Implementation of Continuous Commissioning in the Texas LoanSTAR Program: ‘‘Can You Achieve 150% of Estimated Retrofit Savings’’ Revisited

David E. Claridge, Mingsheng Liu, Yeqiao Zhu, Mustafa Abbas, Aamer Athar, and Jeff Haberl, Texas A&M University

A 1994 ACEEE Summer Study paper (Claridge, et al. 1994) presented a number of case studies which led to development of a methodology for following the retrofits in the Texas LoanSTAR Program with a comprehensive O&M program (now called Continuous Commissioning) which identified operating improvements using measured hourly energy consumption data. It concluded by suggesting that it was realistic to achieve 150% of the audit estimated retrofit savings in a program when the capital retrofit measures were followed by a comprehensive recommissioning program. This paper provides a follow-up on the 16 LoanSTAR buildings discussed in the earlier paper and summarizes the overall savings in the Texas LoanSTAR Program. The program wide measured savings are now 149% of the audit estimated savings. If only the buildings where continuous commissioning has been fully implemented are considered, the combined continuous commissioning and retrofit savings exceed 200% of the audit estimates.

INTRODUCTION

Two papers were presented at the 1994 ACEEE Summer Study (Claridge et al., 1994 and Liu et al. 1994c) which described the development and use of a procedure that uses measured hourly, whole-building energy consumption data to identify and aid implementation of operational improvements in buildings. These papers included ongoing experience with 16 case-study buildings at four sites. The process for identifying and implementing operational improvements was called ‘‘recommissioning’’ or the ‘‘O&M process’’ in the earlier papers. It is now called ‘‘continuous commissioning’’ (CC) to reflect the value of continuing interaction with building operators in achieving and maintaining a finely tuned building.

The buildings investigated in this paper have all participated in the Texas LoanSTAR program. This program is a $98.6 million revolving loan program administered by the State Energy Conservation Office, which retrofits state, local government, and school district buildings within Texas (Verdict, et al., 1990). The buildings retrofit under this program have savings reported based on hourly monitoring of energy consumption and follow-up assistance with fine tuning building operation through the continuous commissioning program.

This paper provides an update on the progress of continuous commissioning in these buildings over the last two years and relates the experience in these buildings to the overall savings within the LoanSTAR Program.

CONTINUOUS COMMISSIONING CASE STUDIES

Four case study sites are considered in this paper. The first is a group of eight buildings in the Texas State Capitol Complex where a number of shut-off measures were proposed in 1992. The second site is two schools which had lighting retrofits performed followed by recommendations for recommissioning their EMCS systems. The third site is a group of five buildings on a medical school campus on the Gulf Coast of Texas, while the last building is part of a large medical complex in Houston, Texas. The last two sites received assistance with the utilization of their EMCS systems to further optimize operation of their facilities.

State Government Buildings

During the Fall of 1992 a comprehensive survey was conducted on eight state government buildings in Austin, Texas to determine potential opportunities for operating improvements (Houcek et al. 1993). None of the buildings had been retrofitted with energy conservation reduction measures (ECRMs), but over $3,000,000 in retrofits were scheduled for these buildings. Hence, the measures investigated for these buildings were primarily shut-off opportunities.

Shut-down Opportunities Identified. The buildings examined ranged in size from 80,000 to 491,000 ft^2 with a total area of approximately 2.2 million ft^2. The annual energy costs varied from $129,736 to $1,117,585, totaling more than $4.2 million for the eight buildings, based on utility billing data from September 1, 1990 through August 31,

Table 1. *Summary of the Shut-Down Savings Opportunities Identified in the 1992 Study of Government Buildings in the Texas State Capitol (Claridge et al., 1994)*

Building ID Code	Air Handling Units	Exhaust Fans	PCs and Office Machines	Lights	Potential Savings ($/year)
SFA	$138,500	$1,500	$15,500	$6,900	$162,400
LBJ	94,800	1,300	28,300	10,900	135,300
WBT	69,700	3,800	17,900	10,900	102,300
JER	24,900	-0-	2,900	3,500	31,300
JHR	-0-	-0-	6,100	8,200	26,000
INS	-0-	-0-	3,700	4,300	14,300
ARC	-0-	-0-	4,300	2,400	8,000
JHW	-0-	-0-	18,100	7,900	6,700
Potential Savings ($/year)	$327,900	$6,600	$96,800	$55,000	$486,300

1991. The shut-down opportunities identified in these eight buildings had potential annual savings of $486,300 (11.5% of total energy cost) as shown in Table 1. The potential savings due to air handler and exhaust fan shut-down (including reduced heating and cooling expense) accounted for 69% of the potential savings. Turning off lights and office machines accounted for the remaining 31% of the potential savings.

