Campus-Wide Continuous Commissioning℠ of University Buildings

*David E. Claridge, Charles H. Culp, Mingsheng Liu**
Song Deng, W. D. Turner, J. S. Haberl
Texas A&M University
**University of Nebraska*

ABSTRACT

Continuous Commissioning (CC℠) began as part of the Texas LoanSTAR program at the Energy Systems Laboratory (ESL) at Texas A&M University. Continuous Commissioning emerged from a program of implementing operation and maintenance improvements following retrofits in buildings. This process identifies and implements optimal operating strategies for buildings as they are currently being used rather than implementing design intent.

Following initial development of the CC process in buildings which had already been retrofit, CC was applied at Texas A&M University where very little retrofit activity has occurred. The CC project for the buildings and central plants on the campus began in 1995. Metering was installed in 78 of the largest buildings on the campus in 1995, as the first step in the process. Continuous Commissioning of selected campus buildings was started during the summer of 1996. The project commissioned 11 buildings during the first year, but the pace of the project was then consciously slowed by Physical Plant leadership to seek the full operational benefits of the commissioning process and not just the energy cost savings. As of the end of 1999, the CC process has been applied to 34 buildings on the Texas A&M campus resulting in substantial improvements to the operation of the campus hot and cold water distribution loops and to the central plant operation. Cumulative chilled water, hot water and electricity savings achieved from Continuous Commissioning on the Texas A&M campus (including buildings, distribution loops and central plants) have exceeded $10 million. CC cost through 1999 was approximately $2.5 million.

Introduction

Continuous Commissioning (CC) began as part of the Texas LoanSTAR program (Turner et al., 1998) at the Energy Systems Laboratory (ESL) of Texas A&M University, working almost exclusively on buildings in Texas. The initial concept was to achieve energy and cost savings with operations and maintenance (O&M) procedures. Continuous Commissioning evolved from this O&M tuning during the 1993 to 1995 time frame. Treating this as a separate discipline helped with the development of the technology and focus on obtaining high energy savings.

As a note, this concept was planned to be a different approach than the "normal" building commissioning practice of making sure the building operates according to the design intent using a process such as that described by ASHRAE Guideline 1 (1996). Normal building commissioning is increasingly being practiced by owners of large buildings because they find it to be a cost effective way to bring buildings on line quickly and with far fewer problems and callbacks after occupancy (Odom and Parson, 1998; Davenny et al., 1999). It is still far from the norm, as Haasl and Wilkinson (1998) reported that only 7% of the state facility administrators responding to their survey reported that many or most of their facilities received some form of commissioning.

Gregerson (1997) investigated existing building commissioning in 1997 and reported average savings of 11.8% for 13 buildings which had undergone conventional commissioning. The average savings noted for the 21 buildings which had undergone CC was 23.8%.

Buildings that have had retrofits and buildings that have not had recent upgrades to the HVAC equipment comprise two significantly different categories. From previous publications, the average savings due to the CC process in buildings that had already been retrofit were about 20% beyond the retrofit savings (Claridge et al., 1994, 1996).

Non-retrofitted buildings that have the CC process applied are the focus of this paper. Chilled water savings averaged 28%, heating savings averaged 54% and electrical savings were smaller, generally ranging from 2 to 20%.

Continuous Commissioning Process

The steps in the Continuous Commissioning (CC) process are shown in Figure 1. The first step is to perform an initial survey of the building to identify the comfort and operational problems which may be present. During this survey, an initial estimate of the potential CC savings and the monitoring requirements is made. One of the fundamental requirements for CC to be effective is to involve the facility staff in each of the steps so that they will understand and support the planned enhancements to the facility. Training in Step 1 is usually informal and generally involves discussions as the CC engineer surveys the facility.

In Step 2, a method for measuring and modeling the baseline performance of the facility must be established to determine the impact of the CC process. Monitoring equipment is installed and a baseline is established. An operations staff person must be involved and should be given installation responsibility if possible. This creates ownership and will allow a much faster repair of sensors when needed. The training in Step 2 is informal and should involve hands-on participation in the installation process.

