to determine savings after CC, and the data before CC were used as the baseline. The ten buildings were divided into two groups, one group which showed good persistence and the other which shows poorer persistence. The reasons for the deviations are discussed, and strategies for maintaining the benefits of Continuous Commissioning are recommended in this paper.

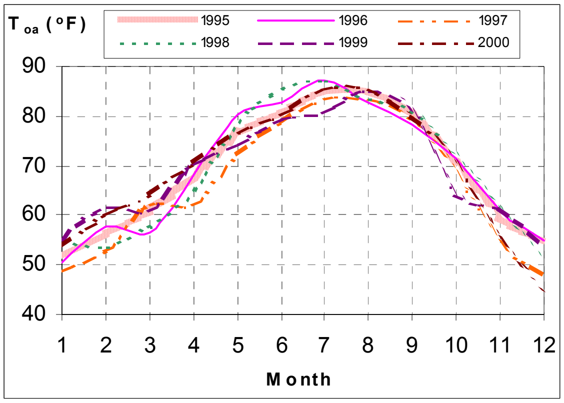
Procedure

The following is a description of the procedures that were followed in this study of persistence of savings obtained from Continuous Commissioning. First, the 10 buildings had to have at least three years history after CC. Second, the hourly monitored data set needed to be fairly complete with good baseline data and a well-documented CC report. Table 1 shows brief information for the 10 buildings.

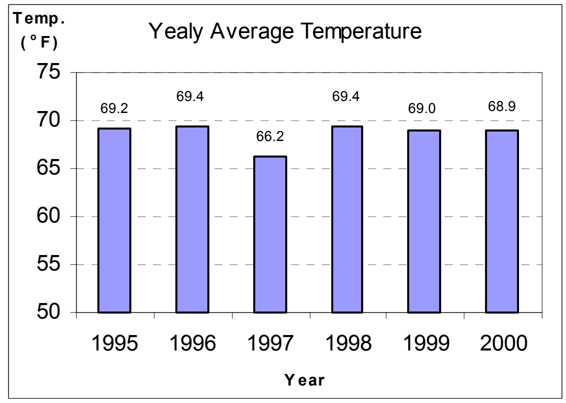
Table 1: Information for 10 Texas A&M University buildings selected for the study.

No.	Building Name	Area (ft^2)	HVAC System Types	CC Period
1	Blocker	255,490	10 DDVAV AHUs & 2 100% OA units 2 SDCV AHUs & 1 Liebert unit	2 / 97 - 4 / 97
2	Eller O&M	180,316	4 DD-Dual Fan VAV AHUs 2 CV MZ Units	2 / 97 - 3 / 97
3	G.R.White Coliseum	177,838	13 CV AHUs 5 SDCV AHUs with reheat coil (Pneumatic)	5 / 97 - 7 / 97
4	Harrington Tower	130,844	1 - 200 hp DDVAV AHU 3 smaller SD AHUs for 1st floor	7 / 96 - 8 / 96
5	Kleberg Building	165,031	2 x 100 hp SDVAV AHUs 2 x 25 hp return air fans	4 / 96 - 7 / 96
6	Koldus Building	97,920	5 SDVAV AHUs 5 SDCV AHUs	3 / 97 - 4 / 97
7	Rich. Petroleum	113,700	7 SDVAV AHUs 2 SDCV AHUs	9 / 96 - 9 / 96
8	Vet Med Center Addition	114,666	5 SDVAV AHUs 4 out of 5 AHUs are 100% OA	10/ 96 - 11/ 96
9	Wehner CBA	192,001	6 DDVAV AHUs 3 SDVAV AHUs	11/ 96 - 12/ 96
10	Zachry Engr Center	258,600	12 DD-Dual Fan VAV AHUs 3 SDCV AHUs	12/ 96 - 3 / 97

Energy consumption for pre-CC and post-CC periods have been determined on a yearly basis. However, to compare the performance of all 10 buildings with the pre-CC baseline, it was decided to use weather data for a common year. After comparing the years 1995 through 2000, it was decided to use 1995 as the “normal” year. Figure A shows the annual and monthly average temperatures for 1995-2000 in College Station, TX. The year 1995 not only had an average temperature nearest to the average for the period, but also the average temperature for every month was within the extremes for that month as well.



