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Mingsheng Liu

University of Nebraska-Lincoln, mliu2@unl.edu

Jinrong Wang

Omaha Public Power District

Ken Hansen

Omaha Public Power District

Ann Selzer

Nebraska State Energy Office

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Continuous Commissioning Leading Energy Project Process - An Industry Approach

*Mingsheng Liu, Ph.D., P.E.
Energy Systems Laboratory, University of Nebraska
Jinrong Wang, P.E., Ken Hansen, P.E.
Omaha Public Power District
Ann Selzer,
Nebraska State Energy Office*

ABSTRACT

Continuous Commissioning (CC[®]) is an ongoing process to resolve operating problems, improve comfort, optimize energy use, and identify retrofits for existing commercial and institutional buildings and central plant facilities. This process was initiated in 1992 and formally documented in 1999 by the Energy Research Journal and in 2002 by the Continuous Commissioning Guidebook for Federal Energy Managers. The CC process has been very successful for many public facilities. A significant amount of energy savings has been achieved and documented.

Recently, the authors developed the Continuous Commissioning Leading Energy Project process and demonstrated this process in over a dozen projects. This process is named the Continuous Commissioning Leading Energy Project process (CCLEP). Qualified engineering firms can apply the CCLEP process to the private and public sectors, new and existing buildings, and to retrofit and commissioning projects.

This paper presents the CCLEP process and the results from seven completed projects.

ABOUT THE AUTHORS

M. Liu, Ph.D., P. E., President and Chief Technology Officer, Building Energy Systems Technology Inc., director of the Energy Systems Laboratory at UNL and the primary founder of the Continuous Commissioning Process (CC[®]), and the founder of the Continuous Commissioning Leading Energy Project, is a professor and chair of the graduate committee,

Architectural Engineering, at the University of Nebraska-Lincoln. Dr. Liu has over 20 years of experience in engineering research and design, and has authored and/or co-authored over 120 technical papers on energy systems efficiency improvement. **K. Hansen**, P. E., is an experienced engineering manager with 29 years of diversified professional background in an electric utility. His areas of expertise are customer sales and services, facility management, facility operations, engineering design, construction, and project management. **J. Wang**, P. E., is a Senior Engineer at an electric utility and has over 20 years of experience in building energy system design/consulting, energy measurement and verification. She is a registered Professional Engineer. **A. Selzer** is a program manager at the Nebraska Energy Office. She has more than 25 years of administrative experience with building energy efficiency projects.

INTRODUCTION

The Continuous Commissioning process (CC[®]) was initiated in 1992 as an Operation and Maintenance (O&M) research activity within the Texas LoanSTAR program. The O&M research activities identified/achieved significant energy savings in buildings where comprehensive retrofits had just been completed by optimizing system operations. The results were first reported by Liu et al [1] on the 1994 Summer Energy Study of American Council for an Energy Efficiency Economy.

The CC[®] was first mentioned in 1995 within the research group at the Energy Systems Laboratory, Texas A&M University. In 1997, average utility cost savings of 22% resulted from

the CC was reported in over 40 buildings in a special E-Source report [2]. In 1999, Liu et al [3] formally documented the CC process in an article published by the Journal of Energy Research. In 2002, the Continuous Commissioning Guidebook was developed for federal energy managers [4].

More important, many advanced technologies have been developed and became the core technologies to reduce building energy consumption and improve building comfort. For example, the advanced economizer eliminated heating penalty in dual duct AHU [5]. Hot air damper technology converts the dual duct constant air volume to single duct VAV without terminal box retrofit [6]. Fan airflow station (FAS) technology ensures accurate and reliable building pressure control [7].

The CC process has been implemented in over 200 buildings and resulted in significant energy savings and comfort improvements. However, the CC process was developed by a group of researchers based on public sponsored special projects. It is necessary to refine and improve the CC process in order to apply the technology to new building construction and to retrofit projects in the private sector.

