VAV System Optimization through Continuous Commissioning® in an Office Building

YoungHum Cho
Graduate Student

Xiufeng Pang
Graduate Student

Mingsheng Liu
Professor of Architectural Engineering, PhD, PE

Energy Systems Laboratory,
University of Nebraska-Lincoln
1110 So. 67th St, Omaha, NE 68182

Abstract

This paper demonstrates the implementation of new innovative technologies during continuous commissioning (CC®) practices to improve building operations and reduce energy costs. The case study building is a 5-story office facility with total floor area of 91,200 square feet, most of which is open space. An energy audit was conducted to evaluate the building's energy performance and identify potential cost-effective energy saving opportunities. Specific Continuous Commissioning® measures were implemented in the building. Indoor comfort was improved and the energy report shows a reduction in electricity consumption. This paper presents procedures, implementations and detailed descriptions of control sequence and operation comparisons before CC® and after CC® for the terminal boxes, air-handling units (AHUs), as well as the chilled water system and hot water system. The results show that electricity savings is 26.8% on average.

Introduction

"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"[1]. In 1988, a group of ASHRAE members proposed building commissioning to ensure that system performance met design specifications. HVAC researchers and engineers have also developed a number of new technologies to improve the existing building energy and comfort performance with CC® [2-4].

The case study building comprises the Tower building and the Crescent building. The 5-story Tower building is used as an office building, which was built in 1988 with a total floor area of 91,244 square feet. CC® was implemented in the Tower building, which is presented in this paper.

This paper presents the case study facility information, existing and improved control sequences and building performance improvement and energy consumption measures before and after CC® implementation.

Facility Information

The plant consists of one chiller and three gas boilers. There are two single-duct VAV air handling units supplying conditioned air to 106 VAV terminal boxes. The typical office hours are from 8:00 a.m. to 5:00 p.m. during the weekdays.

Terminal box

In the tower building, there are two types of VAV terminal boxes. One is a VAV box with reheat coil for exterior zones and the other is a VAV box without reheat coil for interior zones. All of these terminal boxes are controlled by pneumatic controllers. A VAV Terminal Box with reheat coil is shown in Figure 1.

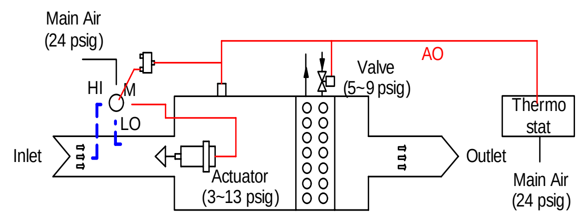

Figure 1. Schematic diagram of VAV Terminal Box with reheat coil

Air-Handling Units

There are two similar single-duct VAV air-handling units serving this building. AHU 1 serves the basement, 1st and 2nd floors. AHU 2 serves the 3rd, 4th and 5th floors. Both use similar control sequences, except that some parameter settings differ. The supply fans and relief fans have their respective VFD controls. One single-duct AHU system is shown in Figure 2.

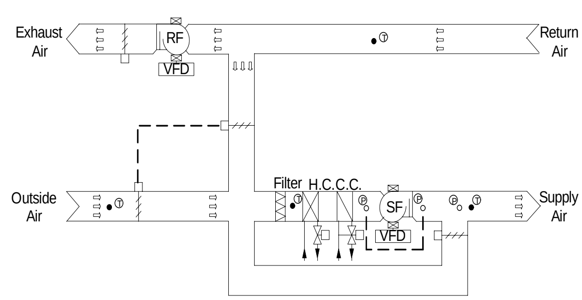

Figure 2. Schematic diagram of AHU

Chilled water system

The chilled water system includes one 250 ton chiller, one 250 ton cooling tower with one 40 HP two-speed tower fan, two 25 HP chilled water pumps and two 20 HP condenser water pumps. The chilled water system is shown in Figure 3.

