Project Report

Create and Identify High Performance and EnergyStar® Buildings in the State of Nebraska through Rebuild America Program

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Project Summary

During the project period (October 2002 to September 2004), the project team has successfully completed the project objectives and goals. The major achievements are listed below:

1. Identified and recruited 137 buildings to join the project, which is 274% more than initial proposed building numbers.
2. Under this program, 29 buildings installed dedicated meters to measure building hourly energy consumption. The data have been used for improving building energy performance.
3. Conducted detailed building energy evaluation in 36 buildings with a total floor area of 10,638,000 square feet. The total potential annual cost savings are $3,217,000/yr. The project costs are $14,320,000. The average project simple payback is 4.5 years.
4. Demonstrated and implemented the CCLRP process in 14 buildings, which have a total floor area of 3,767,000 square feet. Building owners contributed to a total of $1,631,680 for these demonstration projects. The annualized energy cost savings are $558,700/yr. The project simple payback is 2.9 years. The number of demonstration project is 7 times more than the initial proposed.
5. Evaluated the EnergyStar® label qualification in 25 buildings. Four buildings qualified the EnergyStar® label. Two of the four buildings are school buildings with geothermal heat pump system. No energy improvement was conducted by the project team. For other two buildings, CCLRP improved building performance and made them qualify for the EnergyStar® label.
6. Conducted two workshops for the local consulting and building owners to transfer the technologies. The project team also closely worked with a number building owners, control system providers and contractors, and consulting engineers. Through these activities, the project team has transferred many advanced technologies to these professionals.

Many building owners are implementing the energy improvement measures proposed by the project team. Many more building owners want to have their building evaluated through the project. Currently, 78 buildings are on the waiting list. The project team hopes that DOE can provide additional fund to continue the project. In this report, the project achievements are discussed in details. Two CCLRP project reports are attached at the end of the report.

Project Objectives

The initial project objectives are listed below:

1. Make the State of Nebraska one of the top 10 EnergyStar® Building States in two-years and maintain the State leadership thereafter.
2. Develop and demonstrate the Continuous Commissioning Leading Retrofit Process (CCLRP) using three case studies. The case study buildings will be different types. The CCLRP allows building owners to implement major energy efficiency improvements with no or minor initial capital investment.
3. Initiate a statewide energy efficiency and renewable energy improvement. Attract large volume private funds ($10 million/yr) to improve the energy efficiency in the commercial sector in the State of Nebraska.

The project has exceeded the goals and objectives in developing CCLRP process and initiating a statewide energy efficiency improvement. However, the State of Nebraska is not one of the top ten states in number of EnergyStar® buildings. The primary reason is that there is almost no building qualifying the standard without significant energy efficiency improvement. This indicates the strongest need for the Nebraska to improve its building energy efficiency and urgent need assistance from federal government on this issue.

Project Performance

CANDIDATE BUILDINGS

The initial goal of the project was to identify and recruit 50 buildings to the project. In the first three months, the project team sent out the general project information and basic requirement for candidate buildings to 126 building owners. The building owners were required to provide building mechanical and control system design information and utilities bill information to the project team, and give permission to project team to conduct a comprehensive building energy performance evaluation using the CCLRP procedure.

Then our project team followed up each letter and answered many questions by the building owners. During the entire project, the project team continued recruiting the candidate buildings. A total of 137 buildings have been joined the project. The building candidates include 52 office buildings, 25 schools, 15 college buildings, 14 industry facilities, 12 hospitals, and 19 other facilities, such as shopping center and data centers. It should be pointed out the candidate building stock keep growing continuously when more and more building owners hear the project and know more about the project although the project is going to be completed.

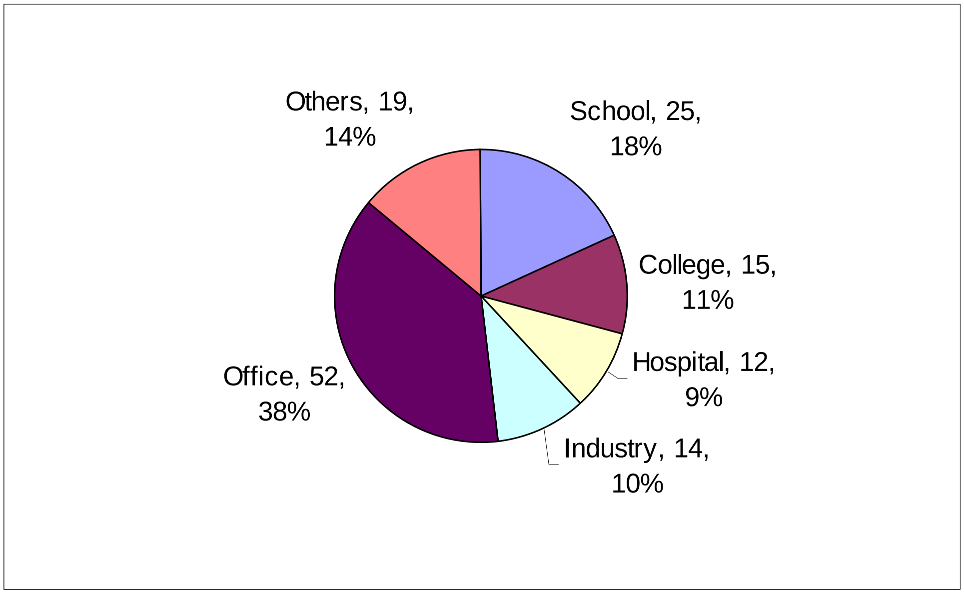


Figure 1: Distribution of Candidate Buildings in the Project (A total of 137 Buildings Are recruited into the Project)

Based on the energy performance evaluation results in the 46 buildings (see Table 2 in the next section), it is estimated the candidate buildings have a total floor area of 24,000,000 square feet. The potential annual electricity energy savings will be 260,729 MWHs/yr. The potential annual heating energy savings will be 655,333 MMBtu/yr. The potential annual energy cost reduction is $8,932,000/yr. If the project simple payback is considered as 3.5 years, it will create $31,264,000 business for local design firms and contractors.

BUILDING ENERGY PERFROMANCE EVALUATION

Detailed energy performance evaluation has been performed in 36 buildings following CCLRP procedures. The energy evaluation following the procedure below:

1. Collect building energy system and control system information, and building energy information.
2. Review building system design, control, and energy consumption information and identify the primary target of the site visit. At the end of the information review, a site visit plan is developed.
3. Conduct field visit. During the field visit, the following measurements are typically performed:
    a. Terminal box: minimum and maximum air flow, and static pressure before the box and the damper position.
    b. AHU: supply airflow, static pressure, supply air temperature, outside airflow and fan power.
    c. Boiler: supply water temperature and pump head and pump power.
    d. Chillers: chiller power, chilled water temperature, condenser water temperature, cooling tower fan power, and condenser water temperature.

e. Chilled water distribution system: pump power, differential pressure at remote coils.
f. EMCS system: key sensor reading, key control sequences.

4. System performance analysis. During this phase, the HVAC system annual operation profiles are reconstructed using the measured data and HVC control sequences. The energy improvement opportunities are then identified.
5. Model calibration. During this phase, a simplified engineering model will be calibrated using field measured data and energy consumption data. The calibrated engineering model is then used to project the potential energy savings.

Table 1 presents the brief information for 36 buildings evaluated using CCLRP method. The information includes the building name floor area, potential annual energy savings, and cost savings.