The CC engineer next performs a detailed facility survey in Step 3. First, dysfunctional equipment comfort issues are identified and remedied. Getting the building back up to proper function is very important as this provides an immediate benefit to the occupants. Teaming the CC engineer with the facility person involved in this step helps to assure that repairs will not be undone if complaints occur. Before proceeding, the facility environment should be comfortable and the equipment should be operating acceptably. For example, if the airflow through air handler 5 is increased to improve the temperature in the Dean's Office, discomfort may be created in the EE Department Head's office, two doors down. The CC team IDENTIFIES these problems, develops a PLAN for solving them and then SOLVES them. The CC engineers work with the facility staff until solutions are identified and in place. The CC engineer must have an excellent fundamental understanding of the systems in the building combined with substantial practical experience with these systems.

Commissioning the equipment to the facility needs and then commissioning the entire facility to the facility needs are completed in Steps 4 and 5. Commissioning to facility needs involves problem analysis and solution. When equipment is oversized, a typical finding, the operation is usually non-optimal. The CC engineer must understand the operation of the equipment in the equipment room and also how energy is transported in the facility.

Monitoring, in Step 6, is key to measuring the changes and being able to report the savings obtained. Monitoring also serves as an early warning if changes were made in the facility which degrade the operation or savings. A CC engineer needs to visit the facility at least yearly to review the operation. Often facility staff change and retraining is necessary. Also, facility use often changes and these yearly visits will be useful for

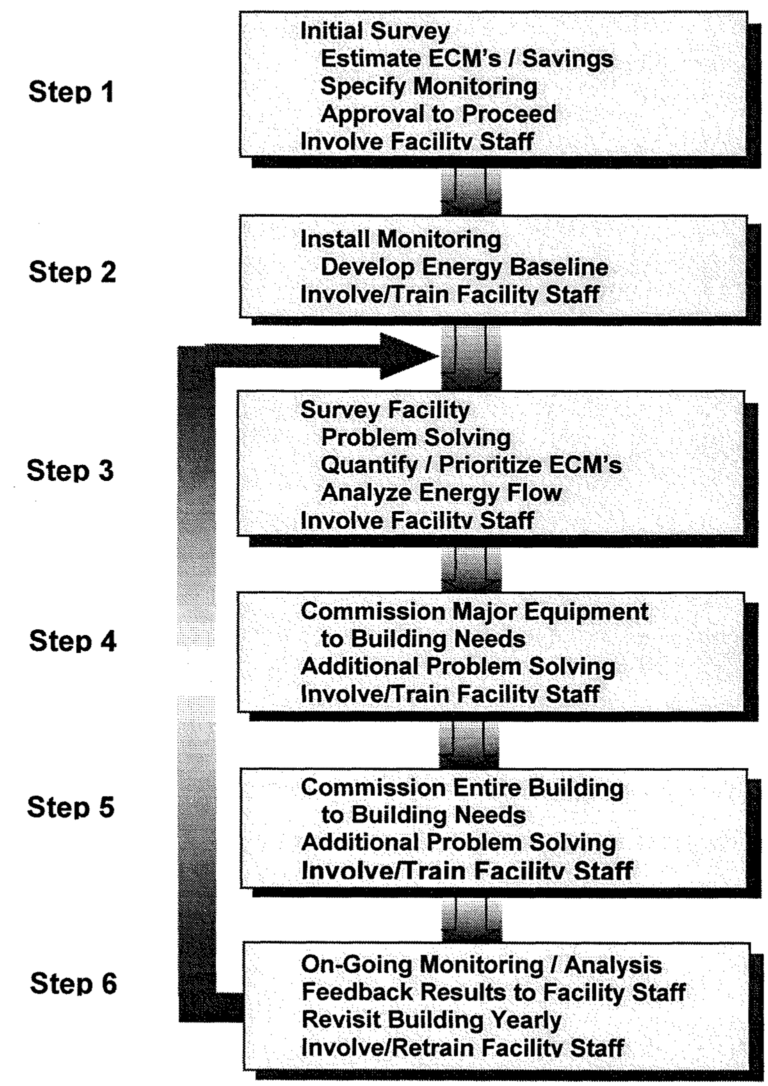

Figure 1. The Continuous Commissioning Process.