The earlier papers reported that partial night shut-down of the SFA building was initiated in the Fall of 1993 following a sequence of meetings with facilities personnel. This was followed by increasing levels of shut-down until savings of approximately $300/day were achieved during early 1984. $200/day were electricity and chilled water savings which were measured and the other $100/day were estimated steam savings.

The night shut-downs in the SFA building have continued but were scaled back due to complaints by some agency heads. They wanted the HVAC systems operating late into the evening in case anyone had to work late. The shut-downs have saved $65,834 in electricity and cooling energy through December, 1995, as shown in Table 2. Installation of variable speed drives, interior lighting control, changeout of incandescent to fluorescent lights, and pumping and piping modifications were carried out from September, 1994 through

Table 2. *Summary of the Cumulative Measured Retrofit and Shut-Down Savings Realized in Eight State Government Buildings*

Building ID Code	Retrofit Savings	Shut-Down Savings	Total Savings
SFA	$302,013	$65,834	$367,847
LBJ	$320,218	-0-	$320,218
WBT	-0-	-0-	-0-
JER	$5,898	-0-	$5,898
JHR	$37,949	-0-	$37,949
INS	$48,705	-0-	$48.705
ARC	$2.098	-0-	$2.098
JHW	$189,354	-0-	$189,354
Totals	$906,235	$65,834	$972,069

September, 1995. These retrofits have saved an additional $302,013 in the SFA Building.

Shut-downs were tried for a few days in the LBJ Building during 1994, but facilities personnel were reluctant to continue these manual shut-downs. Since LBJ and the other buildings were scheduled for EMCS installations/upgrades, no shut-downs were implemented in these buildings. However, a variety of retrofit measures including EMCS controlled night shut-downs, reductions in outside air, domestic HW pump shut-downs, occupancy sensors, hot/cold deck reset, and lighting retrofits were installed in the other seven buildings during 1993–94. These retrofits have resulted in cumulative measured savings of $906,235 through December, 1995 as shown in Table 2.

The continuous commissioning story at this site does not end here. During 1995, the CC engineers revisited the facility and found that there were numerous opportunities for operating improvements in the LBJ Building. These included lowering the duct static pressure, improving the cold deck schedule and reducing pumping power. They also found that several heating and cooling coil thermostats needed replacement or calibration, and valves needed controllers before the operating improvements could be implemented. These controllers and thermostats subsequently replaced a $500,000 retrofit project at a cost of only $12,000 and are expected to save $133,600/year. This is about 90% of the proposed retrofit project savings.

More importantly to the overall program, the working relationship begun with this effort proved extremely valuable. The facility engineer told the CC team about another 99,000 ft^2 building where he was having problems with high room humidity levels and high positive pressure. The high positive pressure had caused security problems by keeping doors from closing when they were opened. To remedy this, the operators had cut a four-foot square hole in the side of the building to lower the pressure!

The building was served by dual duct constant volume systems with a design supply flow of 1.1 cfm/ft^2. The CC team conducted a number of measurements in the building and found that the total supply air flow rate was more than 1.4 cfm/ft^2 and that the building was operated at a positive pressure of 0.1/0.15 in-H_2O. In addition, the building was operating with over 55% outside air. Discussion with the facility engineer revealed that there had been earlier complaints of exhaust odors from an adjacent parking garage. The high outside air fraction and large flow rate had been implemented to solve this problem, following consultation with an IAQ engineer.

The excessive supply air had the following negative results. It

(1) resulted in a need for increased supply temperatures;

(2) this required more hot deck air which increased both HW and CHW consumption; and

(3) the additional hot deck air was not dehumidified and resulted in occasional humidity levels as high as 68%.