Table 1: Summary of Building Energy Performance Evaluation Information

	Name	Type	Floor Area	Energy Savings		Cost Savings
			ft^2	MW	MMBtu	\$/yr
1	Jewish Community Center	church	150,000	462	1,563	$31,600
2	St. Stephen the Martyr	church	91,000	135	592	$10,740
3	Creighton University - Boyne Building	College	181,000	1,659	3,090	$360,000
4	Education Center	College	80,000	155	260	$6,979
5	(i)Structure	Data Center	86,800	419	0	$17,600
6	Nlair Memorial Hospital	Hospital	65,000	248	638	$16,700
7	Creighton University Medical Center	Hospital	500,000	1,632	13,434	$460,000
8	York General Medical Care Services	Hospital	98,000	420	3,458	$37,740
9	3M	Industry	235,000	5,187	8,100	$300,000
10	Omaha World Herald	industry	180,000	1,243	1,882	$95,250
11	Ameritrade	Office	63,500	155	1,625	$14,543
12	AVAYA-Building 20	Office	184,000	349	1,210	$28,400
13	BCBS	Office	80,000	232	1,556	$17,277
14	Central States Health & Life	Office	142,000	1,230	3,808	$69,811
15	Empire Fire	Office	100,000	105	464	$8,125
16	FDR-AK1	Office	282,000	681	4,210	$62,512
17	FDR-Ak2	Office	200,000	339	1,584	$27,782
18	Federal Reserve Bank	office	113,000	225	909	$31,556
19	First National Bank Center	office	249,000	877	94,399	$182,645
20	First National Bank @ 114 & Dodge St.	office	109,000	188	1,928	$22,383
21	First National Bank Tower	office	754,000	56,802	9,849	$356,329
22	Fremont Department of Utilities	Office	26,000	115	0	$5,165
23	Jefferson Pilot Financial	Office	132,000	449	4,787	$39,145
24	Lund Company - Regency Center	Office	71,000	1,032	8,802	$82,967
25	Magnum Resources, Inc.-Security America Building	office	85,000	256	4,752	$42,700
26	Metro Area Transit	Office	348,000	81	4,119	$49,363
27	NP Dodge	office	44,520	121	418	$10,329
28	Physician of Mutual	Office	224,000	428	787	$23,790
29	State of NE. DAS-State Building	Office	268,000	264	757	$22,746
30	Strategic Air & Space Museum	Office	300,000	313		$16,600
31	West Corporation	Office	140,000	393	4,819	$49,003

32	Blair Middle School	School	95,000		423	$2,400
33	Elkhorn Public Schools - Hillrise Elementary	School	38,700	15	92	$1,600
34	Millard West High School	School	337,000	609	8,247	$76,902
35	Westside High School	School	366,000	50	0	$2,290
36	Crossroads Mall	Shopping Center	865,000	2,037	5,697	$119,292
	Total		7,283,520	78,906	198,259	$2,702,264

The total floor area is 7,283,520 square feet. The annual electricity savings are 78,906 MWh. The annual heating energy savings are 198,259 MMBtu/yr. The potential annual energy cost savings based on actual utility rate are $2,702,264, which is equivalent to $0.37/ft^2.

Table 2 presents the average building floor area, average annual building electricity savings, average heating energy savings, and cost savings. The average building floor area is 202,320 square feet. The average annual building electricity energy savings is 2,191 MWH. The average heating energy savings is 5,507 MMBtu. The average annual energy cost savings is $75,063/yr, or $0.37/ft^{2}yr.

Table 2: Average Energy Evaluation Information

Floor Area (ft^2)	Electricity Savings (MWh/yr)	Heating Energy Savings (MMBtu/yr)	Cost Savings ($/yr)
202,320	2,191	5,507	$75,062

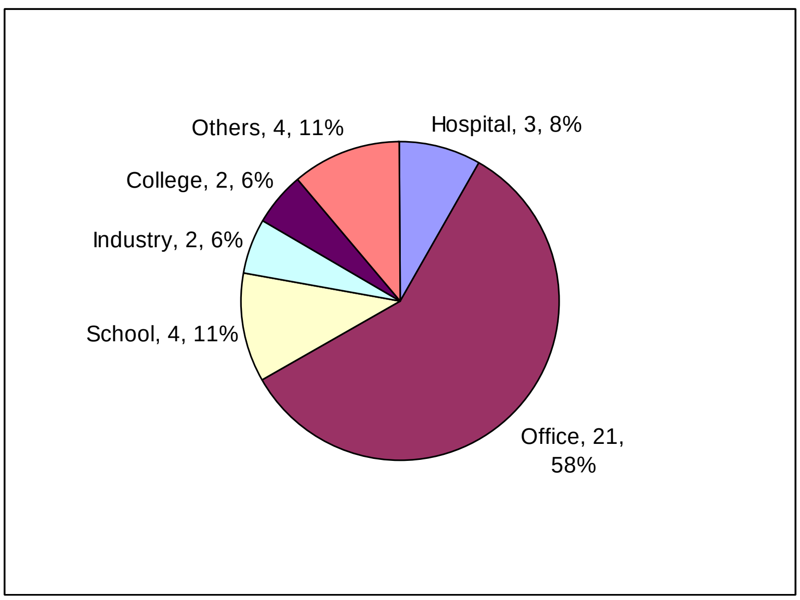


Figure 2: Distribution of Building Energy Performance Evaluated

Figure 2 presents the distribution of building evaluated. The majority buildings are office buildings. It also includes 4 schools, 3 hospitals, 2 industry facilities, 2 college buildings, and 4 others.

CCLRP DEMONSTRATION PROJECTS

In the initial proposal, two demonstration projects are proposed. The first two CCLRP projects were started in August 2002. The first project is Terrace Plaza building, which is 50,000 square feet building built in 1972. Through CCLRP process, both chillers and EMCS system were designed and sized optimally. The cost was minimized. The building electricity energy cost was reduced over 50% (See Appendix 1 for more details).

The second project was Ak2 building, which was built in 2001 with modern EMCS systems. HVAC system operations have been optimized using the existing EMCS systems. Building comfort was greatly improved and HVAC energy consumption and cost was reduced by 45% (See Appendix 2 for details).

The success of these two case studies was quickly spread out in the communities through referral and new paper article. By the end of August 2004, 14 buildings has started and/or completed CCLRP process. Table 3 summarizes the information.

Table 3: Summary of the CCLRP building Information

	Building Name	Type	Floor Area	Energy Savings			Project Cost
			ft^2	MWH/yr	MMBtu/yr	$/yr	
1	St. Stephen the Martyr	church	91,000	135	592	$10,740	$14,000
2	Education Center	College	80,000	155	260	$6,979	$10,052
3	York General Medical Care Services	Hospital	98,000	420	3,458	$37,740	$54,963
4	Ameritrade	Office	63,500	155	1,625	$14,543	$40,000
5	Central States Health & Life	Office	142,000	1,230	3,808	$69,811	$61,000
6	Empire Fire	Office	100,000	105	464	$8,125	$8,500
7	FDR-Ak2	Office	200,000	339	1,584	$27,782	$15,000
8	Jefferson Pilot Financial	Office	132,000	449	4,787	$39,145	$41,400
9	Lund Company - Regency Center	Office	71,000	1,032	8,802	$82,967	$44,880
10	Millard West High School	School	337,000	609	8,247	$76,902	$99,997
11	Westside High School	School	366,000	50	0	$2,290	$20,000
12	Terrace Plaza	Office	49,000	NA	NA	NA	$15,000
13	Mutual of Omaha	Office	2,000,000	NA	NA	NA	$30,000
14	Energy Plaza - OPPD	Office	200,000	NA	NA	NA	$120,880
	Average		152,773	425	3,057	34,275	37,254

The detailed building energy evaluations were not performed for Terrace Plaza, Mutual of Omaha, and Energy Plaza buildings. Based on 11 buildings in which detailed energy evaluation were performed, the average building size is 152,773 square feet. The average annual energy cost savings are $34,275. The average project cost is $37,254.