Recently, Texas A&M University integrated CC[®] as one of the energy conservation measures (ECM) to reduce the overall project payback [8]. In one campus case study, the traditional measures had a potential energy savings of \$488,810/yr with an estimated project cost of \$5,865,460. The simple payback was 12 years. The CC measure had a potential energy savings of \$204,563/yr with an estimated project cost of \$605,000. The simple pay back is 3 years. The total project cost is \$6,470,460 with a potential energy cost savings of \$693,373. The project simple pay back is 9.3 years, which meets the ten-year payback criteria.

In 2002, the U. S. Department of Energy awarded a grant to the Nebraska Energy Office, which enabled the University of Nebraska and Omaha Public Power to develop a process to use Continuous Commissioning in commercial retrofit projects. Consequently, the Continuous

Commissioning Leading Energy Project (CCLEP) was developed. The CCLEP applies system optimization theory and advanced technologies to each mechanical system and control system design, construction, and operation. The preliminary results were presented in WEEC 2003 conference and published in the Journal of Energy Research [9]. Since CCLEP takes an integrated approach, it significantly reduces retrofit costs and maximizes energy cost savings. Major mechanical and control system upgrade/retrofits can be paid back using energy cost savings within 5 years for most buildings and facilities. The CCLEP process applies to private sector and public sectors, existing buildings and new buildings, and commissioning projects and retrofit projects. Therefore, the CCLRP process is renamed as Continuous Commissioning Leading Energy Project process (CCLEP).

This paper presents the CCLEP process, results of seven completed projects and conclusions.

CCLEP PROCESS

The CCLEP process has two stages: the contracting stage and the implementation stage. During the contracting stage, a comprehensive technical evaluation must be performed. Through the comprehensive technical evaluation, innovative technical solutions are developed. The potential cost and savings are also evaluated.

After signing the CCLEP contract with owners, the CCLEP implementation stage starts. The CCLEP has three phases in the implementation stage: planning phase, retrofit and trouble shooting phase, and optimization and follow-up phase.

Planning Phase

Step 1: Develop mechanical design requirements and control system upgrade specifications. Commissioning engineers review/study the project proposal, conduct a site visit, and perform more field measurements if necessary. Based on the information, commissioning engineer(s) develop detailed design requirements of mechanical systems, and

specifications of control systems. The specifications are documented and presented to the mechanical design engineers, the control engineers, and the facility operating engineers.

Step 2: Finalize the mechanical design and control system upgrade scope and requirements. After the design engineers and the control engineers review the specifications, a meeting is arranged. The commissioning engineer(s) clearly present the design specifications and address the suggestions and concerns from the reviewers. A final agreed specification document is issued at/after this meeting.

Retrofit and Trouble Shooting Phase

Step 1: Perform system design

The design engineers perform the system design based on the specifications developed in phase 1. Then, the commissioning engineer(s) review the design documents. A meeting is arranged to finalize the design after addressing the suggestions and recommendations from the commissioning engineer(s).

Step 2: Implement mechanical system retrofit
Mechanical contractor installs the system based on the design requirement. The commissioning engineers conduct performance checks to make sure the systems are installed as required.

Step 3: Implement control system upgrade
Control contractor installs the control hardware and develops the control program. The control contractor installs the control program to the system. The program ensures the systems safe operation. The commissioning engineer(s) perform a function check and make sure the system is properly installed and fully functioning.

A copy of the control program is handed over to the commissioning engineer(s). The commissioning engineer(s) implement the advanced optimal control algorithms which are beyond the typical control system program scope.

Step 4: Trouble shoot and refine the optimal control set points

The commissioning engineer(s) work with the team (technician, facility operating staff) to solve minor existing mechanical and control problems. After mechanical system and control system trouble shooting, the commissioning engineer(s) should determine the optimal control set point and/or schedules. These set points and schedules are then programmed into the version modified by the commissioning engineers.

Optimization and follow up

Step 1: Install the optimal control program
The version programmed by the commissioning engineer(s) is uploaded to the control system. The program must be loaded unit by unit. A comprehensive test must be performed to ensure the proper function and the optimal set point and/or schedule. The commissioning engineers also demonstrate the benefits using short term testing.

Step 2: Follow up
A system is set up to monitor the actual system performance. Generally, the building automation system can be used to trend key operation parameters. The commissioning engineer(s) examine the data periodically to identify the system faults and fine tune the system set points. A four-season follow up is recommended.