additional needs at the site. The CC process optimizes the building as it was being operated. For example, if one-half of a floor of offices was converted to labs, it is very likely the energy use of the space will have changed and mechanical equipment and operating strategies will need to be re-optimized. On-going monitoring data is compared to baseline data after being corrected for variables that were identified as significant from the baseline. Weather is almost always a major influencing variable. Specific facilities can have variables like the number of meals served for a food facility or the number of rooms rented for a hotel.

Continuous Commissioning of a Large Campus

Continuous Commissioning evolved from the O&M tuning in the retrofitted buildings of the LoanSTAR program. The opportunity to benefit from CC seemed to be at least as great in facilities that had not benefited from a major retrofit program. In early 1994, a presentation was given to the Vice-President for Finance at Texas A&M, advocating implementation of the CC process for all campus buildings at Texas A&M. This presentation was next given to the President of Texas A&M and he made the decision to implement CC.

The Continuous Commissioning program was then made an integral part of the campus energy management program and managed through the campus energy managers office within the Office of the Physical Plant. The project was funded from the campus utility budget on the premise that savings from the program would exceed the implementation cost within the two-year university budget cycle.

The Energy Systems Laboratory (ESL) project team was set up to plan and implement the CC project. Physical Plant personnel on the team included the associate director of the Physical Plant, the energy manager, the controls system manager, an engineer from the power plant, the head of the instrument shop at the power plant and specific operations staff knowledgeable on specific buildings. The ESL team included two professors who provided project oversight, the CC director, two project engineers and four staff engineers.

Energy monitoring equipment was installed at a cost of $750,000 in 78 campus buildings jointly selected by the Physical Plant and ESL team members. The equipment was installed over a six month period beginning during the autumn of 1995 to record hourly values of electricity consumption (kWh), chilled water consumption (Btu) and heating water consumption (Btu). This part of the project went as planned and encountered the normal problems which arise in a large metering effort.

The first buildings to have CC applied were selected from those metered as likely candidates for significant savings based on observed consumption patterns – particularly high levels of simultaneous heating and cooling. This phase of the Continuous Commissioning began during the summer of 1996 after about nine months of baseline data spanning winter weather and hot humid weather were available for the initial buildings commissioned. By the end of 1996, 11 buildings had been commissioned – comfort problems had been addressed and basic systems optimization had been carried out. Savings realized in these 11 buildings were approximately $100,000 per month. A decision was made in 1997 to begin work on the power plant and optimize the distribution loops and major equipment within the power plant in parallel with the building commissioning. A brief report on this work has

Physical Plant team decided that complete identification and repair of faulty components and equipment in each building was preferable to faster initial commissioning followed by the need for additional effort to complete the process after the major savings had been achieved. In some buildings, the CC process has identified many failed parts which must be repaired or replaced by maintenance staff. Other buildings have been revisited by the Continuous Commissioning team since a major system retrofit has been implemented after the initial commissioning. By the end of 1999, cumulative chilled water, hot water and electricity savings achieved from Continuous Commissioning on TAMU campus (including buildings, distribution loops and central plants) have exceeded $10 million.

Campus Facility Background Information

Texas A&M University is located in College Station, Texas. The campus has a total conditioned floor area of approximately 14,000,000 square feet. Campus buildings receive chilled water, heating water, and domestic hot water from central plants. Approximately 30 buildings receive steam from central plants for lab and food services. A few buildings use heating water to generate domestic hot water through heat exchangers. Most of the buildings have one or more chilled water pumps, heating water pumps and domestic heating water pumps. Figure 2 shows the diagram for the piping on the main campus and illustrates the scale of the project.

Figure 2. Texas A&M Campus Piping.

The campus has five central plants to provide the chilled water, heating water, steam, domestic heating water and electricity needed in campus buildings. The five plants provide a total cooling capacity of 38,100 tons, steam generation capacity of 750,000 lb/hr and electric generation capacity of 36.5 MW.