ENERGYSTAR BUILDING EVALUATION

EnergyStar evaluation was performed in 25 buildings. Table 4 presents the summary information.

Table 4: Building List of EnergyStar Evaluation

Facility Name	Total Floor Space (Sq. Ft.)	Actual Annual Energy Intensity (kBtu/Sq. Ft.)	Rating
Aksarben #2 (after CC)	195,580	57.5	85
BCBS South Office Building	112,000	97.5	N/A
Beadle Middle School	125,458	54.9	29
BPS Welcome Center	37,662	49.6	46
Educational Service Unit #3	80,000	63.5	61
Elkhorn Ridge Middle School	95,000	39.9	N/A
Empire Fire & Marine INS (after CC)	125,556	74.10	77
HPER Bulding	168,116	36.2	N/A
St. Stephen Church	91,000	62.3	70
Millard West High School	337,871	98.1	15
Miller Park Elementary	67,216	51.3	23
Norris Elementary	49,607	80.6	37
North Elementary	15,485	79.7	N/A
Peter Sarpy Elementary School	63,816	56.7	53
Rohwer Elementary	60,366	37.9	76
Rosehill Elementary	39,374	62.1	19
Saint Stephen	90,000	65.6	54
Spring Ridge Elementary	55,000	66.8	16
Strategic Air & Space Museum	300,000	26.9	N/A
Twin Ridge Elementary	40,895	57.3	47
Valmont Plaza East	74,000	190.2	41
Valmont Plaza West	110,000	161.0	41
Wake Robin Elementary	45,782	52.1	49
Westside High School	366,323	68.8	26
Wheeler Elementary	60,366	38.7	76

At the end of August 2004, the project team identified two EnergyStar buildings and created two EnergyStar buildings through CCLRP process.

The initial goal of the project was to identify and create 20 EnergyStar buildings. This goal was not achieved because of the following reasons:

- The project team initially thought that many new schools with geothermal heat pump system would satisfy the requirement of EnergyStar buildings. After many building evaluation, we found it was not.
- Many office buildings have poor envelope design, such as single glazed windows.
- Many HVAC systems are out of date.
- Many EMCS systems are not fully utilized.

The finding of the project indicates the strong need of the energy efficiency improvement projects in the State of Nebraska. Table 4 shows that many of the good buildings at the State of Nebraska are below national average based on EPA's EnergyStar profiling.

TECHNOLOGY TRANSFER AND INITIATE STATEWIDE ENERGY EFFICIENCY PROGRAM

To transfer the CCLRP technology, the project team has conducted the following activities:

- Conducted a workshop to the Omaha ASHRAE chapter. The workshop detailed the CCLRP technology, process, and case studies to 50 participants, which include HVAC engineers, architects, control providers, building owners, and facility management and operating staff.
- Conducted a workshop to the Nebraska hospital association in Lincoln, Nebraska. The workshop presented the CCLRP technology, process, and case studies to 24 participants, which include hospital facility management and operating staff, and control system providers.
- Omaha Herald New Paper interviewed the project team and published an article on the CCLRP process.
- OPPD published three articles in its IDEA magazines which circulate in its customers.
- OPPD presented the CCLRP in its 2004 customer meeting.

The project has created an excellent start for the statewide energy efficiency program. Through this program, the detailed energy evaluation has been performed in 36 buildings. 14 of these 36 buildings have implemented CCLRP process through the project team. Other building owners implementing CCLRP process them own. For example, the Creighton Medical Center has started the implementation process with total project cost of $3,500,000.

Case Study I: Continuous Commissioning (CC)

Facility: First Data Corporation (FDC) – AKSARBEN 2 Building, Omaha, NE

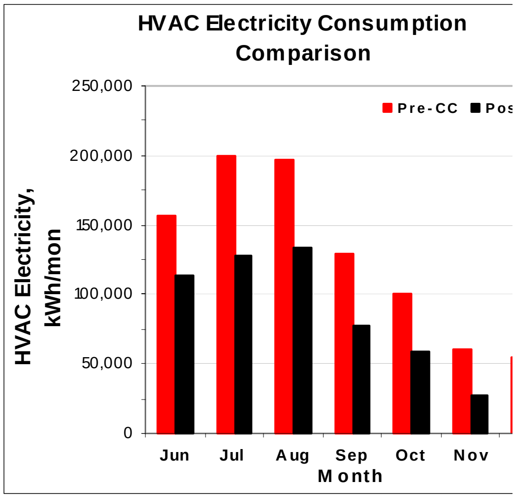
Built in 2001
4-story office building with 195,580 ft2
Two SD VAV AHUs
Two centrifugal chillers
Ten boilers
Advanced EMCS system

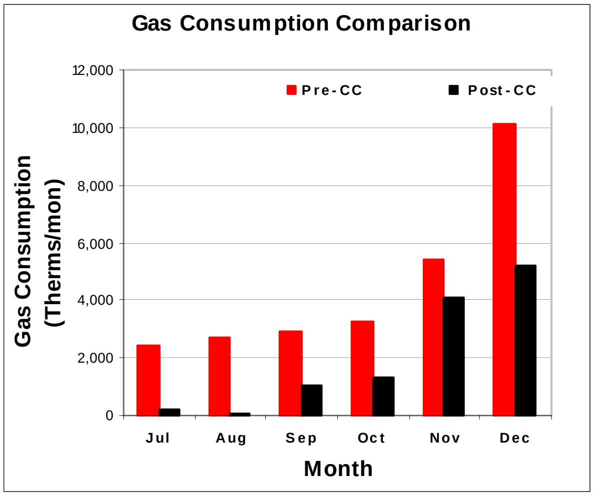
Continuous Commissioning Services (completed in June 15, 2003)

- Implemented optimal control on AHU, such as 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.
- Modified the boiler operation sequences.
- Others.

Benefits

- Maintain building comfort temperature 24 hours per day and seven days per week.
- Reduced comfort complaints and improved system reliability.
- Reduced HVAC utility costs by 40% based on last nine months of utility data since project completion (June15, 2003).
- Qualified for EnergyStar Building in five months after CC completion.