RESULTS AND DISCUSSIONS

In this section, the building and system information and the results of CCLEP implementation in seven buildings will be summarized and discussed. More detailed information for each facility can be found in the appendix.

Table 1 summarizes the building and HVAC system information. The year of construction varies from 1958 to 2001. The building size varies from 35,000 square feet to 337,871 square feet with the average size of 148,700 square feet. Six buildings are typical commercial office buildings. Of the six, three buildings have 24/7 operation and other three have a nighttime shut down. One is high school with 24/7 operation.

Table 1: Summary of the Building and HVAC System Information

Building	Year of Built	Size (ft ²)	Function	Occupancy Schedule	HVAC Schedule	Primary System	Secondary System	Control System
1	2001	195,580	office	24/7	24/7	2 water cooled chillers, 10 hot water boilers	2 Single duct VAV AHUs	DDC
2	1972	49,436	Office	6:00/ 8:00	5:00/9:00	1 water cooled chiller, 1 hot water boiler	1 single duct VAV AHU	DDC and pneumatic
3	1970	71,000	Office	6:00/ 8:00	5:00/9:00	3 air cooled chillers, three hot water boilers	1 dual duct VAV AHU	Pneumatic
4	1988	232,037	Office	24/7	24/7	Ice storage system, 3 water cooled chillers, electrical boilers	4 single duct VAV AHUs	DDC
5	1974	136,552	Office	6:00/ 8:00	5:00/9:00	1 water cooled chiller, one hot water boiler	1 single duct VAV AHU	Pneumatic
6	1983	35,000	Office	24/7	24/7	1 air cooled chiller, two hot water boiler	1 single duct VAV AHU	DDC
7	1995	337,871	High school	6:00/ 8:00	5:00/9:00	2 water cooled chillers, 2 hot water boilers	29 AHUs	DDC

The primary system includes both water and air cooled chillers. Six buildings have gas boilers and one has an electric boiler.

The AHUs include both the variable and constant air volume systems, and both the single duct and dual duct systems. The AHUs size varies from 2,000 CFM to over 150,000 CFM. The building automation varies from the most advanced system with wireless sensors to aged pneumatic controllers.

Table 2 summarizes both the retrofit and optimization measures for each building. The primary system optimization measures include advanced building pressure control [Patent pending]; optimal VAV air handling unit control [Patent pending]; optimal single zone control; dynamic airflow terminal box airflow reset [Patent pending]; single chilled water loop operation; and optimal boiler control.

The advanced building pressure control uses the Fan Airflow Station (FAS) technology to implement true volumetric tracking in VAV air handling units. It ensures the positive building pressure and minimizes the return fan power consumption.

The optimal VAV air handling unit control resets the supply air fan speed according to building load and supply air condition to minimize the fan power and ensure the sufficient airflow to each box. Resets the supply air temperature to maximize the use of economizer and prevent compressor hunting and chiller hunting. The optimal single zone control

modulates both the airflow and supply air temperature in a constant air volume system to minimize the reheat and maintain the suitable room relative humidity control.

The dynamic airflow terminal box control adjusts the terminal box airflow based on the zone load and the building load to ensure the minimal reheat and the excellent indoor air quality.

The single chilled water loop technology achieves the variable flow in both the primary and the secondary circuits and adjusts both the water flow and the supply water temperature based on the building load. It minimizes both the pump and chiller electricity consumption and ensures the sufficient water flow to each terminal unit.

The optimal boiler operation selects the number of boilers and supply water temperature to prevent excessive water leakage through control valves; maximizes the boiler efficiency; and minimizes the pump energy consumption. These technologies are implemented in all buildings as necessary. During the CCLEP process, function tests and check-ups are performed for all control sensors, actuators, and mechanical parts.