It was recommended that supply air be reduced to 0.85 cfm/ft^2 and outside air to 0.1 cfm/ft^2. It was also suggested that hot deck temperature be reduced and that cold deck temperature be increased when ambient temperatures are below 60°F. These measures were implemented and humidity levels dropped below 55% in all rooms and the positive pressure was reduced to well below 0.1 in-H_2O. The energy consumption in the building was also reduced by an average of $4,170/month (31%) during the first five months following implementation of these operating changes!

The success of this effort has led the facilities staff to enthusiastically cooperate with the CC team in additional buildings. This work will be reported elsewhere.

School District

In 1991, the LoanSTAR Program funded conversion of four-lamp fixtures to two-lamp fixtures with reflectors in 45 schools in a large school district in north Texas. Based on LoanSTAR monitoring budget guidelines, two of these schools had hourly monitoring equipment installed to meter the electricity and gas consumption with submetering of the lighting circuits. when the subsequent lighting savings in the two schools monitored were only half to two-thirds the predicted levels, the CC team investigated. As reported earlier, they found the opportunities shown in Table 3 (Liu et al. 1993a, 1993b, 1994c)

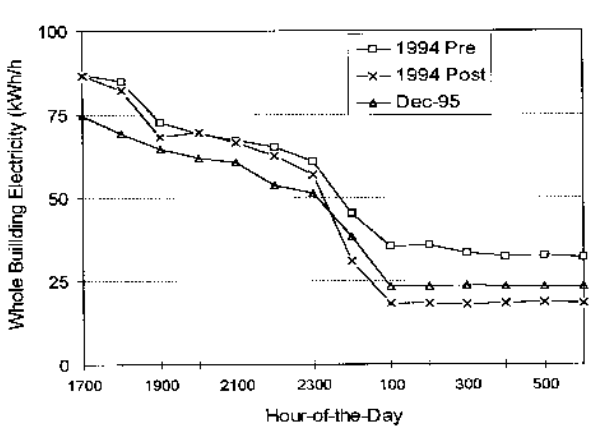
Implementation efforts were successful in one of the schools (DMS), but unsuccessful in the other (SES). Subsequent investigation revealed that the central EMCS had been disabled in SES—and in a large majority of the other schools in the district. The potential savings to the school district of repairing the system were estimated to be approximately $1.5 million/year and the school district hired a contractor to repair the systems.

Subsequently, no changes were observed in the consumption at SES and we learned that the district had decided to upgrade the EMCS system while repairing it. It came back on line one year after the night shut-downs were implemented at DMS, and has performed very well. Figure 1 shows the average hourly electricity consumption at this school for the weekday ‘‘unoccupied hours for the week immediately preceding implementation (1994 Pre), the week immediately following implementation (1994 Post) and a week in Decem-

__Table 3.__ Summary of Potential CC Savings for Two Monitored Schools (Claridge et al., 1994)

Item	Annual Savings	Note
Gas	$4,952	Turn off HVAC system by EMCS
Other-than-lighting Electricity	$43,063	Turn off HVAC system by EMCS, install time clock on compact and window A/Cs
Daytime Lighting	$681	Install motion sensors in auditorium, gymnasium, and activity center
Evening Lighting	$4,728	Turn off lights where custodians are not working
Night Lighting	$3,723	Turn off lights when custodians leave
Total	$57,147	

***Figure 1.** Average SES hourly weekday electricity consumption during unoccupied hours for three weeks during 1994 and 1995.*



ber, 1995 (Dec-95). 1995 electricity savings from the HVAC shut-off at the two schools totaled $35,279. These savings are somewhat below the projected $40,000/year, because the district has started operating the schools during the summer since the original projections were made. But the CC savings are still more than three times the $10,521 realized by the lighting retrofits during 1995. The combined $45,800 savings from the retrofits and HVAC shut-off were 246% of the audit estimated retrofit savings of $18,641.

However, no further implementation efforts were made in the district by the middle of 1995. Inquiries revealed that that the school district had spent approximately $40,000 on the EMCS at SES, and didn't feel they had the money available for similar expenditures at other schools.