Case Study II: Continuous Commissioning (CC) Leading Energy System Upgrades

Facility: Terrace Plaza, Omaha, Nebraska

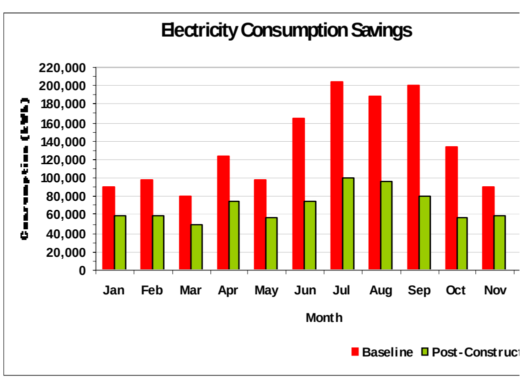
- Built in 1972.
- 3-story rental office building
- 49,436 ft2
- A single-duct cooling only VAV AHU
- A 150 ton chiller
- 52 pneumatic boxes
- Perimeter radiator heating

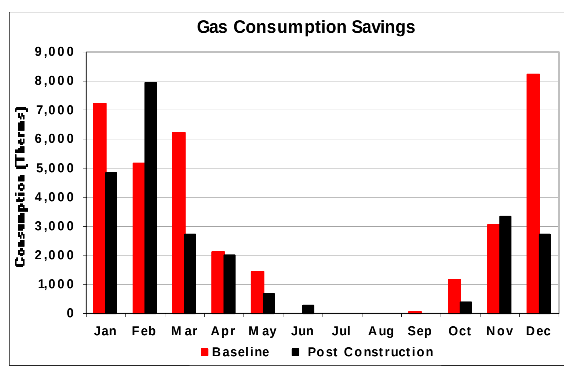
Implementations of Continuous Commissioning Leading Energy System Upgrades

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

Benefits

- Improved reliability of HVAC system operation
- Improved building comfort
- Reduce overall maintenance costs
- Reduced electricity consumption of 47% and natural gas consumption of 28%, based on the first year of utility data since project completion. The total energy utility cost savings is $38,675/yr ($.78/s.f. per year) at the current average prices of $0.044/kWh for electricity and $.633/therm for gas.





IMPLEMENTING THE CONTINUOUS COMMISSIONING PROCESS IN RETROFIT PROJECTS

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ABSTRACT

Continuous Commissioning (CC^{SM}) 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. CC focuses on optimizing/improving overall building systems control and operations and on meeting existing facility needs. Implementation of the CC process has typically decreased building energy consumption by 20% in over 100 large buildings where it has been implemented. This paper presents methods and procedures for applying CC concepts to building commissioning projects in order to reduce the initial cost and maximize energy savings. The process is demonstrated using case studies where the retrofit project was decreased by 25% while the energy savings was increased by 30%.

ABOUT THE AUTHORS

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INTRODUCTION

The Continuous Commissioning (CC) process has proven to be one of the most cost-effective processes to improve existing building energy performance and comfort. The CC process has resulted in an average energy reduction of over 20% in 130 buildings [1, 2, 3, 4] with simple paybacks in typically less than two years.

The major CC savings result from implementation of innovative engineering measures and optimal controls of HVAC systems. Most of these measures, if not all, can be implemented during the design phase of new building construction and existing building retrofits, if these measures are specified clearly and properly. Therefore, it is generally believed that a well-designed new building with state-of-the-art technologies has little or no potential of reducing energy by retrofit or commissioning. However, CC is suitable for new and well designed systems. This paper first presents a case study to demonstrate the comfort improvement and energy savings achieved in new buildings with state-of-the-art technologies through Continuous Commissioning.

The process of implementing innovative engineering measures and optimal controls during retrofitting is called the CC Leading Retrofit Process (CCLRP). Since implementation of innovative measures and optimal controls during a design phase may result in significant energy savings and comfort improvement without a CC cost or with significantly lower CC cost, old buildings with no advanced equipment and control strategies definitely have energy savings potential. CCLRP is one of the most effective ways for old buildings to achieve energy savings and thermal comfort improvement. This paper presents the CC Leading Retrofit Process using a case study building in which measured building performance improvements are demonstrated.

CC PROJECT

The case study building, located in Omaha, Nebraska, was built in 2001. It has four stories with a total gross floor area of 247,500 square feet. The building is served by two chilled water central air-handling units (AHUs) which are located in the penthouse. Chilled water is supplied by two in-house chillers. The case study building meets the EnergyStar requirements. The building is well-designed and maintained.

A detailed energy study concluded that significant energy improvements can be achieved in the building by optimizing the control schedules. In the following sections, the existing and optimal control schedules of the case study building are compared.

VAV Box Operation Schedule:

Schedule before CC: The unoccupied schedule ran from 10 p.m. to 3 a.m. (unoccupied hours). During unoccupied hours, the systems had a zero supply airflow rate set point and nighttime temperature reset. Depending on outside air conditions, the room temperature could be anywhere from 65°F to 85°F. Positive pressure in the building was not ensured because the AHU may not have supplied any air to the building when the exhaust fans were on.

Schedule after CC: The unoccupied schedule goes from 5:30 p.m. to 7 a.m. During unoccupied hours, the terminal box will reset the minimum airflow to zero for the exterior zone and 10% for the interior zone. The zone temperature remains at the daytime set point. The improved schedule differs from the existing schedule in the following ways:

- It provides occupants thermal comfort at all times and reduces late night and weekend workers' complaints.
- It provides positive building pressure at all times and prevents moisture condensation damage in buildings.
- It reduces building energy cost by extending unoccupied hours from 5 hours to 14 hours on the weekdays.
- It saves fan power during a warm-up or cool-down period (See Figure 3 for details).
- It saves chilled water pump and chiller power during the cool-down period.
- It extends the service life of the fan, pump motors and chillers.

Supply fan control:

Schedule before CC: The supply fan was controlled to maintain the duct static pressure, which was determined based on the following rules:

At least one terminal box damper was maintained at a maximum open position (96%). If the maximum damper position was less than the maximum damper position set point, then the static pressure set point was decreased, and vice versa.

The static pressure set point was not allowed to be lower than 1.5 inH_2O.

The static pressure was not allowed to be higher than 2.5 inH_2O.

Figure 1 shows the actual fan speed and static pressure set point of AHU2 for a typical day operation (May 2). AHU1 had a similar profile. AHU2 had its static pressure set point at 1.5 inH_2O the entire time. The static pressure set point was set at too high a value. Extra fan power was being consumed and more noise was being produced.

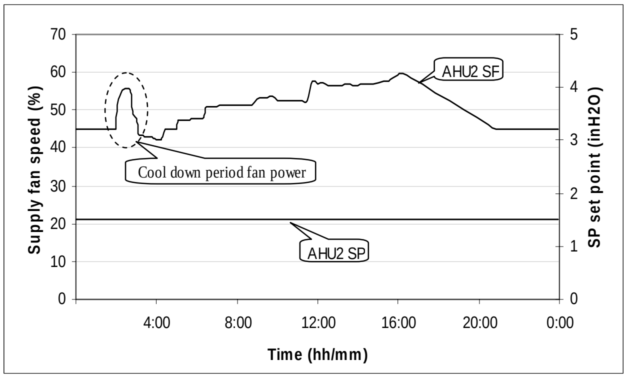

Figure 1: Supply Fan Speed and Static Pressure Set Point (May 2)

Schedule after CC: Reset the static pressure set point based on fan speed. Figure 2 shows the comparison of the existing schedule and new schedule of AHU2. The optimal static pressure set-point schedule will allow the damper to be fully open to save fan power and reduce noise level.

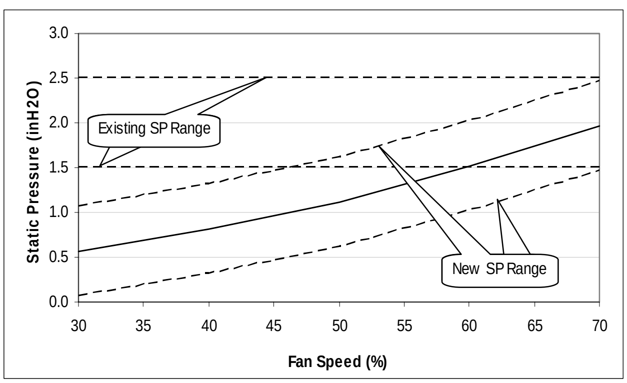

Figure 2: Comparison of Existing and Recommended Static Set Point Schedule

Supply air temperature reset:

Schedule before CC: When the outside air temperature was lower than 50°F, the supply air temperature was maintained at 63°F. When the outside air temperature was higher than 75°, the supply air temperature was maintained at 53°F. The supply air temperature was reset linearly from 63°F to 53°F when the outside air temperature increased from 50°F to 75°F. The current schedule may not maintain good building humidity control during mild and humid weather conditions due to a relatively high supply air temperature set point. It can also cause excessive chiller and pump power since the supply air temperature was set at lower than the design value during summer.