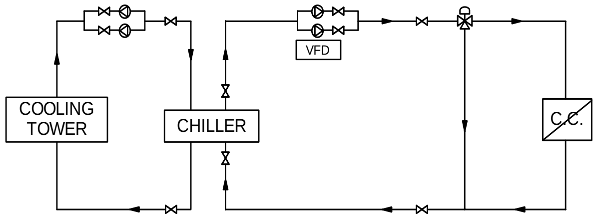

Figure 3. Chilled water system schematic diagram

Hot water system

The hot water system consists of three gas boilers, seven main loop constant-speed pumps and two Tower loop constant-speed pumps. The hot water is directly supplied to the Crescent building, and is supplied to the Tower building through a heat exchanger. The system is shown in Figure 4.

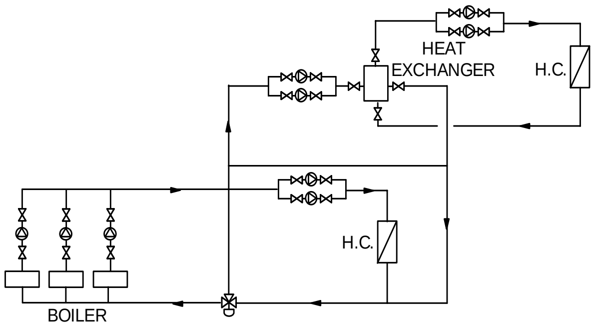

Figure 4. Hot water system schematic diagram

Continuous Commissioning (CC®)

The CC® of the case study building started in October 2005. Most of the recommendations were implemented by April 2006.

The CC® process started by verifying the existing control sequences and taking measurements for selected parameters under the existing operating schedules. Based on the actual site conditions, recommendations for commissioning were developed. Table 1 summarizes the major recommendations and actions taken.

The major control schedules comparison before CC® and after CC®, as well as other CC® activities, are presented in the subsections.

Table 1. Summary of major CC® measures

System	CC®
Terminal boxes	- Reset minimum primary airflow Solve building thermal comfort issue by fixing box mechanical problem
AHUs	- Reset duct static pressure
	- Reset supply air temperature
	- Optimize mixed dampers (economizer)
	- Optimize the preheating valve control
	- Implement the relief fan and building pressure control
	- Optimize operation schedule
Chilled water system	- Reset chilled/condenser water temperature setpoint
	- Implement chilled water pump speed control
	- Optimize operation schedule
Hot water system	- Reset heating water temperature setpoint
	- Optimize operation schedule

Terminal Boxes

The major CC® measures for the terminal boxes involve resetting the minimum primary airflow and fixing the box mechanical problems to achieve building thermal comfort.

Existing schedule: The terminal boxes were originally tested and balanced to provide a minimum primary airflow of 25-50%. The existing control was the cause of several problems. First, the minimum primary airflow of 25-50% caused a majority of the rooms to become too cold when the boiler was not operating during the summer months. Second, the lack of maximum primary airflow caused several rooms to be too hot on a continual basis.

Improved schedule: To solve these problems, adjustments to the minimum and maximum primary airflows were made. Where applicable, the minimum primary airflow in interior zone was set to 0% and the exterior zone was set to 20%. This eliminates the need to operate the boiler during the summer months while maintaining the room temperatures at normal levels, resulting in significant fan power and reheat energy savings. By doing this in conjunction with proper static pressure control from the air-handling units, the rooms receive adequate cooling airflow and do not overwhelm the fan.

Results: After adjustment of the minimum and maximum primary airflows, hot and cold complaints were significantly reduced throughout the building. Moreover, fan and reheat coil energy consumption also decreased. Figure 5 shows the comparison one reheating coil energy consumption of data after reset of the minimum airflow (post-CC). When the outside air temperature is 55°F, the energy consumption is 8177 Btu/hr when there is conventional minimum airflow (56%). On the other hand, the energy consumption is 4623 Btu/hr when there is improved minimum airflow (22%). The thermal energy consumption of improved minimum airflow is less than that of the conventional minimum airflow by 43 %. Therefore, according to adjustment of the minimum airflow, the terminal box in exterior zone can reduce thermal energy.