The CC team then offered to work with the facilities crews to make the other systems operational. They eventually learned that most of the systems had been disabled following complaints when requests for evening HVAC hadn't been properly implemented or because suitable room comfort conditions were not being maintained during normal occupied hours. Consequently, the O&M staff began working with the facilities personnel to identify the source of numerous hot/cold problems in the schools, to improve system operations and to implement late-night shut-downs. The CC team coordinated efforts of the facility staff to improve the EMCS operating schedule and initiated reconnection of all relays which had been disabled. This effort will save the district about $500,000/year when fully implemented. The facilities staff is enthusiastic about this approach, because it promises to both solve some of their problems and to reduce operating costs. However, implementation has again been slow—this time due to the district administration's reluctance to make it a priority.

Medical School Research Center

Five buildings with a total floor area of 779,000 ft^2 at a large medical school research center in Southeast Texas received retrofits under the program. These buildings had a total annual energy bill of $2,709,000 following the retrofits for an average cost of $3.48/$ft^2$ as shown in Table 4. Two of the buildings are hospitals, two are laboratory/classroom buildings and one is a medical research library. The major retrofit implemented in all five buildings was installation of energy management and control systems (EMCS) which provide monitoring, temperature control, start/stop control of major AHUs and pumps, and control of some lighting (Liu, et al. 1993c).

All of the buildings at the Medical Center are operated continuously and the library has critical temperature/humidity requirements since it contains a major rare books collection. Examination of these buildings found that the limited opportunities for start/stop control had been implemented and that lighting levels were generally appropriate, although hallway lighting levels in one building (JSS) substantially exceed IES standard levels and delamping in this building offers the potential for annual savings of $45,900.

Table 4. *Energy Use Characteristics of Five Medical Center Buildings (Claridge et al., 1994)*

Building Type	*JSN* Hospital In-patient	*CSB* Lab & Class	*BSB* Lab & Class	*MLB* Library	*JSS* Hospital	*Total*
Floor Area (ft^2)	75,700*	124,900	137,900	67,400	373,000	778,800
Thermal Energy ($/yr)	$405,300	$235,300	$573,900	$153,200	$759,000	$2,126,600
Electricity ($/yr)	$96,800	$115,200	$97,000	$41,800	$231,600	$582,400
Total Energy ($/yr)	$502,100	$350,500	$670,900	$194,900	$990,600	$2,709,000
Total Energy ($/ft^{2}· yr)	$6.64	$2.81	$4.87	$2.89	$2.65	$3.48

*Including a kitchen area (18,000 ft^2)

The HVAC systems in three of these buildings (CSB, JSS and JSN) are dual duct constant volume systems. They use 50%–100% outside air because of medical requirements, and humidity levels are high at this Gulf of Mexico location, so the systems also utilize a ‘‘precooling’’ coil, to reduce mixed air humidity levels. This permits the main cooling coil to primarily provide sensible cooling. A portion of one building (JSN) has a single duct constant volume system using 100% outside air and the other two buildings use a hybrid system which is basically a constant volume reheat system, except it uses a single heating coil to provide reheat to all zones.

The requirements for continuous operation and for very high outside air fractions severely limit the effectiveness of most traditional O&M measures. However, these factors lead to the relatively high operating costs shown in Table 4 and combine to create greater opportunities for optimization of the air handling systems.

Optimization of the AHU hot deck and cold deck setpoint schedules by lowering hot deck temperatures and raising cold deck temperatures to the maximum extent feasible was performed in these buildings using procedures described elsewhere (Liu et al., 1993c, 1994b, 1994c). It was reported (Claridge et al. 1994) that implementation of improved schedules in the BSB building had saved $42,600 for the first 117 days following implementation in 1993 which was consistent with the annual savings of $156,000 predicted for this building.

The $517,800/yr in savings opportunities identified for this site through improved hot deck/cold deck reset schedules or commissioning of the EMCS are shown in Table 5. Note that these opportunities correspond to 19% of the energy consumption of these buildings and an additional $74,000/yr in opportunities were identified for implementation of an economizer in MLB and delamping in JSN.