Results of Continuous Commissioning of University Buildings

Continuous Commissioning of the campus buildings began during the summer of 1996 after collection of several months of baseline consumption data. Case studies of two of the buildings which have gone through the CC process follow with a summary of the results from the first twenty buildings for which at least two years of savings data are available.

Memorial Student Center

The Memorial Student Center is a large two-story complex with a basement having a total conditioned space of 369,000 square feet. It consists of banquet rooms, student activity rooms, cafeterias, a two-story bookstore, a bowling alley, meeting rooms, television rooms, a ballroom and other miscellaneous rooms.

Forty (40) air handler units (AHU's) with pneumatic controllers supply the conditioned space. Each of the areas served was carefully detailed and studied as part of the CC activity in this building. Six areas were consistently too cold and one was too warm. Problems found included an outside air (OA) fan not working (impacted AHU's 1, 3, 12, 13, 17 and 18), supply air flow in error by over ± 20% (in some cases over 80% excess observed), controls disabled, faulty control of numerous coupled heating and cooling coils, excessive hunting in the controls of 2 AHU's (AHU 25 and 27), clogged reheat coils, broken thermostats and pneumatic controllers, negative building pressurize, and numerous other issues.

Examples of the CC changes implemented include:

- Cleaned the reheat coils. This resulted in almost doubling the CFM in affected AHUs and meeting comfort requirements in affected zones
- Increased cold deck temperatures in numerous AHU's to stop over-cooling.
- Recalibrated thermostats and replaced broken thermostats and pneumatic controllers.
- Eliminated the negative building pressurization.

Figure 3 shows the chilled water (ChW) and hot water (HW) consumption as a function of ambient temperature before and after CC. The savings in this building are quite typical of those achieved in other campus buildings that have been commissioned. Savings totaled 13,649 MMBtu of chilled water, 23,236 MMBtu of hot water and 1,528,000 kWh in the first 24 months following commissioning of the building. Cost savings were $218,202 at standard campus costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for hot water and $0.02788/kWh for electricity. The heating and cooling savings corresponded to a 23% reduction in thermal energy use.