Schedule after CC: When the outside air temperature is lower than 50°F, maintain the supply air temperature at 63°F. When the outside air temperature is higher than 55°, maintain the supply air temperature at 55°F. Reset the supply air temperature linearly from 63°F to 55°F when the outside air temperature increases from 50°F to 55°F. The improved operation schedule eliminates the problems associated with the existing schedules. It also saves significant chiller and pump power during summer operations.

Return fan control:

Schedule before CC: The return fan was controlled by relief damper position according to the following rules:

When the relief damper was less than 25% open, the relief chamber static pressure set point was controlled at -0.02 inH_2O.

When the relief damper was higher than 96% open, the relief chamber static pressure was controlled at 0.1 inH_2O.

When the relief damper was less than 50% and 75% open, the relief chamber static pressure was controlled at 0.0 and 0.1, respectively.

The relief damper position was controlled by the building static pressure sensor.

This return air control schedule maintained negative (-0.02 inH2O) static pressure during the summer. Consequently, the relief air damper served as outside air intake. Since the relief air damper can be as high as 25% open, the uncontrolled outside air intake can be significant. This can cause excessive chilled water energy consumption.

Negative building pressure was also observed. The current control schedule could not maintain positive building pressure.

Schedule after CC: Control the return fan by supply fan tracking. The positive building static pressure can be maintained by a certain amount of difference between supply airflow and return airflow.

Economizer control:

Schedule before CC: When the outside air enthalpy was higher than 17Btu/lbm, the economizer control was turned off. This control schedule did not take 40% of the free cooling season (1455hrs/3837hrs).

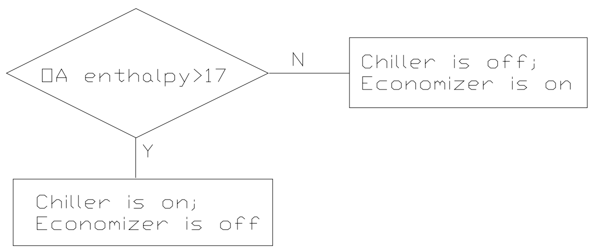

Figure 3: Flow Chart of Current Economizer Control

Schedule after CC: When outside air enthalpy is less than return air enthalpy, the economizer will be enabled. This will increase economizer operation time by 1450 hours per year and significantly reduce electricity energy consumption during these hours. Figure 4 shows the control logic. The recommended economizer operation will significantly improve the indoor air quality since more outside air is provided to the building over 1450 hours per year.

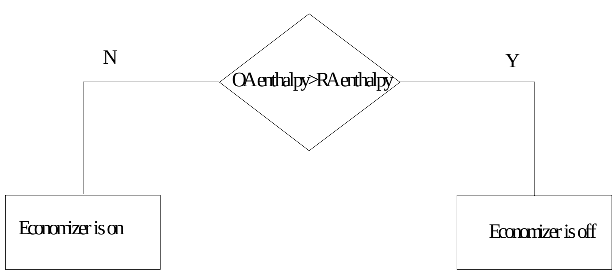

Figure 4: Recommended Economizer Control

Minimum outside air intake:

Schedule before CC: Calculate the required outside air for ventilation purposes using the design occupancy schedule during the non-economizer period, which controlled minimum outside air damper by comparing outside airflow station measurement results. During unoccupied hours, there was no outside air intake. Due to malfunctioning of the AHU2 outside airflow station, the controller was overridden by zero minimum outside air intake. Field inspection proved the malfunction flow station was due to broken transducer connection. It was also found that outside air damper could not be fully closed due to inappropriate installation, which caused excessive outside air intake all times.

Schedule after CC: Recalculate occupied minimum outside air requirements based on the current occupancy schedule instead of the design occupancy schedule, and the unoccupied minimum outside air requirements based on the exhaust fan operation schedule. New occupied minimum outside air intake will reduce cooling and heating consumption, and unoccupied minimum outside air intake will keep positive building pressure.

Chiller and chilled water loop control:

Schedule before CC: The chiller was turned on when the economizer was off (schedule as shown in Figure 5). Chilled water supply temperature was maintained at 40°F; when chilled water supply temperature was higher than 42.5°F, the second chiller was on. The chilled water had a primary loop/secondary loop, as shown in Figure 6, which are circulated by a primary pump and secondary pump, respectively. The previous chiller and chilled water pump system controls had the following disadvantages: (1) excessive building bypass flow; for example, the temperature difference between chilled water supply and return can be as low as 2°F, (2) low load operation of both chillers, (3) excessive primary pump power and condense water pump consumption, and (4) excessive secondary pump energy consumption due to inappropriate minimum differential pressure set point.

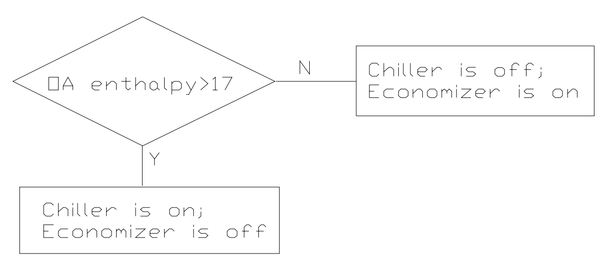

Figure 5: Chiller On/Off schedule before CC

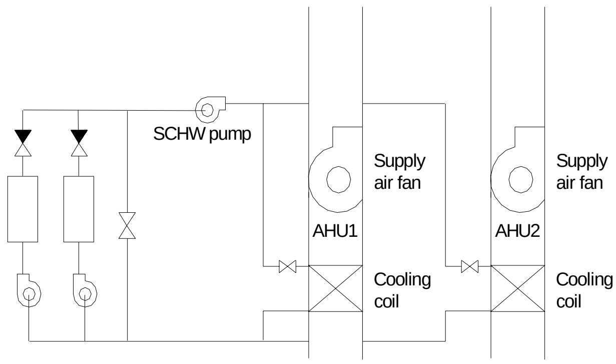

Figure 6: Chilled water loop before CC

Schedule after CC: When the outside air temperature is higher than 60°F or the mixed air temperature is higher than the set point plus the dead band, turn the chiller on. Close the bypass valve and change two chilled water loops into one single loop (as shown in Figure 7). Control chiller operation by building load which is separated into LOWLOAD mode, HIGHLOAD mode and SNDCHILLER mode.