Retrofits have been performed in five buildings. The retrofits include upgrading building automation systems; Retrofitting lightings; replacing IGV with variable frequency drives; replacing existing chillers; installing hot air dampers; installing VFD on hot water pumps; and installing VFD on constant air volume AHUs. Replacing old pneumatic systems with DDC control is critical for implementing the

advanced optimal operation and control measures. Lighting retrofits are one of the classical and cost effective measures. Replacing IGV's with VFD's greatly improves the system reliability and reduces both thermal and electricity energy consumption. The thermal energy savings comes from reduced terminal box leakage due to improved static pressure control. The actual savings are significantly higher than the typical projected using "classic" savings calculation methods. Replacing chillers is also one of the typical retrofit measures. The capital cost is often high with very a long pay pack period. However, the CCLEP process ensures the accurate chiller capacity determination and reduces the initial cost. For example, the existing chiller in building 2 was 150 tons. The building had experienced "too hot" problems during summer. An engineering calculation sized the new chiller to be 200 tons due to excessive load from single pane glass. During the CCLEP process, a detailed airflow measurement was performed for AHU. Based on the measured data, it was determined that 120 tons is sufficient. After discussing both results, a 150 ton chiller was installed in 2002. The chiller performance has been measured in the last three years. The maximum peak load was measured to be 110 tons.

Installing hot air dampers on dual duct systems [6] can convert a constant air volume dual duct system into a VAV system without retrofitting the terminal boxes. This is one of the most cost effective measures for many buildings with dual duct systems. It reduces fan power, heating, and cooling energy consumption. More important, it solves "too hot" complaints as well.

Installing VFD's on the hot water pumps can be more cost effective than installing VFD's on chilled water pumps in certain climates since the operation hours of the hot water pump can be longer than the chilled water pump operation. More important, the VFD not only reduces pump power, it improves the water loop pressure control to avoid excessive differential pressure on control valves. Consequently, it reduces the thermal energy consumption and enhances the building comfort.

Installing VFD's on the constant air volume systems is one of the most cost effective energy improvement measures. The VFD will allow quasi-implementation of VAV operation in the constant air volume systems. It can achieve up to 80% of the energy savings of complete VAV conversion with less than 20% of the cost.

The CCLEP process develops and evaluates the retrofit measures using measured data with solid engineering analysis. It reduces unnecessary cost. For example, Building 5 had experienced "too hot" problems at its 4th and 5th floors before the CCLEP project. A solution was developed to retrofit ductwork for the entire 4th and 5th floors. During the CCLEP process, it was found that the AHU could not provide enough airflow to the 4th and 5th floors due to the high duct pressure loss through the sound attenuator. After an engineering analysis, it was determined to remove the sound attenuator. Removing the sound attenuator actually reduced the sound level in buildings due to reduced fan speed. The fan can also supply sufficient air to both 4th and 5th floor. The complete duct retrofit for both 4th and 5th floors was avoided.

Table 3 summarizes the measured energy savings. The measured whole building electricity savings varies from 13% to 65%. The measured gas savings varies from 24% to 52%. The CCLEP process has a very attractive simple pay back, from 1 to 5 years, since it minimizes the initial retrofit cost and maximizes the energy savings.

The CCLEP process maximizes the energy efficiency of the entire building facility. For example, two of the buildings have been achieved the EnergyStar label. It should be pointed out that Building 2 scored 85% in the EnergyStar evaluation with single glazed windows. It is most likely the only EnergyStar building even with single glazed window in similar climates.

Table 2: Summary of the Optimization Measures and Retrofit Measures

Bldg	Optimization Measures	Retrofit Measures
1	(1) Optimal AHU control; (2) dynamic terminal box airflow reset; (3) Optimal single loop chiller system control; and (4) Optimal boiler system control	NA
2	(1) Optimal AHU control; (2) Advanced building pressure control; (3) Optimal single loop chiller system control; and (4) Optimal boiler system control	(1) Replaced existing chiller; (2) Lighting retrofit; (3) DDC control upgrade
3	(1) Optimal AHU control; (2) Implement single duct VAV technology in dual duct system; (3) Optimal terminal box control; (4) Advanced building pressure control; (5) Optimal single loop chiller system control; and (6) Optimal boiler system control.	(1) DDC upgrade; (2) Replace IGv with VFD in AHUs; (3) Install VFD on the hot water pump; and (4) Install hot air dampers.
4	(1) Optimal AHU control; (2) Advanced building pressure control; (3) Optimal single loop chiller system control; (4) Optimal boiler system control; and (5) Disable ice storage system	(1) Partial lighting retrofit
5	(1) Optimal AHU control; (2) Advanced building pressure control; (3) Optimal single loop chiller system control; and (4) Optimal boiler system control.	(1) DDC upgrade; (2) Install VFD on variable pitch fans and chilled water pump; (3) Remove sound attenuator.
6	(1) Optimal AHU control; (2) Advanced building pressure control; (3) Optimal single loop chiller system control; and (4) Optimal boiler system control.	(1) Replace IGv with VFD
7	(1) Optimal AHU control; (2) Optimal single zone control; (3) Optimal terminal box control; (4) Optimal single loop chiller system control; and (5) Optimal boiler system control.	NA