(a)



(b)

Figure A: College Station weather data during last six years.

CHW and HW energy consumption has been measured for each year, and three-parameter or four parameter change-point models of cooling and heating consumption have been determined as functions of ambient temperature by E-Model (Kissock et al., 1994), a program for data processing, graphing, and modeling energy consumption data. Basically, each building has five years of CHW and HW models, including the baseline model. The consumption was then normalized to 1995 weather by using the models for each year's data with the 1995 temperature data. There will be some differences between measured energy consumption and normalized energy consumption, but normalization removes variation due to weather differences. However, the measured electricity consumption data have been used since the buildings do not contain chillers and electricity consumption is only slightly affected by ambient temperature. The energy savings have been determined as the differences between the baseline consumption and the consumption for each year (all normalized to 1995 temperature data). Savings and trends have been investigated in the chronological order of pre-CC, post-CC, and current performance.

Savings after CC

As mentioned above, chilled water and hot water savings after CC were determined based on the 1995 weather data as the normal year, but electric savings were from actual data without weather normalization. Figure B shows the result of the savings for each building. All the ten buildings have reduced chilled water and hot water energy consumption since the CC activities, although the savings have degraded somewhat with time. For the electrical consumption, the Richardson Petroleum and the Wehner Buildings show negative savings of thirteen percent and seven percent, respectively.