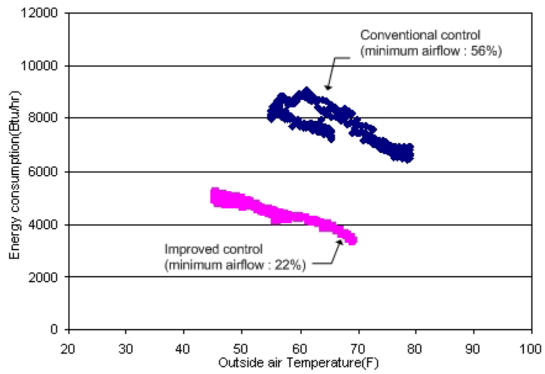

Figure 5. Comparison of energy consumption pre- and post-CC

VAV Air-Handling Units

The major CC® measures for the VAV air-handling units are resetting the duct static pressure, resetting the supply air temperature, optimizing the economizer, optimizing the pre-heat valve control, implementing the relief fan and building pressure control and optimizing the operation schedule. The AHUs operation schedule is shown in Table 2.

Table 2. AHUs Operation Schedule

		Monday		Tuesday ~ Friday		Saturday	
		ON	OFF	ON	OFF	ON	OFF
AHUs	Pre - CC	Operator manually starting and stopping					
	Post - CC	3:30am	6:00pm	4:30am	6:00pm	5:30am	1:00pm

Static pressure control

Existing schedule: The static pressure schedule was maintained at a constant set-point under normal operating conditions. Static set-points were 1.25 in. W.C. and 0.75 in.W.C by operator. Figure 6 shows the trend data for the static pressure and fan speed prior to commissioning (pre-CC) for AHUs 1 on February 25, 2006.

Improved schedule: The static pressure set-point resets based on the airflow ratio. The VFD is modulated to maintain the supply duct static pressure at its set point.

Results: Figure 7 shows the trend data for static pressure and fan speed after implementation of the new control sequence (post-CC) for AHUs 1 on March 16, 2006. Comparison of the trend data for the existing and improved control schedules reveals a reduction in fan speed, as shown in Figure 8. The decline in fan speed results in major power savings and a reduction in noise.

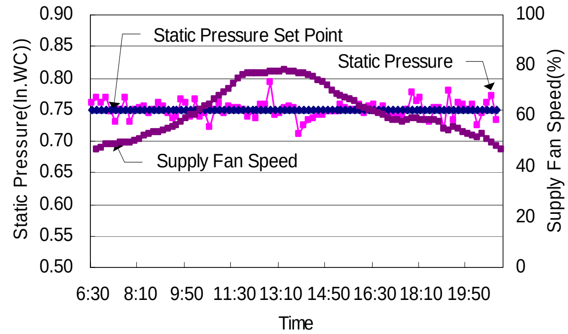

Figure 6. AHUs 1 pre-CC static pressure and fan speed trend (February 25, 2006)

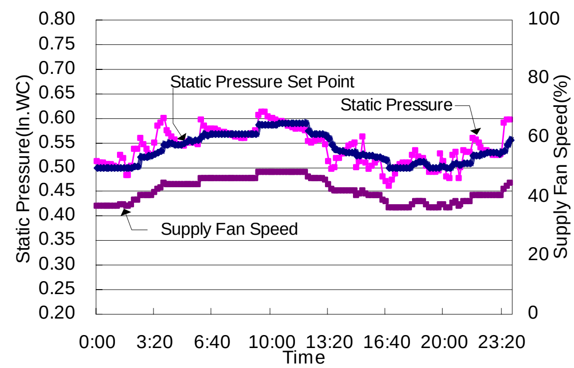

Figure 7. AHUs 1 post-CC static pressure and fan speed trend (March 16, 2006)

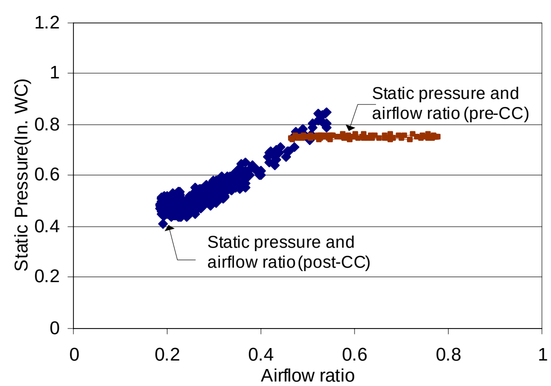

Figure 8. Comparison of static pressure and ratio trends

Supply air temperature control

Existing schedule: The supply air temperature set-point is maintained as 55°F during the summer and 61°F during the winter. Figure 9 shows the trend data for airflow ratio and supply air temperature prior to commissioning (pre-CC) for AHUs 1 on February 25, 2006.