Table 3: Summary of the Actual Energy and Cost Savings

Building	Electricity Savings			Natural Gas Savings			Total Energy Cost Savings	Savings Period
	Energy, kWh	Cost, \$	%	Energy, Therm	Cost, \$	%	\$	Month
1	482,086	\$12,052	13	30155	\$20,418	49	\$32,470	12
2	841680	\$37,228	53	17032	\$13,096	44	\$50,324	12
3	294912	\$18,669	65	45929	\$35,868	52	\$54,537	10
4	1093617	\$34,928	17				\$34,928	7
5	675360	\$30,379	40	11486	\$10,461	43	\$40,840	6
6	595968	\$20,860	32	15847	\$12,908	51	\$33,768	6
7	267840	\$7,500	11	27884	\$21,656	24	\$29,156	7
Total	4,251,463	\$161,616	33	148,333	\$114,407	44	\$276,023	

The CCLEP process significantly reduces maintenance costs. Based on the available building owner's records, the control system maintenance was reduced by 70% for Building 1. The maintenance labor cost for Buildings 2, 4, and 6 was reduced by 60%.

The CCLEP ensures the best building comfort. For example, the school district evaluated the school comfort performance using faculty votes. The high school scored 3 out of 5 before the CCLEP project. Two other high schools in the same district had a comfort index of 3.5 and 3.9 during the same period. After completion of the CCLEP project, the project high school scored 4.5 and other two schools remained at the same levels.

CONCLUSIONS

The CCLEP process was implemented in 7 buildings. The projects cover a wide range of HVAC systems, such as water-cooled chillers, air-cooled chillers, variable air volume and constant air volume systems, the single duct and dual duct systems, for both retrofit and optimization, and both pneumatic and DCC systems. The results showed that the CCLEP process is suitable for industry implementation.

The CCLEP process and technology uses the most advanced technology, maximizes the energy cost savings and minimizes the cost. The major chiller replacement and comprehensive control system upgrades can be paid back within

5 years. The CCLEP makes it possible for major system retrofits through energy cost savings.

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CCLRP Project Brief 1

Building Information:

- Built in 2001
- 4-story office building
- 195,580 square feet
- Two Single Duct VAV AHUs
- Two centrifugal chillers
- Ten boilers
- Advanced EMCS system

System Optimization:

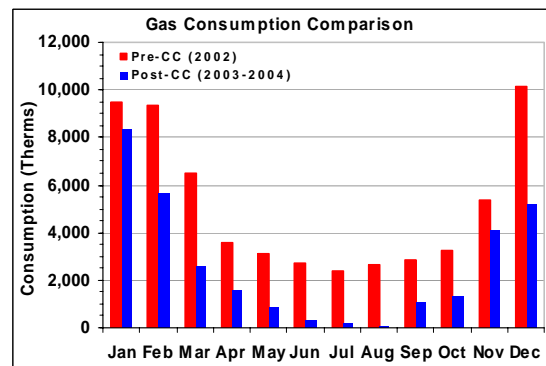
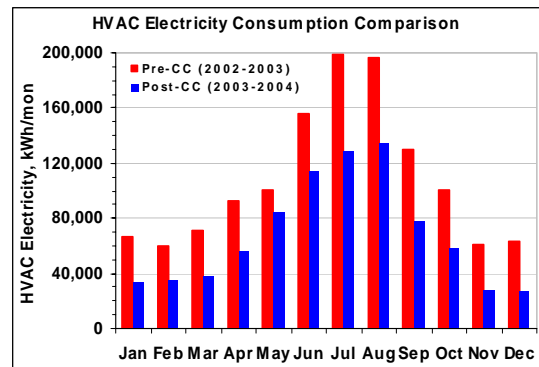
- Optimized controls for AHUs, including static pressure reset, outside air control, and supply air temperature reset
- Implemented dynamic airflow reset in terminal boxes
- Implemented variable chilled water flow with optimal chilled water supply temperature reset
- Optimized boiler operation