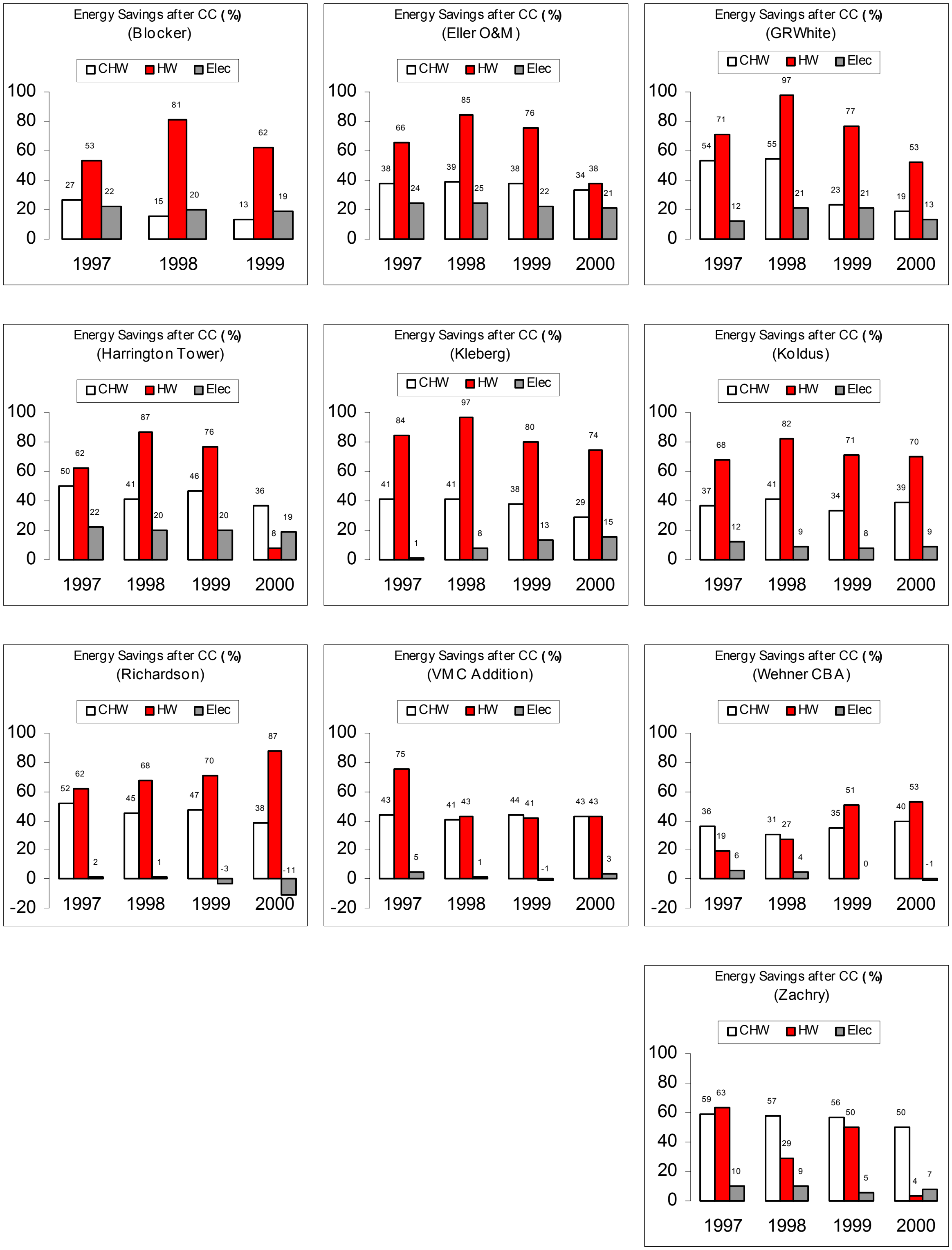
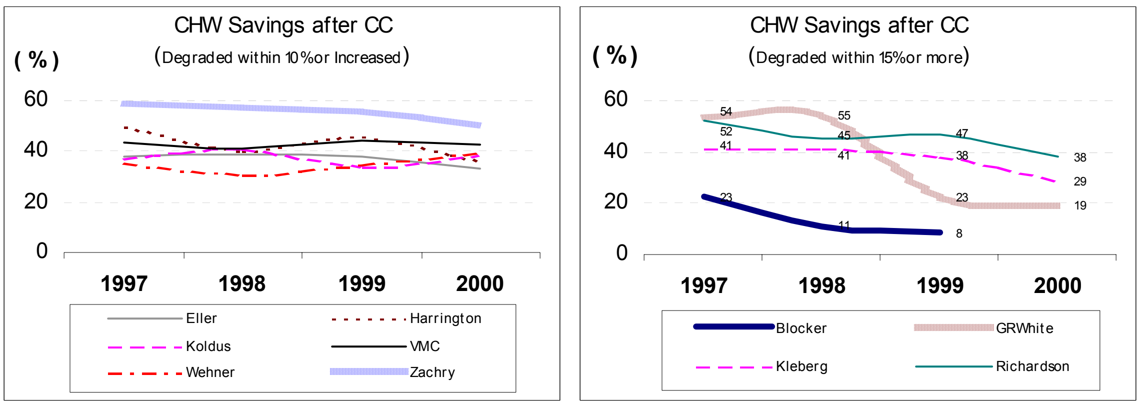


Figure B: Trends of energy savings results after CC activity for 10 buildings at Texas A&M University, College Station, TX.

Chilled Water Savings

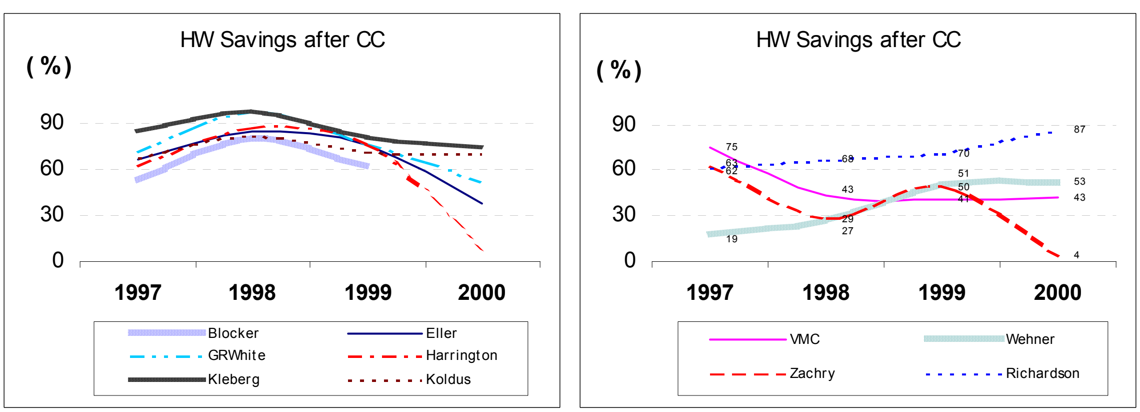
To see clearly the chilled water savings after CC, the ten buildings were divided into two groups, one for the buildings that show good persistence of savings (less than 10 % decrease during the 3~4 years after CC) and one for the buildings with significant degradation. Overall, chilled water savings average around 40% from the pre-CC baseline. Figure C(a) is the grouping of six buildings showing little degradation (or increased savings). Figure C(b) shows the four buildings with degraded performance.