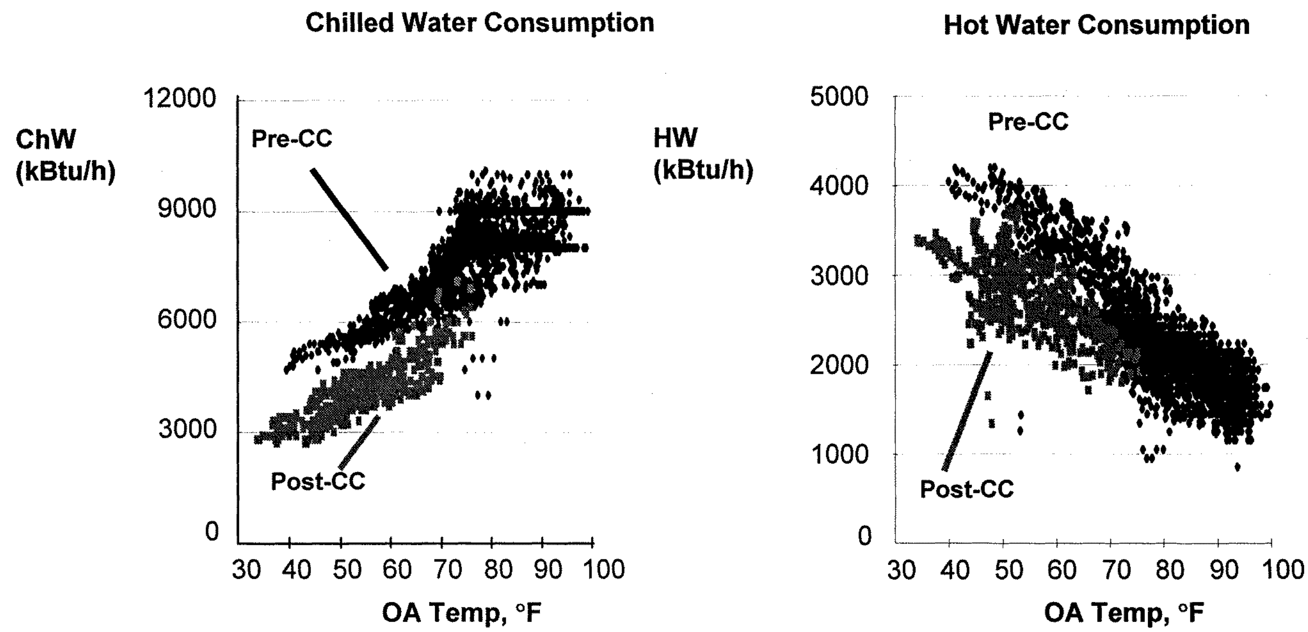

Figure 3. Memorial Student Center

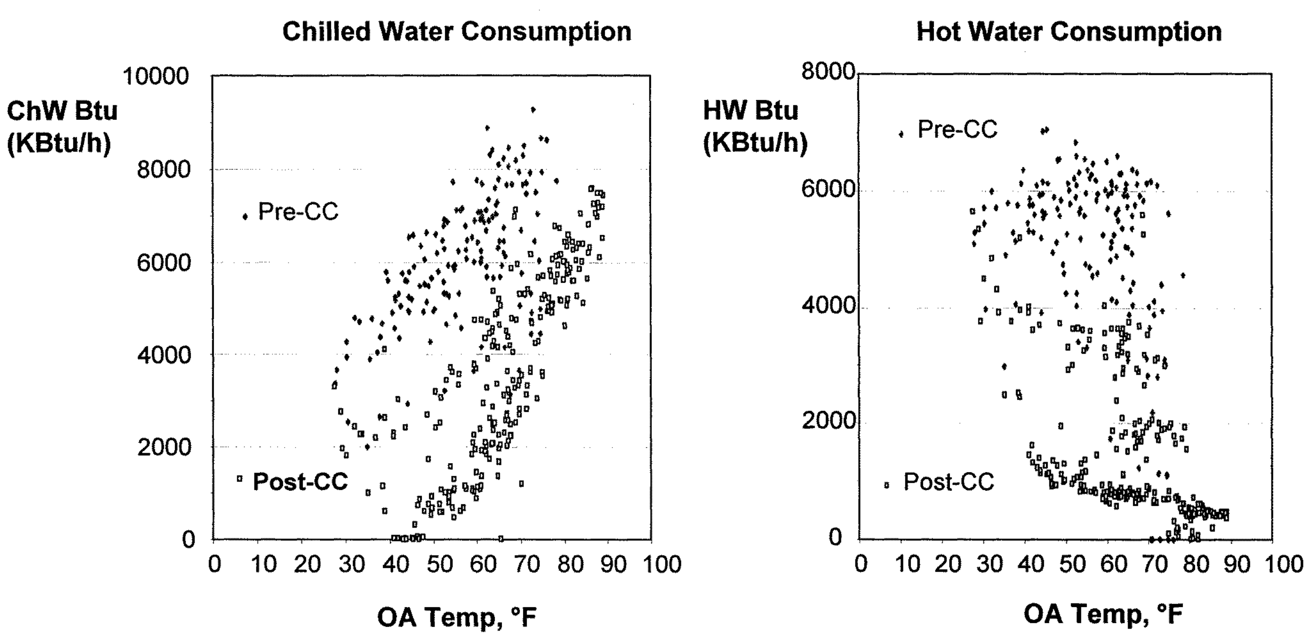

Figure 4. Kleberg Building

Kleberg Building

The Kleberg Building has four floors above ground and a basement with a total conditioned space of 165,000 square feet. It consists of a four story atrium in the center of the building; lecture halls located on the first floor; offices looking into the atrium on floors 2, 3 and 4; and laboratories surrounding the offices on the upper three floors.