System Retrofit

- NA

Benefits

- Reduced comfort complaints and maintained building comfort 24 hours per day, seven days per week
- Improved system reliability
- Reduced HVAC electricity consumption by 37 % and gas consumption by 49%, based on one year of utility data since project completion
- Qualified as an Energy Star building five months after CC completion



CCLRP Project Brief 2:

Building Information:

- Built in 1972
- 3-story rental office building
- 49,436 ft²
- A single-duct cooling only VAV AHU
- A 150 ton chiller
- 52 pneumatic boxes

System Optimization

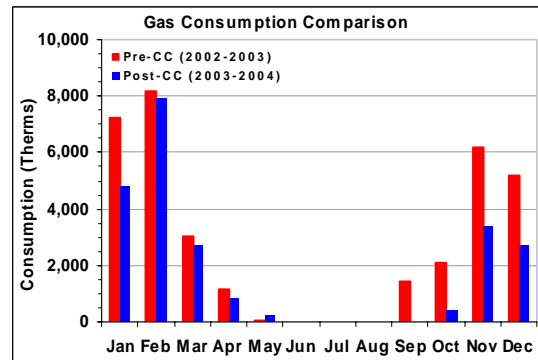
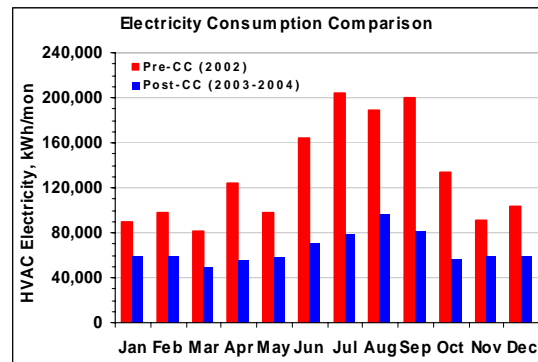
- Optimal static pressure reset, outside air control, and supply air temperature reset
- Advanced building pressure control
- Implemented variable chilled water flow with optimal chilled water supply temperature reset
- Optimized boiler operation

Retrofit

- Chiller Replacement
- Upgrades of AHU, Temperature control, and Lighting systems

Benefits

- Improved reliability of HVAC system operation
- Improved building comfort
- Reduce overall maintenance costs
- Reduced annual electricity consumption by 50% (over \$0.68/ft² per yr) and gas consumption by 34%, based on one year of utility data since project completion



CCLRP Project Brief 3CCLRP

Project Brief 3

Building Information:

- Built in 1970
- 5-story office building with 71,000ft² and single pane glass windows
- One dual-duct VAV AHU
- Three air-cooled chillers
- Three boilers
- Pneumatic controls

System Optimization

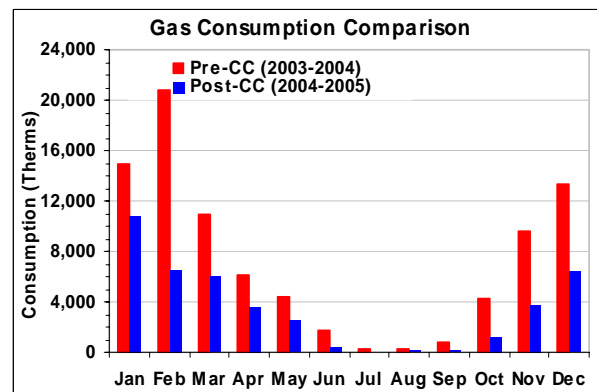
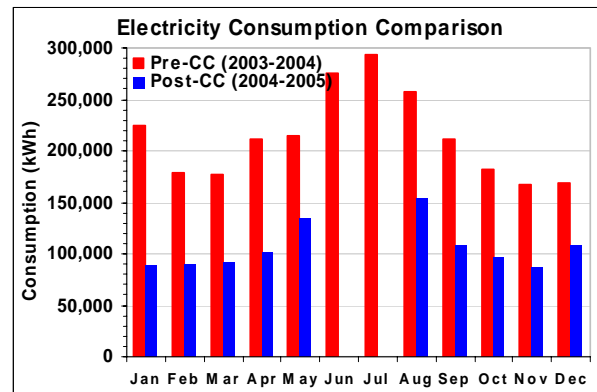
- Optimized control of AHU including static pressure reset, outside air control, and supply air temperature reset
- Implemented dynamic airflow reset in terminal boxes
- Implemented variable chilled water flow and optimized chilled water supply temperature reset
- Modified the boiler operation sequences
- Others