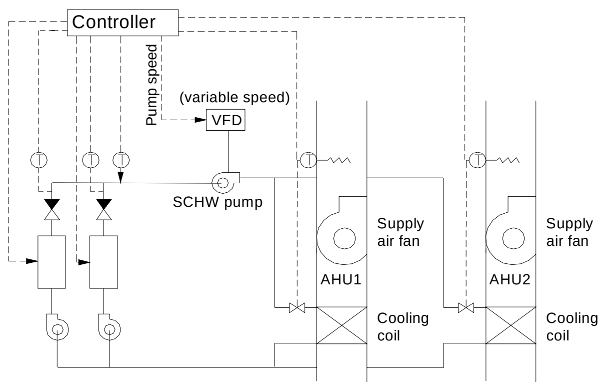

Figure 7: Chilled water loop and control after CC

During LOWLOAD mode, only one chiller is on and one primary pump circulates the chilled water through the cooling coils. The chilled water supply temperature is reset to maintain cooling coil valve position at 80% ~ 100% open. When the chilled water temperature reaches the minimum value and the maximum chilled water valve is 100% open, the chiller mode switch to HIGHLOAD mode. If the outside air temperature is below 57°F and the mixed air temperature is below the supply air temperature set point, the chiller is turned off.

During HIGHLOAD mode, the secondary chilled water pump is enabled to increase chilled water flow rate through the coils with minimum chilled water supply temperature (45°F). The secondary chilled water pump speed is controlled by VSD to maintain the cooling coil valve at 80%~100% open. If the chilled water temperature is higher than the chilled water temperature set point and the maximum valve position is 100%, the chiller mode is switched to SNDCHILLER mode. The chiller mode switches to LOWLOAD mode automatically when the supply air temperature is less than the set point minus dead band.

Under SNDCHILLER mode, both chillers are on. When the temperature difference between the chilled water supply and return is lower than 5°F and the supply air temperature is lower than the set point minus dead band, the chiller mode switches back to the HIGHLOAD mode.

Boiler control:

Schedule before CC: The boiler was controlled by the hot water supply temperature set point. When outside air temperature was higher than 50ºF, the supply water temperature was 140ºF. When outside air temperature was lower than 0ºF, the supply water temperature was 190ºF. When the outside air temperature was 40ºF, 30ºF, 20ºF, and 10ºF, the supply water temperature was 150ºF, 160ºF, 170ºF, and 180ºF respectively. Figure 8 shows the hot water supply and return water temperature (May 1). The temperature difference between supply and return was mostly less than 5°F. The existing boiler and hot water pump schedules had the following disadvantages: (1) excessive building bypass flow, e.g., the hot water supply temperature was the same as the return temperature most of the time under mild weather, and (2) excessive boiler operation when outside air temperature was high.

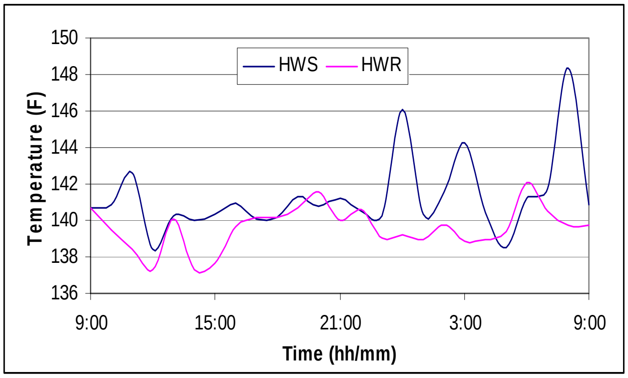

Figure 8: How water supply and return temperature

Schedule after CC: When the outside air temperature is higher than 50ºF, maintain the supply water temperature at 110ºF. When the outside air temperature is lower than 0ºF, maintain the supply water temperature at 160ºF. When the outside air temperature is 40ºF, 30ºF, 20ºF, and 10ºF, the supply water temperature will be 120ºF, 130ºF, 140ºF, and 150ºF respectively. When the outside air temperature is higher than 60ºF, turn off the boilers.

Hot water pump control:

Schedule before CC: Hot water pump was running year-round to maintain the differential pressure of the remote reheat coil at $17ftH_2O$ even though boilers were off. Field measurement detected that when the outside air temperature was 53°F, the hot water pump provided 75% of the design pump head to keep $17ftH_2O$ set point with the same supply hot water temperature and return hot water temperature. The previous hot water pump schedule had excessive hot water pump energy consumption due to inappropriate DP set point and no disable command when boilers were off.

Schedule after CC: The hot water pump speed is controlled to maintain the differential pressure of the remote reheat coil at 8 ftH_2O (adjustable). Shut off the hot water pump when boilers are disabled, and program the pump to be enabled once a month during the boiler disable period for maintenance purposes.

Results: The hot water pump can be shut off about four months a year instead of running year-round.

CC RESULTS

This section presents the building energy system performance and energy savings of the case study building after optimal control schedule implementation. The optimal VAV box operation schedule expands the building thermal comfort up to 24 hours a day.

Figure 9 presents the measured AHU 2 supply fan speed and the static pressure set point on June 21, 2003. AHU1 has a similar profile. The duct static pressure can be as low as 0.2 during unoccupied hours and fan speed can be as low as 20%. Significant fan power and noise level are reduced.

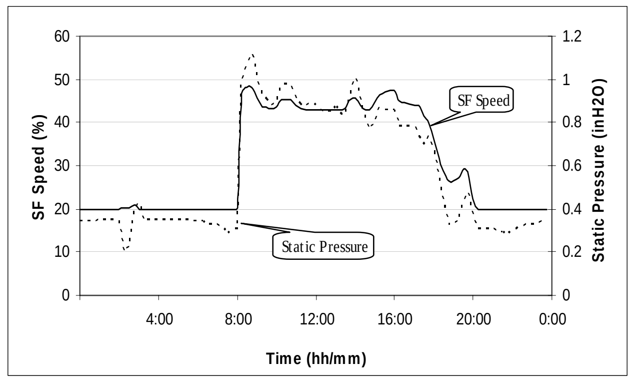

Figure 9: Measured supply fan speed and static pressure under the optimal schedules for AHU 2 on June 21, 2003

Figure 10 presents the measured chilled water supply and return temperature and the difference of the supply and return chilled water temperatures on July 2 under the optimal control schedule. The chiller operation stayed in LOWLOAD mode during unoccupied hours (midnight to 8 a.m. and 6 p.m. to 12 midnight). The chilled water temperature was reset to maintain minimum chilled water flow. When the outside air temperature increased and the building was occupied, the chiller operation was switched to HIGHLOAD mode. The chilled supply water temperature was maintained at the minimum set point (45ºF) and the secondary pump was enabled to circulate more chilled water flow through the cooling coils.

At approximately 1:30 p.m., the chiller was not able to maintain the minimum supply water temperature due to increased chilled water flow. At 2:30 p.m., when the chilled water temperature was higher than the set point plus the dead band, the second chiller was turned on. The temperature difference between chilled water supply and return was maintained at about 10°F most of the time. The chiller and chilled water loop returned to LOWLOAD mode after 6 p.m. The chiller and chilled water loop operated in response to the building load. Chiller efficiency and cooling coil heat transfer were improved significantly. The supply air temperature was still maintained at 55°F to satisfy the building humidity and comfort requirements.

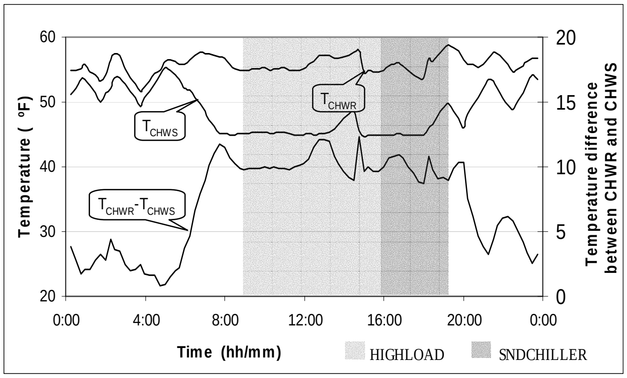

Figure 10: Measured chilled water supply and return temperatures, and their difference on July 2, 2003 (Remove the supply air temperature)

Figure 11 compares the daily HVAC electricity consumption under both the original and optimal control schedules. The original data were measured from June 16 to June 30, 2002. The current data were measured on the same dates in 2003. The mean HAVC electricity consumption was generated for each hour. The HVAC electricity difference varied from 80 kW to 150 kW.