(a) (b)

Figure C: Yearly CHW Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Hot Water Savings



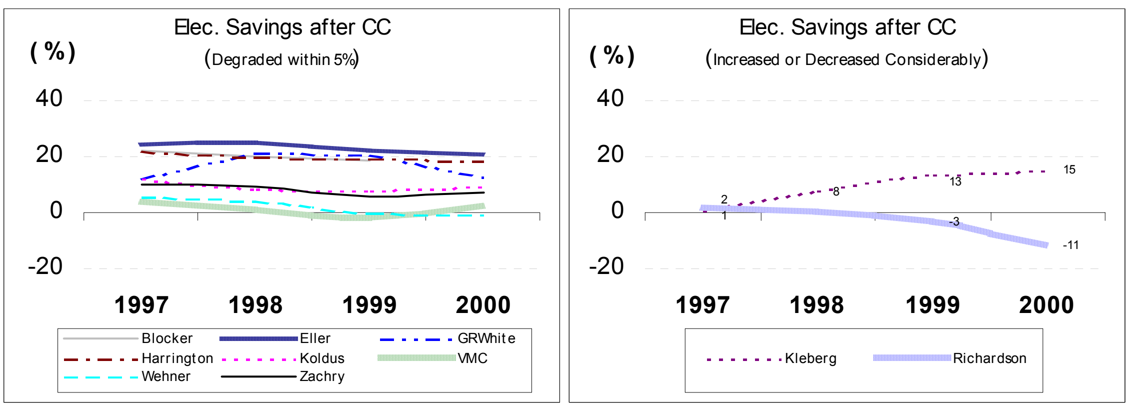
(a) (b)

Figure D: Yearly HW Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Hot water consumption has been significantly reduced since CC was performed, but the amount of the savings for each year fluctuates widely, making it difficult to determine annual trends. Figure D(a) shows the series of the six buildings with fairly consistent savings. Figure D(b) shows widely varying results for the HW savings. The buildings averaged hot water savings around 62 % after CC.

Electric Savings

Electric savings have been consistent for eight buildings after CC, as noted in Figure E(a), but two buildings display a wider range of variation, as noted in Figure E(b). One of these buildings shows increased savings over time after CC, and the other building (Richardson) has negative electrical savings overall.



(a) (b)

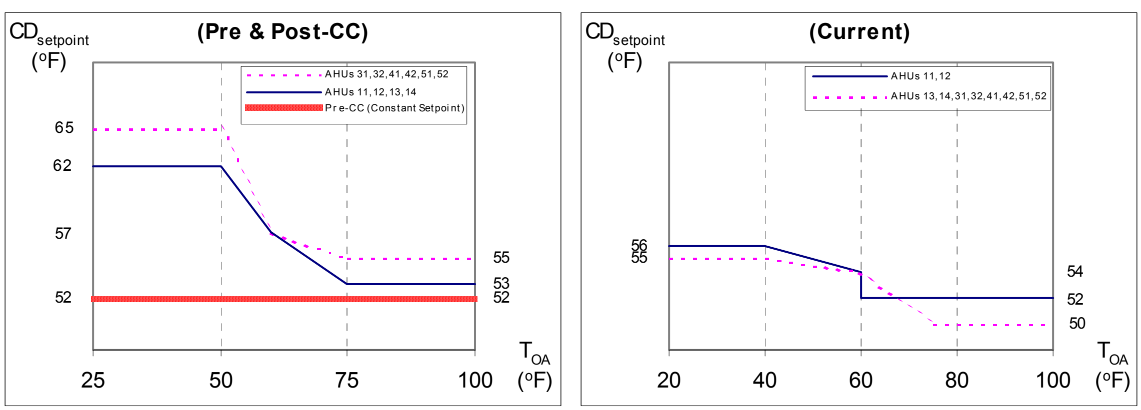
Figure E: Yearly Electric Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Comparisons between Pre, Post, and Current EMCS Settings