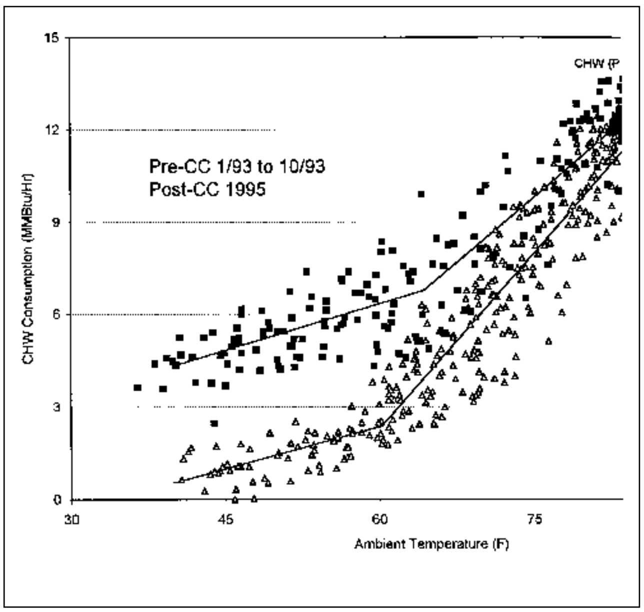
The optimized deck schedules were implemented in all of the buildings except MLB, the research library. Concerns about any change in humidity levels prevented implementation here, but it was possible to reduce steam and chilled water use during unoccupied hours by valving off portions of the building. The initial implementation in the CSB and JSS buildings were not fully successful due to leaky hot deck dampers and high static pressure in the ducts. These problems were solved by installing hot air dampers in the main hot air ducts (Liu et al., 1996). The results of the CC effort in the JSS Building are shown in Figure 2. This figure plots the daily values of average hourly chilled water and hot water consumption for the year preceding the start of CC (Pre-CC 1993) and for calendar year 1995 (Post-CC 1995). Best-fit two-parameter and four-parameter regression lines are fit to each set of data as appropriate to clarify the reductions due to the CC effort. The JSS Building has saved $166,342/year, or 17% of its previous consumption, since implementation of the CC measures in 1994.

The measured cost savings in these five buildings due to continuous commissioning measures are summarized in Table 6. The table shows the average annualized CC savings for each building since the CC measures were implemented. These results come from measures implemented for as little as three months and as long as 30 months. The average savings due to the CC measures in these five buildings are 22.5% of previous consumption. The annualized measured retrofit savings in these buildings are $213,479, or 79% of the

Table 5. Summary of Potential Cost Savings at Five Medical Center Buildings Due to Optimized Hot Deck and Cold Deck Schedules (Claridge et al., 1994)

Savings	JSN	CSB	BSB	MLB	JSS	Total
Chilled water $/yr	$54,300	$55,700	$108,700	$27,700	$124,500	$370,900
Condensate $/yr	$12,700	$18,000	$47,300	$18,800	$50,100	$146,900
Total $/yr	$67,000	$73,700	$156,000	$46,500	$174,600	$517,800
$/ft²yr	0.84	0.59	1.13	0.69	0.47	0.66
%	13%	21%	23%	24%	18%	19%

Figure 2. *Average daily values of hourly chilled water and hot water consumption for a medical research center building for 1995 and for the year prior to implementation of continuous commissioning in the building.*



audit estimated savings of $271,328/year for the measures implemented. The combined annual savings of $823,122 are 303% of the audit estimated retrofit savings.

Medical Research Building

In a large medical school facility in Houston another building was studied. This facility is an 8-floor, 120,370 ft² medical research facility built in 1986. The building exhibits many of the factors present in the previous medical research center case study: the building is in continuous use, has very high outdoor air fraction and has stringent temperature and humidity requirements because it contains extensive animal research laboratories.

The major difference between this facility and the preceding center was the more aggressive energy management program in place at this center for several years. All fluorescent fixtures were changed to T-8 lamps with electronic ballasts and reflectors, and virtually all incandescent lights were replaced with screw-in fluorescents in 1991. The water loop and air handlers were commissioned in November, 1992 with measured savings in the first year of $145,700 (7915 MMBtu chilled water, 9957 MMBtu steam). Cold-deck reset with ambient temperature was implemented in November, 1993 resulting in measured savings of $62,600 (3723 MMBtu chilled water, 3974 MMBtu steam) during the first two months (Liu et al. 1994b).

Consequently, when the CC team visited this facility in January, 1994, the facility energy management staff primarily expressed interest in obtaining case study examples of the safety and reliability of variable-flow fume hoods and documentation of the effectiveness of medical incinerators to counter objections to the operation of such a facility in an urban environment.