The HVAC system has two 100HP single duct variable air volume (SDVAV) AHUs with pre-heat and terminal reheat and two 25 HP return air fans. The ChW and HW are supplied from the campus central plants. The labs are divided into 12 zones, each having fan powered boxes with terminal reheat. The offices have 100 VAV boxes and the labs have 120 VAV boxes. This building was selected for early commissioning due to its extremely high thermal energy use. It can be seen in Figure 4 that heating use was essentially independent of temperature at about 6000 KBtu/hr while cooling use varied from 4000 to 9000 KBtu/hr. The major problem was a high pre-heat setpoint which caused all outside air to be preheated above 100°F year round. This problem was corrected immediately and both heating and cooling consumption dropped by 2000 KBtu/hr or more as shown by the intermediate points in Figure 4.

Additional problems included broken VAV boxes, cold labs due to VAV dampers stuck open, warm labs due to VAV dampers which would not fully open, lab pressure which was too negative, mold caused by condensation, low main pneumatic air supply pressure, incorrect calibration of the pressure sensor for the exhaust dampers, and numerous other issues.

Examples of CC solutions implemented include:

- Replaced or fixed broken VAV boxes
- Installed VSD fans on the fume hoods for less than a 1-year payback
- Optimized the cold deck and preheat schedules
- Used the economizer cycle
- Reduced building pressure from 0.05" to 0.02"
- Reset static pressure from 1.5" to 1.0"
- Optimized ChW pumping control

Figure 4 shows that following implementation of these measures, heating consumption has varied between 500 and 2000 KBtu/hr while cooling consumption has been reduced by about 4000 KBtu/hr. Cooling savings totaled 105,000 MMBtu (45%) and heating savings 142,400 MMBtu (89%!) in the first 39 months following CC implementation. Cost savings totaled \$1,167,600 or \$2.18/ft^2-year for the same period.

Continuous Commissioning Results for 20 Campus Buildings

Measures similar to those discussed for these two buildings were implemented in 18 additional buildings by the end of 1997. Table 1 summarizes the results for all 20 buildings. Chilled water savings came to an average of 28%, with a range of - 13% to + 82%. Heating savings averaged 55%, with a range of 2% to 89% with five buildings showing savings above 75%. Electric savings are generally much smaller, having a range of 1% to 21%. In the cases where electric savings were not expected since fan speeds or lights were not changed, they were not reported. Buildings with savings at the low end of the ranges given (e.g. Heldenfels, Clinical Sciences, Heep, etc.) have generally had preliminary CC measures implemented when a decision was made to concentrate attention on other buildings until planned control system upgrades were completed in these buildings.

Using the campus energy costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for heating hot water and $0.02788/kWh for electricity, cumulative savings for these buildings are $4,147,000 for the months shown in Table 1. The results have also been examined to see if the initial buildings, which were chosen on good potential savings, showed substantially higher savings than the subsequent CC buildings. The first 10 buildings Continuously Commissioned showed average chilled water savings of 29.3% while the next 10 had savings of 26.2%, so the difference is certainly not dramatic. For hot water, the savings for the first 10 buildings averaged 56.8% while the next 10 produced average heating savings of 50.1%. The CC process has been applied to 14 additional buildings on the Texas A&M campus since 1997.

Comfort is a factor addressed early in the CC process. In general, comfort improves while reducing the consumption. First, the equipment is brought up to working status. Second, the equipment is tuned to meet the needs of the space. Finally, many of the changes simply minimize wasting heating and cooling energy, which do not directly impact comfort. Numerous reasons exist for negative savings. We found that changes in space utilization, changes in plug load (adding more computers), individuals using space heaters are but a few of the reasons. By monitoring the energy use on a regular basis, trends can be identified, investigated and fixed.

Table 1. Baseline consumption and commissioning savings for 20 campus buildings.