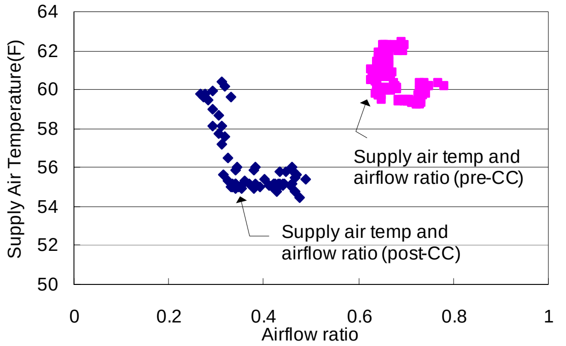

Figure 9. Comparison of the supply air temperature and airflow ratio trend

Improved schedule: The supply air temperature set-point is based on building load. Before the supply fan air flow reaches its minimum limit, which is 30% of maximum flow, the constant supply air temperature set point is adjusted to 55˚F. In addition, the upper limit of the supply air temperature is 68˚F when the outside air humidity ratio is low. Figure 10 shows the supply air temperature control sequence.

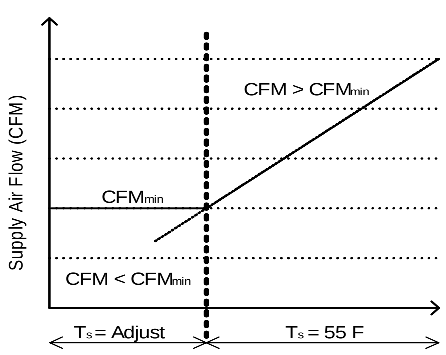

Figure 10. Supply air temperature control sequence

Results: Figure 9 shows the trend data for the airflow ratio and supply air temperature after implementation of the new control sequence (post-CC) for AHUs 1 on March 22, 2006. Comparison of the trend data for the existing and improved control schedules reveals a reduction in fan speed caused by reducing supply airflow from the supply air temperature reset. The decline in fan speed results in major power savings.

Preheating coil

Existing schedule: The existing control modulates the pre-heat valve to maintain the supply air temperature set-point. Figure 11 shows the trending data for the pre-heat coil valve and supply air temperature prior to commissioning (pre-CC) for AHUs 1 on January 11, 2006.

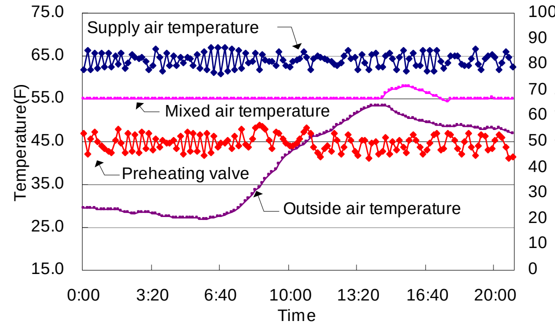

Figure 11. AHUs 1 pre-CC HW valve and supply air temperature (Jan. 11, 2006)

Improved schedule: The pre-heat valve remains closed unless the mixed air temperature reaches the lower limit temperature. Then, the pre-heat valve will modulate to maintain the supply air temperature set-point.

Results: Figure 12 shows the trending data for the preheating coil valve and supply air temperature after implementation of the new control sequence (post-CC) for AHUs 1 on March 21, 2006. The new controls eliminate the use of preheat under most operating conditions. The only period where preheat is required is when the outside air is extremely cold, when the mixed air temperature reaches the lower limit temperature value.