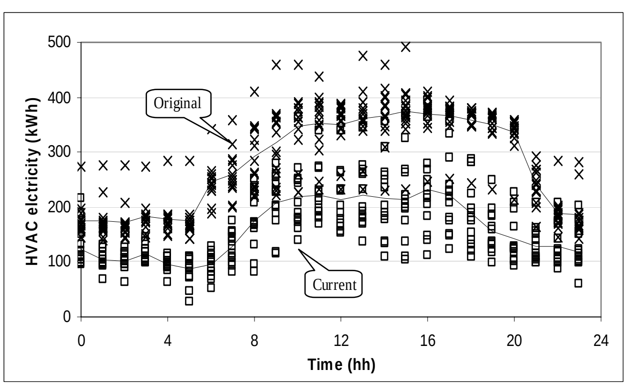

Figure 11: Comparison of daily profiles of HVAC electricity consumption

Figure 12 compares the HVAC electricity consumption under previous and the optimal schedules against the ambient air temperature. With temperature corrections, it appears that the average hourly electricity savings is approximately 85 kW. Based on these measured results, the annual electricity energy savings was estimated as 744,600 kWh, which is 18% of the entire building electricity consumption and 40% of the annual HVAC electricity energy consumption. If the electricity price is \$0.05/kWh, the annual electricity cost is \$37,240/yr.

Figure 13 compares the gas consumption at the same month before and after CC. Significant amount of gas energy savings have been achieved. Due to limited data, the annual energy savings can't be projected accurately at this time.

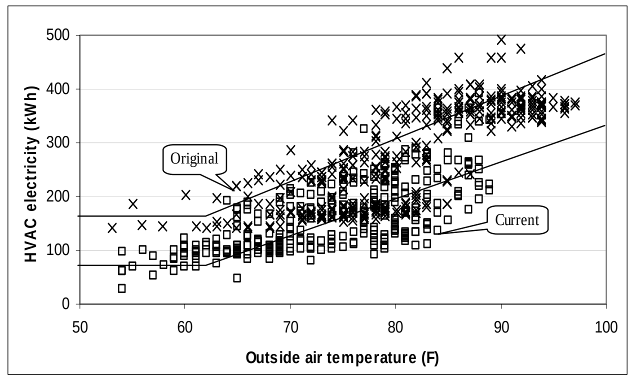

Figure 12: Comparison of correlations between HVAC electricity consumption and outdoor air temperature

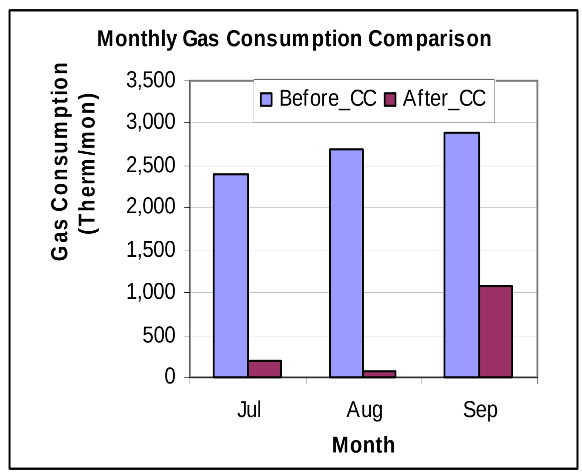

Figure13: Gas monthly bill comsumption comparison

CCLRP PROJECT

The case study building, located in Omaha, was built in 1972 and renovated in 1987. This 3-story building has a floor area of 59,400 square foot. The single panel glass window area is 45% of the total exterior envelope. It is used as a typical rental office building. The building is occupied from 6 a.m. to 10 p.m. during the weekdays and 6 to 8 hours on Saturday.

HVAC systems are located in the penthouse and serve the entire building. Most of the systems are original and are 30 years old, except the cooling tower which was replaced five years ago. The chilled water system includes a 150-ton chiller, a cooling tower, a constant speed chilled water pump (10 HP), a condensing water pump (7.5 HP), and two cooling coils. A two-way control valve is located in the inlet of the upper coil. The chiller typically starts by late April and is shut off by late October, depending on the outside air temperature. The systems are operated 24 hours per day and seven days per week.

The hot water heating system consists of one boiler and three constant-speed pumps (two 2HP and one 0.5HP), which serve radiators. The pumps for the first and second floor have three-way valves. Modulations of the valves are controlled by the floor thermostats. The boiler is activated when outside air temperature is below 52°F and operated 24 hours per and seven days per week.

The AHU is a single-duct cooling only VAV system. The AHU consists of one supply fan of 100 HP and one return fan of 50 HP. There are a total of 52 VAV boxes (no reheat coil). The minimum airflow of the VAV boxes is set to zero. The AHU operates all year round, 24 hours per day and 7 days per week.

The research team conducted a detailed field energy performance measurement and found the following:

The 30-year-old existing chiller has never produced sufficient cooling to meet building demand and humidity control. The building has excessive heat and humidity during the summer.

The existing pump system has a constant flow operation of 24 hours per day, 7 days per week.

The lower cooling coil consumes the pump head twice as much as the upper one, even though all valves are open.

The condenser water pump is 30 years old and is leaking.

The cooling coils have to be manually operated instead of automatically modulating based on the supply air temperature as the design intent.

The outside air damper has to be manually operated based on the season or outside air, instead of based on the mode of occupancy and outside air temperature according to the original design intent.

Outside air intake is twice as much as necessary, even though the outside air damper is fully closed.

The building pressure reading indicates that the building is in a negative pressure condition.

The original VFD control for the return fan system cannot automatically turn on after being shut off.

Air-handling unit fan energy consumption is twice as much as usual.

Based on the findings mentioned above, the energy assessment team (UNL and OPPD) recommended the building owner use the CCLRP process to improve the building performance. The proposed CCLRP processes are: (1) replace the existing chiller, (2) implement advanced chiller control technologies during the retrofit process, (3) upgrade AHU and chiller control systems, (4) replace old components such as the leaking condensing water pump, outside air damper and return fan VFD and (5) remodel some of the air distribution system to improve building comfort. The proposed work scope was much broader than the building owner planned. However, the project cost was within the owner's budget. After building owner reviewed the proposal, retrofit of the lighting was added to the project list. The CCLRP requires all team members (design engineers, contractor, commissioning team, project, and building owner) to work closely together. The project management was very challenging since the process was new to most of the team members.

With the upgraded control systems, improved operating schedules and advanced control technologies have been implemented in the retrofitted systems. The improved operating control schedules include curtailment of system operation hours, customized supply air temperature reset, optimization of economizer and minimum outside air intake, and duct static pressure reset. Besides those CC measures, some of the advanced technologies are demonstrated below.

Chiller and chilled water loop control:

Figure 14 presents the implemented variable water flow chiller system. A VFD is installed on the chilled water pump. The chilled water pump is directly controlled to maintain the AHU supply air temperature when its speed is higher than the minimum value (60%). When the pump speed is maintained at the minimum value, the chilled water supply temperature is reset to maintain the AHU supply air temperature. This control sequence significantly reduces the pump power and improves the chiller operation performance as well. Figure 15 presents the measured pump power and outside air temperature for a typical spring day operation.