However, subsequent examination of the building and its systems found three major opportunities as shown in Table 7. Cold decks were operating 2-4 °F below their set-points due to sensor calibration problems. This was costing an estimated $111,000 per year. An ''optimized'' reset schedule for the cold deck and hot deck which increased cold deck temperatures in cool weather and decreased hot deck temperatures in warm weather could produce additional savings of $143,053 per year. It was also observed that air exchange rates in much of the building were higher than those required

Table 6. *Summary of Measured Cost Savings at Five Medical Center Buildings Due to CC Measures from Implementation Date Through December, 1995.*

Savings	JSN	CSB	BSB	MLB	JSS	Total
Annualized ($/yr)	$164,320	$50,752	$193,900	$34,329	$166,342	$609,643
$/ft^2-yr	2.17	0.41	1.41	0.51	0.445	0.78
Per Cent	33%	14%	29%	18%	17%	22.5%
Months Implemented	27	3	30	13	16	

Table 7. *Summary of Potential CC Savings in a Medical Research Building*

	Electricity		*Condensate*		*CHW*		*Total*
CC Measure	MMkWh	Dollars	MMBtu	Dollars	MMBtu	Dollars	Dollars
1. Sensor Calibration			6,072	$48,576	7,523	$62,441	$111,017
2. Optimized Schedule			5,830	$46,640	11,616	$96,413	$143,053
3. Reduced CFM	1.332	$39,962	5,014	$40,112	4,913	$40,778	$120,852
Total	1.332	$39,962	16,916	$135,328	24,052	$199,632	$374,922

Note: The annualized cost savings were calculated using the following energy prices: $8.30/MMBtu for chilled water, $8.00/MMBtu for condensate, and $0.03/kWh for electricity.

by the ASHRAE Standard (ASHRAE 1991) for laboratory spaces and that reduced air flow rates had the potential to save an additional $120,852/year.

The facility staff subsequently implemented optimized outside air reset and cold deck reset, repaired the valve, and commissioned the water loop and AHUs. These CC measures have dramatically reduced the CHW consumption as shown in Figure 3. The figure shows daily values of hourly average consumption for January through October 1993 (Pre-CC) and for 1995 (Post-CC). The lines are four-parameter regression fits to the data. Figure 4 shows the same data and models for HW consumption. It is evident that two years after CC began, thermal savings are typically 2-3 MMBtu/hour. The measured annualized 25-month CC savings through December 1995 at this building are $195,869/year. This building is part of a larger complex, and audit estimated retrofit savings are not available for this building individually. However, for the complex, measured retrofit savings are 125% of audit estimates and CC savings increase this to 211% of audit estimated savings.

SUMMARY RESULTS OF CONTINUOUS COMMISSIONING IMPLEMENTED IN 16 BUILDINGS

This paper has described the progress and the specific savings levels realized in a set of 16 buildings which were discussed at the 1994 ACEEE Summer Study. The dollar value of the CC measures identified in the 1994 paper and the measured CC savings realized in these buildings are shown in Table 8.

In the eight State Office buildings, only 6% of the original O&M shut-off measures identified were ever implemented, due to reluctance to engage in manual shut-offs and occupant resistance to evening shut-offs. However, the working rela-

Figure 3. *Average daily values of hourly chilled water consumption for a medical research building for 1995 and for the 10-months prior to implementation of continuous commissioning in the building.*