Checking and optimizing Energy Management Control System (EMCS) settings are some of the most important parts of CC activities. All buildings are being controlled by a Direct Digital Control (DDC) system, which has been installed by Siemens^{TM}. Many local settings, including cold deck and hot deck temperatures, and static pressures, are not only controlled and set with the computer, but also surveyed and measured by CC engineers in the field during CC activities. According to the CC measures implemented between 1996 and 1997 and based on existing control settings, some reasons for the savings trends could be found. In this section only some typical buildings are selected to show why the savings are going down.

Cold Deck / Discharge Temperature Settings

Cold deck or cooling coil discharge temperature settings affect CHW consumption. The Blocker Building is selected among the 10 buildings, since this building shows typical EMCS set-point histories and a relatively large degradation of savings after CC. All buildings, except the Koldus Building, currently have different set points which demand more energy than those set during the CC. As shown in Figure F(a), the cold deck set points for 10 AHUs in the Blocker building had been constant at 52 F and then were reset during CC; however, the reset points are not the same as current settings, and the current settings require more cooling. The exact history as to when the cold deck settings were changed is not known, but it is likely that several reset processes could have occurred since CC completion.

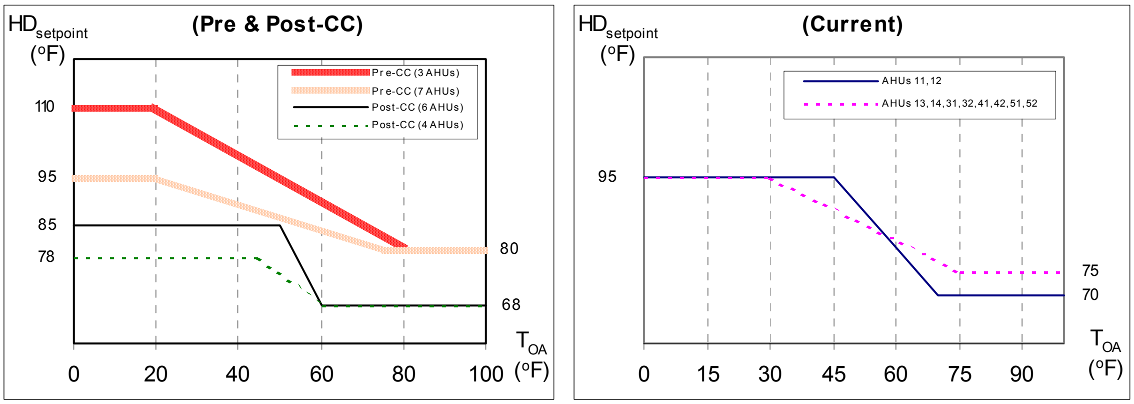


(a) (b)

Figure F: Comparison of pre-CC, post-CC, and current Cold Deck schedules in the Blocker Building.

Hot Deck Settings

Five out of the ten buildings have dual duct AHU systems; so these buildings have hot deck settings. Hot deck settings are one of the main factors affecting hot water consumption. Two buildings currently have the same hot deck settings implemented during CC, and the other three have different set points, which now call for more heating. The Blocker Building set points have been changed since the CC activity, as shown in Figure G, and demand more hot water during the entire year. The hot deck temperature settings for the summer may not cause higher consumption because many of the area maintenance operations staff will manually turn off the hot water valves in the summer.