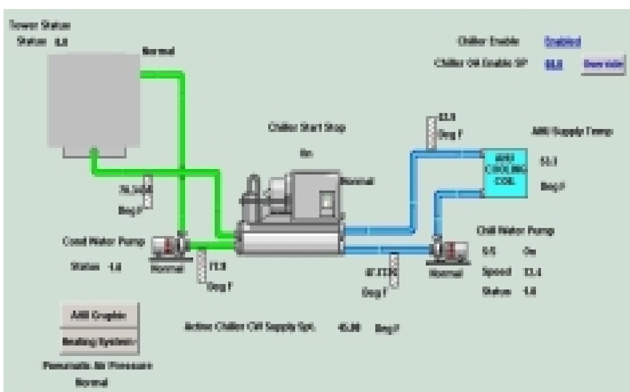

Figure 14: Schematic Diagram of Chiller Systems

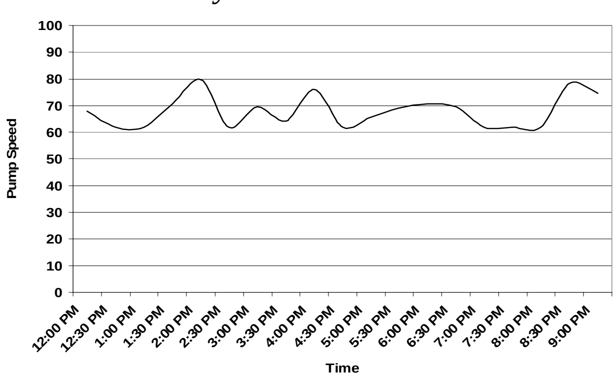

Figure 15: Measured Chilled Water Pump Speed for a Typical Spring Day

Supply and return fan controls:

Fan airflow station technology has been implemented for the building pressure control as shown in Figure 16 [5]. Two tachometers are installed to measure the supply and return air fan speeds. The differential pressure sensors are installed to measure both the supply and return air fan heads. The fan airflows are determined using the measured fan heads and fan speeds integrated with fan curves. The constant airflow difference of the supply and return air fans is maintained to keep the positive building pressure. Figure 16 presents the measured supply air and return airflow and the building pressure using the existing sensor. The fan airflow station has achieved true volume tracking in the building. However, the reading from the existing building differential pressure sensor varies significantly from time to time. Actually, the "dynamic" building pressure is the reflection of the wind variation. It is concluded that the direct building pressure control is incapable of maintaining the building pressure control properly under windy conditions. In fact, it causes fan hunting and shortens the return air fan life span.

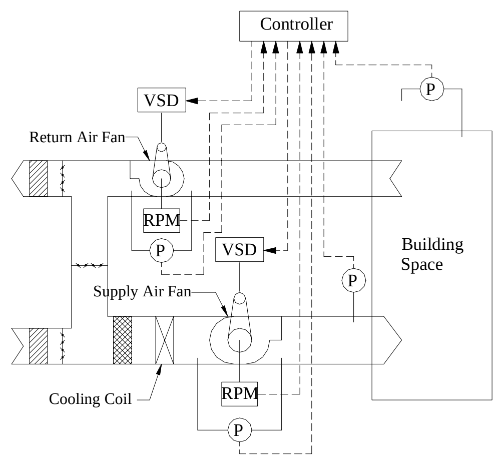

Figure 16: Schematic diagram of the AHU fan AIRFLOW sTATION control

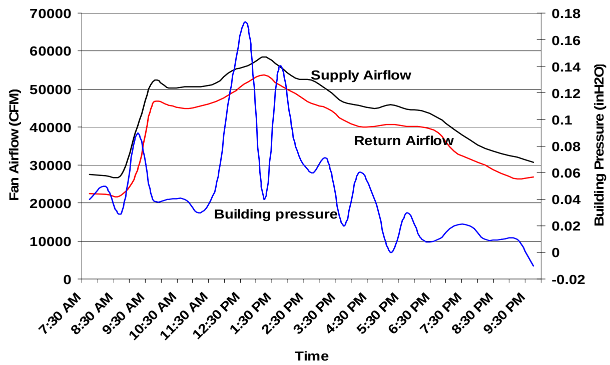

Figure 17: Measured Supply and Return Airflow and Building Positive Pressure for a Typical Day

The integrated fan speed and supply air temperature is implemented to minimize the fan power and reheat energy consumption. The supply air static pressure is reset proportional to the square of the fan airflow rate. When the airflow is higher than the minimum airflow required for circulation, the supply air temperature is set at the minimum value. When the airflow is lower than the minimum airflow, the supply air temperature is reset to maintain the supply air temperature at the minimum airflow.

CCLRP RESULTS

Figure 17 presents the electricity consumption savings between the pre- and post-CC process. Figure 18 presents the utility savings. The electricity savings is as high as 48% for the last four months, and utility savings is about 36% due to the fact that the current demand charge is still affected by the peak demand of the preceding year.

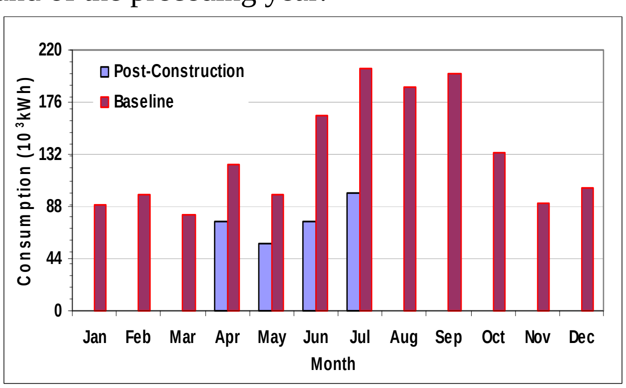

Figure 17: Electricity Consumption Savings

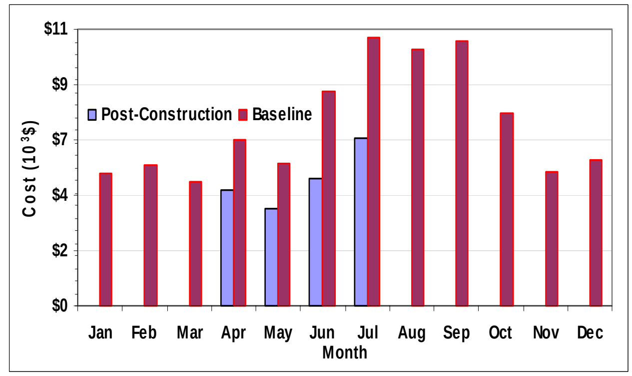

Figure 18: Utility Cost Savings

The CCLRP process has provided rewarding projects to the building owner, commissioning team, design engineers, and the project management team. The building owner has a project completed with 30% capital savings. The commissioning team has its advanced control schedule designed and implemented by design and control engineers. The commissioning is much easier. The design and control engineers have complete confidence of their design that uses advanced technologies since the commissioning team provides the detailed technical information to them. The project management team receives timely help from the commissioning team to answer the “tough calls” from building owners.

CONCLUSIONS

Through the DOE-sponsored Rebuild America program, the authors have successfully demonstrated that the continuous commissioning (CC) process can significantly reduce building energy costs. The CCLRP process can implement the advanced control and optimization measures during the design phase. The CCLRP process can significantly improve the building energy performance when the building is initially constructed and reduce CC costs.

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