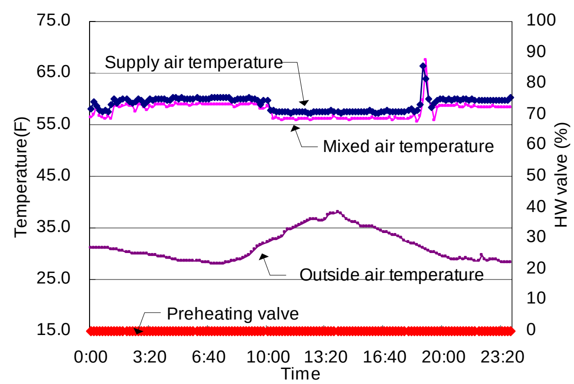

Figure 12. AHUs 1 post-CC HW valve and supply air temperature (March 21, 2006)

Economizer and outside air control

Existing schedule: The outside air economizer was enabled when the outside air temperature was less than 55°F. The outside air economizer was disabled when the outside air temperature was greater than 60°F. The minimum outside air damper position was maintained at 30% open during both occupied and unoccupied hours. Figure 13 shows the trend data for the outside air temperature and outside air intake prior to commissioning (pre-CC).

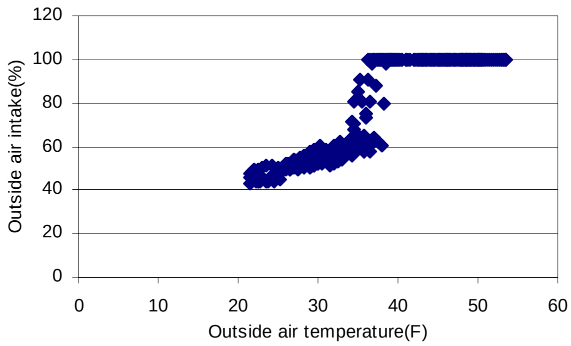

Figure 13. Pre-CC outside air temperature and outside air intake

Improved schedule: When the outside air temperature is lower than 68°F, the economizer is enabled. Table 3 and Figure 14 give the outside air damper control sequence of the AHUs under economizer mode. The minimum outside air damper position corresponds to the occupied and unoccupied periods. The minimum outside air damper position is maintained at 10% open during occupied hours and at 0 % during unoccupied hours. To verify indoor air quality due to reduction in minimum air flow, indoor air quality meters are installed in occupied spaces of the interior and exterior zones on each floor. The average CO_2 level on each floor is in the range of 350 ~ 550 ppm. Therefore, it is judged that IAQ problems due to reduction in minimum airflow rate will not occur.

Table 3. Outside air damper control sequence under economizer mode

Outside air temperature	Outside air damper operation
supply air temp setpoint < T_{OA} =< 68°F	100 % open
T_{OA} =< supply air temp setpoint	Modulate to maintain mixed air temperature set point determined by the supply air temperature control between maximum and minimum position
T_{OA} > 68°F	Minimum position (10%)

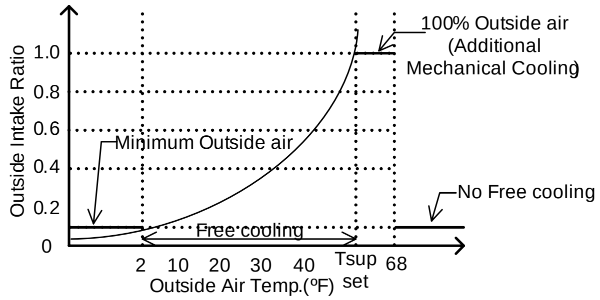

Figure 14. Outside air damper control schedule under economizer mode

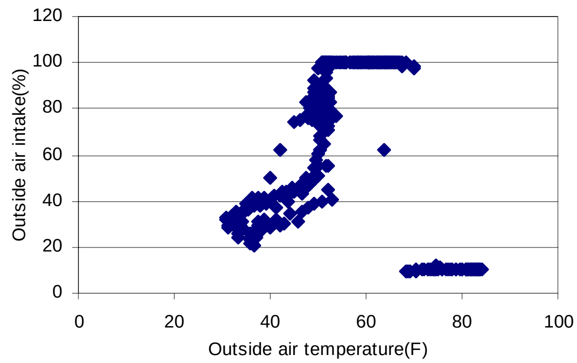

Figure 15. Post-CC outside air temperature and outside air intake

Results: Figure 15 shows the trend data for outside air temperature and outside air intake after implementation of the new control sequence (post-CC). The existing control schedule does not take full advantage of the free cooling, while the improved schedule greatly reduces the cooling energy consumption.

Relief fan control

Existing schedule: The existing control modulates the relief fan VFD to maintain the building pressure at its set-point (0.02 in.W.C). The relief damper is modulated according to the relief fan VFD speed.