Retrofits:

- Upgraded the pneumatic HVAC controls to DDC controls
- Replace IGV with VFD

Benefits

- Reduced comfort complaints and improved system reliability
- Received complete DDC controls and remote web access
- Reduced electricity utility costs by 47% and gas utility costs by 53% based on the last ten months of utility data since project completion (August, 2004)



CCLRP Project Brief 4

Building Information:

- Built in 1988
- 10-story office building with 232,037ft²
- Single duct VAV AHU with fan powered terminal boxes.
- Water-cooled chillers
- Electrical boilers
- DDC controls

System Optimization

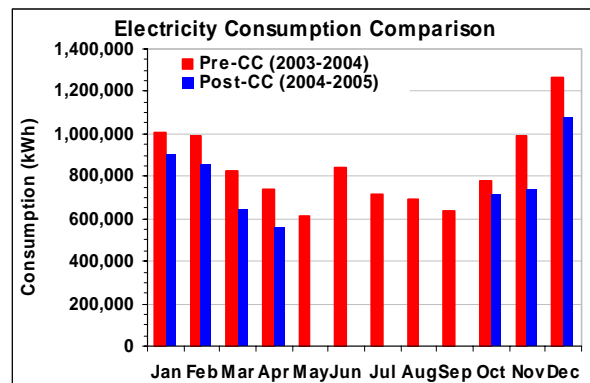
- Integrate and optimized control of AHUs, including static pressure reset, outside air control, and supply air temperature reset
- Implemented variable chilled water flow and optimized chilled water supply temperature reset
- Modified the boiler operation sequences
- Lighting retrofits

Retrofits

- NA

Benefits

- Reduced comfort complaints and improved system reliability
- Reduced electricity consumption by 17% and electricity costs by 14%, based on the last eight months of utility data since the onset of major CC construction (October 2004).



CCLRP Project Brief 5

Building Information

- Built in 1974
- 6-story office building
- 136,552 square feet
- 1 Single Duct VAV AHU
- 92 VAV terminal boxes
- 1 Water-cooled centrifugal chiller
- 1 gas boiler
- 1 Cooling tower
- Original pneumatic controls

System Optimization

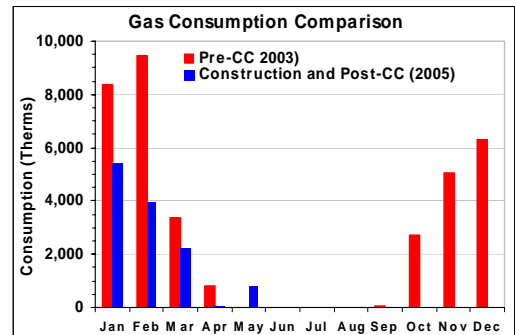
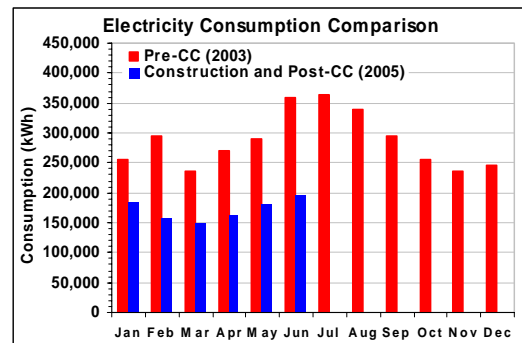
- Advanced building pressure control
- Optimal AHU control
- Integrated and optimized HVAC system