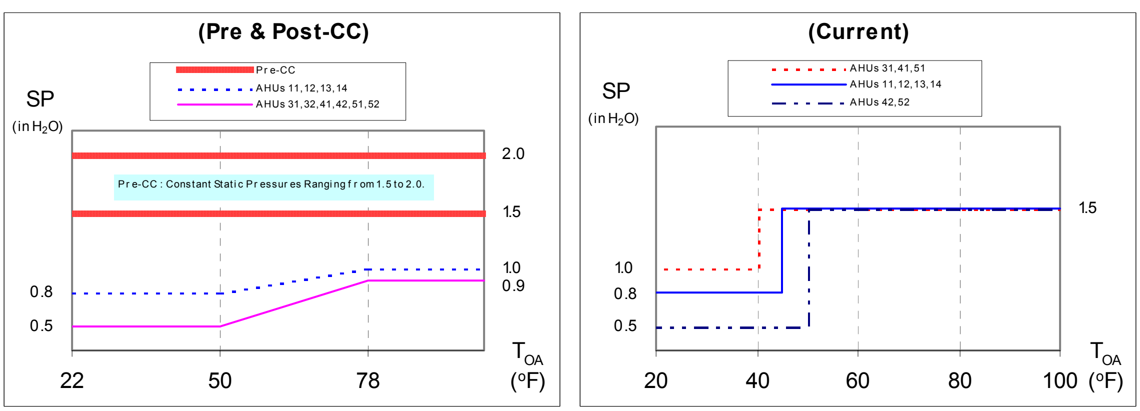


(a) (b)

Figure G: Comparison of pre-CC, post-CC, and current Hot Deck schedules in the Blocker Building pre-CC, post-CC.

Static Pressure Settings

Static pressure settings can affect not only CHW and HW consumption, but also electricity consumption.



(a) (b)

Figure H: Comparison of pre-CC, post-CC, and current Static Pressure schedules in the Blocker Building.

There are eight buildings equipped with Variable Air Volume (VAV) AHU systems. The Koldus Building has had the same settings since CC activity, but the others show that current settings demand more static pressure, which means cooling, heating, and electrical demands have been increased over time. Figure H(a) has the pre and post-CC settings for the Blocker Building, and Figure H(b) shows the current static pressure settings for the various air handlers.

Other Settings

Building differential pressure settings and control of outside air are also important CC measures to save energy and to maintain comfort. These control schemes generally have not been changed after CC. Some buildings also have economizer cycles to achieve comfortable conditions by using ambient air without refrigeration. The Harrington Tower, for example, uses two types of economizers, one temperature-controlled and one enthalpy-controlled. Changes in these parameters will impact the CC energy consumption, but these have not been investigated in detail for this paper.

Persistence Analysis

The 10 buildings investigated here were commissioned only and did not have any major retrofits other than controls upgrades. Table 2 summarizes the cost saving results for all 10 buildings. Energy cost savings were calculated by using the historic campus energy costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for hot water, and $0.02788/KWh for electricity.

Cost savings for the first year of 10 buildings after CC were $1,126,000 and, based on this number, if we assume this reduction persisted, the calculated savings for four years after CC, (3 years for the Blocker building), would be $4,422,000. The averaged savings after CC, $4,255,000, were a little lower than that. As seen in Table 2, only two buildings, Kleberg and Wehner, have saved more money per year since the CC process than the first year right after CC. The savings of the other buildings have decreased.

Chilled water savings for all 10 buildings for the first year after CC came to an average of 44%, hot water savings 62%, and electric savings 12%. On the other hand, chilled water savings since CC activities averaged 40%, hot water savings averaged 62%, and electric savings averaged 11%. Hot water savings have maintained the same rate of savings during the last 4 years after CC process. These numbers above represent a successful result of persistence of savings obtained from Continuous Commissioning activities. These buildings have been followed-up after commissioning, recalibrating EMCS settings, troubleshooting some problems, and monitoring the energy use on a regular basis. Texas A&M University has been adding more students to the campus for the past several years, which could add additional occupant and plug-loads. This is one of the main factors increasing energy demand.