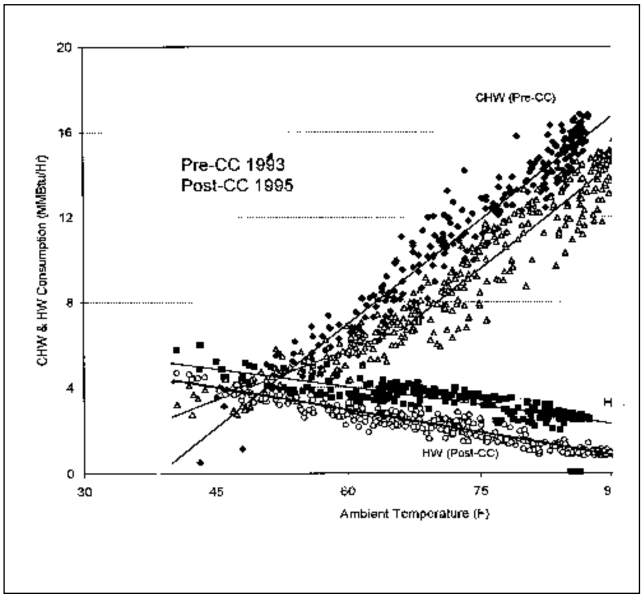
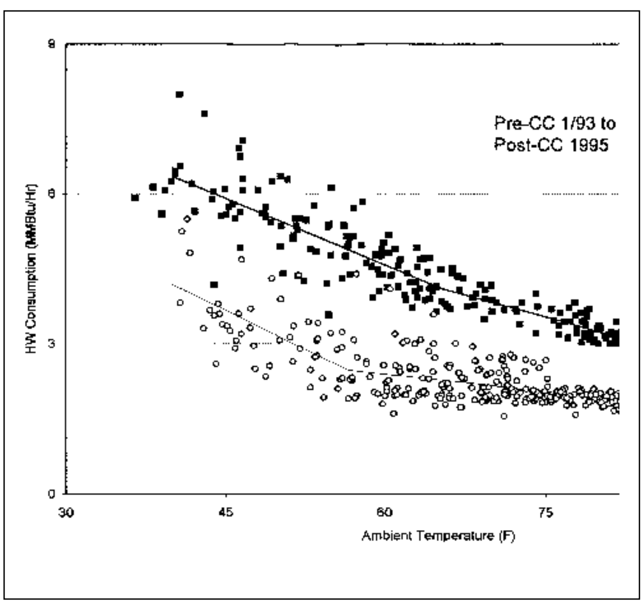


Figure 4. *Average daily values of hourly hot water consumption for a medical research building for 1995 and for the 10-months prior to implementation of continuous commissioning in the building.*



tionship developed over the past two years and resolution of problems the operators had in two other buildings has resulted in enthusiastic participation of most facility staff members in a renewed effort to recommission these systems which has resulted in savings of over $100,000/year in other buildings. It seems likely that over the next year or so, total savings at this complex will approach or exceed the $486,00/year from the measures originally identified, but not implemented.

At the second site, the two schools have successfully realized about two-thirds of the savings opportunities identified in the original study. The Medical Center has successfully implemented CC measures which are saving 18% more than the original estimates. The other medical research building is realizing slightly over half the savings potential identified.

The CC measures implemented in the 16 buildings discussed have resulted in $863,928/year in measured savings. This is 60% of the original CC estimate, but for the three sites where implementation is complete, measured CC savings are 88% of the initial estimates. When the CC savings are added to the retrofit savings for the three sites where implementation is complete, the sum of retrofit savings and CC savings exceeds 200% of the audit estimated savings at each site.

CONTINUOUS COMMISSIONING SAVINGS IN THE LOANSTAR PROGRAM

It was suggested two years ago that it was realistic to achieve 150% of the audit estimated retrofit savings in a program when the capital retrofit measures were combined with a comprehensive recommissioning program (Claridge, et al. 1994). This paper has emphasized the CC savings achieved in 16 buildings. On a broader scale, the cumulative savings of the retrofit and CC measures implemented in the LoanSTAR program are shown in Table 9. It can be seen that the retrofit savings are now 120% of the audit estimated savings and the sum of the retrofit and CC savings totals 149% of the audit estimated savings. In the case study buildings described in this paper, where CC efforts have been substantially completed, the combined CC and retrofit savings exceed 200% of the audit estimates. It seems clear that overall LoanSTAR program savings will ultimately be well above 150% of the audit estimated savings.

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Table 8. Summary of Continuous Commissioning Savings in 16 Buildings

Buildings	State Offices	Two Schools	Med. Res. Ctr.	Med. Res. Bldg.	Total
Potential Savings ($/yr)	$486,300	$57,147	$517,800	$374,992	$1,436,239
Implemented Savings ($/yr)	$30,385	$28,031	$609,643	$195,869	$863,928

Table 9. Cumulative Measured LoanSTAR Program Savings Through February 1996.

Savings	Amount
Audit Estimated Savings	$16,958,000
Measured Retrofit Savings	$20,306,000
Measured CC Savings	$5,000,000
Total Savings	$25,306,000

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