Retrofit

- Upgraded energy management controls, and lighting systems
- Upgraded AHU fan and chilled water pump motors with VFDs
- Remove sound attenuator

Benefits

- Reduced comfort complaints
- Improved system reliability
- Reduced electricity consumption by 40 % and electricity demand by 43% based on 6 months of utility data since major CC implementation (completed in February 2005)



CCLRP Project Brief 6

Building Information

- Built in 1983 (East wing in 1996)
- 1-story office building with 63,650 square feet
- 37 water-source heat pumps (Center and West wing)
- Single Duct VAV AHUs (East wing)
- 1 Air-cooled screw chiller (East wing)
- 2 gas boilers
- 1 Cooling tower
- Advanced EMCS system

System Optimization

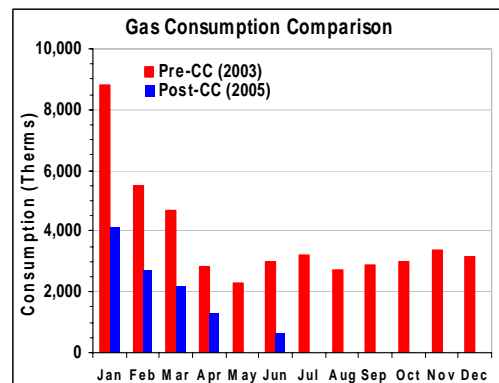
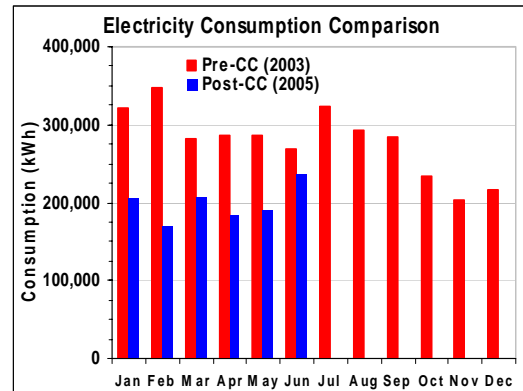
- Optimized terminal box minimum air flow
- Developed a supply air temperature reset schedule to reduce cooling and heating energy consumption
- Developed economizer and chiller control schedules to maximize economizer use and reduce chiller energy consumption
- Reset minimum air intake during occupied hours based on current number of occupants to eliminate over-ventilation and ensure indoor air quality
- Optimized operation of three Liebert units in data center

Retrofit

NA

Benefits

- Reduced comfort complaints
 - Maintained building comfort 24 hours per day, seven days per week
 - Improved system reliability
- Reduced electricity consumption by 38.3 % and gas consumption by 59.5%, based on 3 months (4 months for gas) of utility data since project completion (December 2004)



CCLRP Project Brief 7

Building Information

- Built in 1995 (1998 addition)
- 2-story high school
- 337,871 square feet
- 29 VAV AHUs
- 2 Water-cooled centrifugal chillers
- 2 gas boilers
- Advanced EMCS system

System Optimization

- Optimized economizer operation and reset minimum outside airflow set point to save cooling energy
- Optimized static pressure set points, supply air temperature reset schedules and control sequences of AHUs to improve humidity control and save fan, cooling and reheat energy
- Optimized terminal box controls and minimum air flow set points
- Optimized cooling tower operation to maximize chiller efficiency and reduce tower fan energy consumption
- Implemented “Optimal Smart Start” technology to improve occupant comfort and maximize chiller efficiency
- Optimized boiler ventilation control and hot water temperature set point to maximize boiler efficiency
- Optimized chilled and hot water systems to reduce pump energy consumption

Retrofit

NA

Benefits

- Reduced comfort complaints

- Eliminated building pressurizations problems
- Maintained building comfort 24 hours per day, seven days per week
- Improved system reliability
- Reduced electricity consumption by 10 % and gas consumption by 24%, based on 6 month (7 month for gas) of utility data since project completion (November 2004)