	Area (ft2)		Months Savings	Baseline Use (kWh or MMBtu)	Savings (kWh or MMBtu)	% Saved
Kleberg Building	165031	Cooling	39	230881	105095	45.5
		Heating	39	160176	142411	88.9
Heldenfels Hall	104959	Cooling	39	81765	2298	2.8
		Heating	39	38881	13218	34.0
		Electricity	39	7746898	715753	9.2
Harrington Tower	165000	Cooling	39	45738	19362	42.3
		Heating	39	25493	19444	76.3
		Electricity	39	5516098	1081241	19.6
Langford Arch.	102105	Cooling	39	67627	22250	32.9
		Heating	39	23010	11799	51.3
Reed McDonald	80218	Cooling	39	68330	17249	25.2
		Heating	39	26898	16605	61.7
Rich. Petroleum	113700	Cooling	36	62447	19429	31.1
		Heating	36	56123	14166	25.2
Vet Med Center Addition	114666	Cooling	35	91292	32747	35.9
		Heating	35	49502	33263	67.2
Vet Med Hospital	140865	Cooling	35	96830	28158	29.1
		Heating	35	38308	34179	89.2
		Electricity	35	12226200	209231	1.7
Heep Center	158979	Cooling	35	68936	-9092	-13.2
		ccwbheat	35	14018	1178	8.4
		Electricity	35	16352010	1937587	11.8
Zachry Engr Center	324400	Cooling	33	14070	11545	82.1
		ccwbcool	33	105728	56433	53.4
		Fans	33	4552669	1035389	22.7
Clinical Sciences (Vet)	103440	Cooling	33	54289	-7015	-12.9
			33	28448	7564	26.6
New Business Bldg	192001	Cooling	33	48735	13300	27.3
		Heating	33	39360	13500	34.3
Blocker	257953	Cooling	31	61900	12067	19.5
		Heating	31	20894	13089	62.6
		Electricity	31	11450010	1377017	12.0
Eller O&M	180300	Cooling	31	61682	14024	22.7
		Heating	31	14691	9365	63.7
		Electricity	31	10498078	615501	5.9
Koldus Building	110272	Cooling	29	38341	6915	18.0
		Heating	29	3831	2642	69.0
		Electricity	29	6573502	334814	5.1
G. R. White Coliseum	177383	Cooling	27	54882	29605	53.9
		Heating	27	35249	29132	82.6
		Electricity	27	3456510	741578	21.5
G.R White Annex		Cooling	27	32382	15131	46.7
Read Building	153886	Cooling	27	27814	46	0.2
		Heating	27	13326	1975	14.8
Memorial Student Center	368935	Cooling	24	111687	13649	12.2
		Heating	24	45376	23236	51.2
		Electricity	24	14407887	1582238	11.0
MSC Annex		Cooling	24	20316	7788	38.3
		Heating	24	7514	3986	53.0

Summary and Conclusions

Continuous Commissioning requires a common sense approach to maintaining building mechanical and control equipment. We have yet to find any building with all of the mechanical systems working optimally. A detailed fundamental understanding of the equipment and functions of the building is used to solve long term problems. Solutions which optimize building performance in the context of current use are implemented rather than solutions which implement design intent. The energy conservation measures are almost entirely operational changes, though minor retrofits to the mechanical systems are sometimes implemented. Monitoring is very useful for identifying problems and for maintaining operational savings once these changes have been implemented. Finally, both informal and formal training of the facility staff is essential to maintain optimal operating practices.

Continuous Commissioning requires on-going monitoring and analysis. At the Energy Systems Laboratory, the monitored data is collected and quality checked weekly. The analysis is performed monthly and put into a Monthly Energy Consumption Report (MECR). The MECR shows trends and savings. Based on these reports the building staff can take appropriate action to correct a degrading situation.

Results from the first 20 buildings on the A&M Campus to benefit from the CC process show cumulative savings for these buildings (24-39 months after CC) of $4,147,000. The CC process has been applied to additional buildings on the Texas A&M campus since 1997 and the process has been applied to implement substantial improvements to the operation of the campus hot and cold water distribution loops and to the central plant operation. By the end of 1999, cumulative chilled water, hot water and electricity savings achieved from Continuous Commissioning on the Texas A&M campus (including buildings, distribution loops and central plants) have exceeded $10 million with an expenditure to date of under $2.7 million. Straight line paybacks in the order of 1 to 2 years are expected with Continuous Commissioning.