Improved schedule: When the outside air damper operates between its minimum position and maximum position, the fan airflow station will be applied to the relief fan speed control. The relief fan VFD will be modulated to maintain a relief airflow set point. The relief damper will be fully open when the relief fan is enabled. When the outside air temperature is higher than 68°F, the relief fan is disabled.

Results: Figure 16 shows the trend data for supply and relief airflows after implementation of the new control sequence (post-CC) for the AHUs 1 on March 27~29,

2006. The new controls eliminate the issue of the building pressure. The new control method eliminates the original building pressure control issue by maintaining a positive pressure (0.05 in. W.C.) in the building.

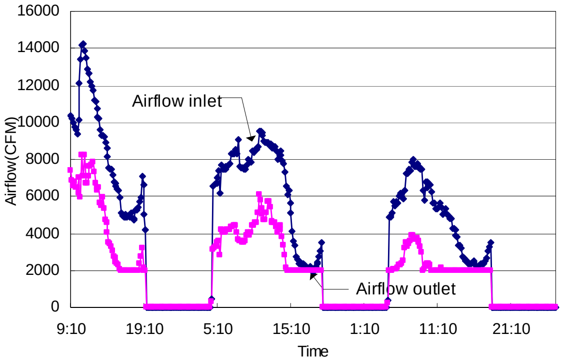

Figure 16. Post-CC supply and relief airflows (March 27~29, 2006)

Chilled water system

The major CC® measures for the chilled water system are the reset of the chilled water temperature set-point, the reset of the condenser water temperature set-point, implementation of chilled water pump speed controls, and an optimized operation schedule. The chilled water system operation schedule is shown in Table 4.

Table 4. Chilled water system operation schedule

		Monday		Tuesday ~ Friday		Saturday	
		ON	OFF	ON	OFF	ON	OFF
Chiller	Pre - CC	Operator manually starting and stopping					
	Post - CC	3:30am, Oat > 55F	6:00pm	4:30am, Oat > 55F	6:00pm	5:30am, Oat > 55F	1:00pm

Chiller start/stop

Existing schedule: To control the chiller, the operator manually turns on/off the chilled water system.

Improved schedule: The chiller starts based on the outside air conditions and occupied hours. The chiller starts at 55°F and stops when the outside air temperature is less than 52°F.

Results: Automatically starting and stopping the chillers eliminates the need of operator to operate the chiller.

Chilled water temperature

Existing schedule: The chilled water supply temperature set-point is maintained at 42°F during normal operation.

Improved schedule: The chilled water supply temperature set-point is reset between 42°F and 48°F based on the chilled water pump speed with minimum speed.

Results: By dynamically adjusting the chilled water supply temperature based on the pump speed, the combined pump and chiller energy consumption are minimized. Figure 17 shows the trend data for chilled water pump speed and supply water temperature after implementation of the new control sequence (post-CC) on June 7~11, 2007.

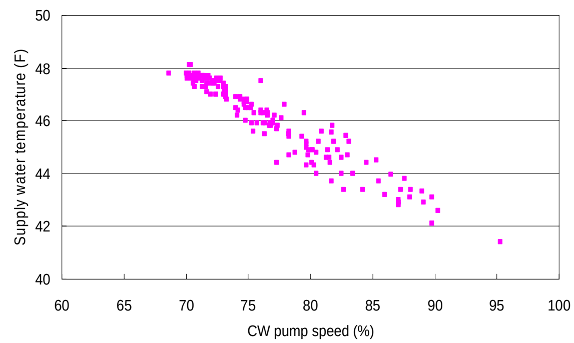

Figure 17. Post-CC supply water temperature and pump speed (June 7~11, 2007)

Chilled water pumps

Existing schedule: The chilled water system is configured with two constant flow chilled water pumps without VFD.

Improved schedule: The chilled water pumps are modulated in unison to maintain the supply air temperature. When the three-way cooling control valve at the most resistant water loop is fully open, modulate the VFD speed between its low limit and high limit to maintain the supply air temperature at its set point. The chilled water pump speed increases to maintain the supply air temperature set point when the cooling control valve is over 95% open. The pumps run 10 minutes before the chiller starts.