Table 2: Cost savings calculations for the first year and 4 year average after CC activity

No.	Buildings	Type	Baseline Energy Use	First Year(1997) after CC				4 yrs Avg. after CC
				Energy Use	Savings	Cost Savings		
					MMBtu/yr	Each $/yr	Total $/yr	Total $/yr
1	Blocker	CHW	21974	16924	5050	$ 23,583	$ 75,175	$ 68,515 *
		HW	8735	4093	4643	$ 22,054		
		Elec (KWh)	4832440	3772959	1059481	$ 29,538		
2	Eller O&M	CHW	30632	18946	11686	$ 54,573	$ 111,626	$108,346
		HW	7584	2578	5005	$ 23,776		
		Elec (KWh)	4891451	3697901	1193550	$ 33,276		
3	G.R.White Coliseum	CHW	18872	8717	10155	$ 47,422	$ 124,750	$115,570
		HW	21295	6091	15205	$ 72,222		
		Elec (KWh)	1480499	1297385	183114	$ 5,105		
4	Harrington Tower	CHW	14181	7104	7077	$ 33,049	$ 63,739	$ 57,054
		HW	6896	2603	4293	$ 20,394		
		Elec (KWh)	1666050	1296727	369323	$ 10,297		
5	Kleberg Building	CHW	59271	34864	24407	$ 113,979	$ 278,303	$279,930
		HW	40812	6523	34289	$ 162,871		
		Elec (KWh)	5510592	5458473	52119	$ 1,453		
6	Koldus Building	CHW	19265	12182	7083	$ 33,076	$ 49,519	$ 48,823
		HW	2176	704	1472	$ 6,993		
		Elec (KWh)	2850190	2511244	338946	$ 9,450		
7	Richardson Petroleum	CHW	28526	13599	14927	$ 69,707	$ 121,576	$118,250
		HW	17277	6565	10712	$ 50,884		
		Elec(KWh)	1933040	1897734	35306	$ 984		
8	VMC Addition	CHW	40892	23115	17777	$ 83,017	$ 101,059	$ 92,649
		HW	3569	887	2682	$ 12,739		
		Elec(KWh)	4185825	3995579	190245	$ 5,304		
9	Wehner CBA	CHW	19193	12327	6865	$ 32,061	$ 48,038	$ 56,889
		HW	13393	10876	2517	$ 11,956		
		Elec(KWh)	2554720	2410493	144227	$ 4,021		
10	Zachry Engr Center	CHW	40830	16714	24116	$ 112,622	$ 146,494	$130,730
		HW	4415	1630	2785	$ 13,229		
		Elec(KWh)	7502371	6761957	740414	$ 20,643		

* This cost saving is based on 3 years average after CC

Conclusions & Recommendations

Continuous Commissioning consists of a large number of tasks that take substantial time and effort to maintain building mechanical and control equipment. This investigation of the persistence of savings obtained from Continuous Commissioning found that the savings have slowly degraded over the years, but are still saving large amounts of money and energy annually. Results of the 10 buildings on the Texas A&M University campus at College Station showed cumulative savings of $4,255,000 during the last four years after CC. The results from this study demonstrates to the building owners (Texas A&M) that their commissioning investment has not significantly degraded over time, but it does indicate that CC settings should be verified periodically.

Acknowledgements

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References

Claridge, D.E., Culp, C.H., Deng, S., Turner, W.D., Haberl, J.S., and Liu, M., 2000a. "Continuous Commissioning of a University Campus," *Proc. of 8th National Conference on Building Commissioning*, Kansas City, MO, May 3-5, pp. 12.1 - 12.9.

Claridge, D.E., Culp, C.H., Liu, M., Deng, S., Turner, W.D., and Haberl, J.S., 2000b. "Campus-Wide Continuous Commissioning^{SM} of University Buildings," *Proc. of ACEEE 2000 Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, Aug. 20-25, pp. 3.101-3.112.

Kissock, K., Wu, E., Sparks, R., Claridge, D., Mahoney, J., and Haberl, J., 1994. *Users Manual for Emodel Version 1.4*, ESL-SW-94/12-01, Energy Systems Laboratory, Texas A&M University.