References

ASHRAE, 1996. *ASHRAE Guideline 1-1996: The HVAC Commissioning Process*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Claridge, D.E., Haberl, J., Liu, M., Houcek, J., and Athar, A., 1994. "Can You Achieve 150% of Predicted Retrofit Savings: Is It Time for Recommissioning?" *ACEEE 1994 Summer Study on Energy Efficiency In Buildings Proceedings: Commissioning, Operation and Maintenance*, Vol. 5, American Council for an Energy Efficient Economy, Washington, D.C., pp. 73-87.

Claridge, D.E., Liu, M., Zhu, Y., Abbas, M., Athar, A., and Haberl, J., 1996. "Implementation of Continuous Commissioning in the Texas LoanSTAR Program: `Can You Achieve 150% of Estimated Retrofit Savings' Revisited," *Proceedings 4, Commercial Buildings: Technologies, Design, and Performance Analysis. ACEEE 1996 Summer Study on Energy Efficiency In Buildings*, American Council for an Energy Efficient Economy, Washington, D.C., pp. 4.59-4.67.

Davenny, Mike, Doering, Dave and McGuire, Todd, 1999. "Case Study: Commissioning the Boeing Commercial Airplane Group Headquarters Office Building," *Proceedings of the 7th National Conference on Building Commissioning*, Portland, OR, May 3-5.

Deng, S., Liu, M. and Turner, D., 1998. "Reducing Pump Power Consumption by 40% (1000 kW) through Improved Pump Management in a Central Plant," 33rd Intersociety Engineering Conference on Energy Conversion, Colorado Springs, CO, August 2-6, 1998.

Gregerson, Joan, 1997. "Cost Effectiveness of Commissioning 44 Existing Buildings," Fifth National Conference on Building Commissioning, Huntington Beach, CA April 28-30.

Haasl, Tudi and Wilkinson, Ronald, 1998. "Using Building Commissioning to Improve Performance in State Buildings," *Proc. 11th Symposium on Improving Building Systems in Hot and Humid Climates*, June 1-2, Fort Worth, Texas, pp. 166-175.

Liu, M., Houcek, J., Athar, A., Reddy, A. and Claridge, D., 1994. "Identifying and Implementing Improved Operation and Maintenance Measures in Texas LoanSTAR Buildings," *ACEEE 1994 Summer Study on Energy Efficiency In Buildings Proceedings: Commissioning, Operation and Maintenance*, Vol. 5, American Council for an Energy Efficient Economy, Washington, D.C., pp. 153-165.

Liu, M., Zhu, Y., Park, B. Y., Claridge, D. E. and Feary, D. K., 1999a. "Airflow Reduction to Improve Building Comfort and Reduce Building Energy Consumption-A Case Study," *ASHRAE Transactions*, No. 4271, Vol. 105, Part 1, pp. 384-390.

Liu, Mingsheng, Claridge, David E., and Turner, Dan, 1999b. "Advancement of Continuous Commissioning in the Energy Systems Laboratory, Texas A&M University, *Proceedings of the 7th National Conference on Building Commissioning*, Portland, OR, May 3-5, pp. 10.2.1-10.2.16.

Odom, J. David and Parsons, Scoty, 1998. "The Evolution of Building Commissioning at Walt Disney World," 6th National Conference on Building Commissioning, Lake Buena Vista, FL, May 18-20.

Rose J. R. and Kopko W. L., 1994. "A Novel Method for Resetting Duct Static Pressure for Variable Air Volume Systems," *ACEEE 1994 Summer Study on Energy Efficiency In Buildings Proceedings: Commissioning, Operation and Maintenance*, Vol. 5, American Council for an Energy Efficient Economy, Washington, D.C., pp. 219-223.

Turner, W.D., Claridge, D.E., O'Neal, D.L., Haberl, J.S., Heffington, W.M., Harvey, T. and Sifuentes, T., "Program Overview: The Texas LoanSTAR Program; 1989-August, 1997," *The Eleventh Symposium on Improving Building Systems in Hot and Humid Climates Proceedings*, June 1-2, 1998, Fort Worth, Texas, pp. 99-112.