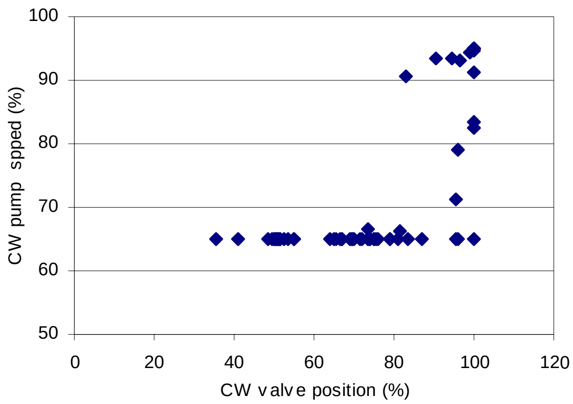

Figure 18. Post-CC CW pump speed and CW valve position

Results: Figure 18 shows the trend data for the chilled water pump speed and cooling coil valve position after implementation of the new control sequence (post-CC) on April 14, 2006. Modulating the pump to maintain the supply air temperature set-point provides the greatest system operating efficiency.

Condenser water temperature

Existing schedule: The condenser water temperature set-point was maintained at 82°F under all operating conditions. Figure 19 shows the trend data for condenser water temperature prior to commissioning (pre-CC) on April 13, 2006.

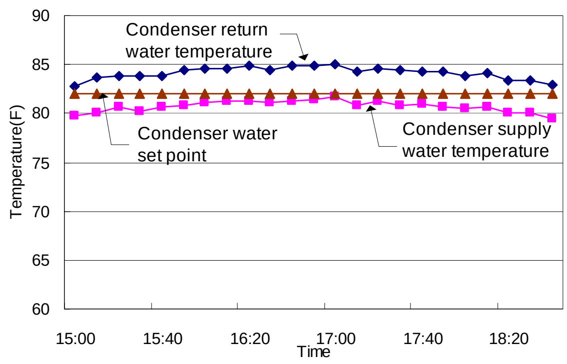

Figure 19. Pre-CC condenser water temperature trend (April 13, 2006)

Improved schedule: The two-speed cooling tower fan will be enabled when the condenser water pump is on and cycled on to maintain the condenser water temperature set-point. The condenser water temperature set-point is reset between 75°F and 90°F based on the outside air wet-bulb temperature.

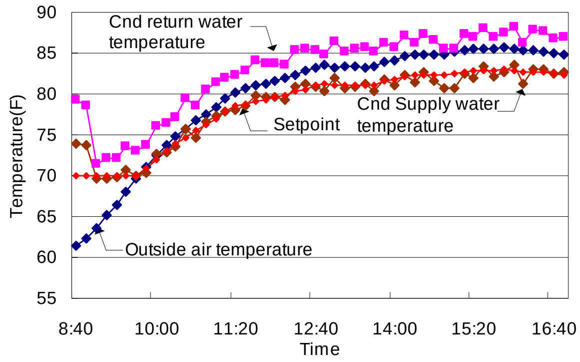

Figure 20. Post-CC condenser water temperature trend (April 14, 2006)

Results: The lowest condenser water temperature available from the cooling tower is a function of the outside air wet-bulb temperature and the cooling tower fan speeds. As the outside air wet-bulb temperature falls, the chiller power is reduced. Figure 20 shows the trend data for condenser water temperature after implementation of the new control sequence (post-CC) on April 14, 2006.

Hot water system

The major CC® measures for the hot water system to reset hot water temperature set-point and develop an optimized operation schedule. The hot water system operation schedule is shown in Table 5.

Table 5. Hot water system operation schedule

		Monday		Tuesday ~ Friday		Saturday	
		ON	OFF	ON	OFF	ON	OFF
Boiler	Pre - CC	Operator manually starts and stops					
	Post - CC	3:30am, Oat < 50F	6:00pm	4:30am, Oat < 50F	6:00pm	5:30am, Oat < 50F	1:00pm

Boiler enable

Existing schedule: The operator manually turns on/off the hot water system. Normally, boilers work year-round.

Improved schedule: The boilers are enabled based on the outside air conditions and occupied hours. The boilers start at 50°F and stop when the outside air temperature is higher than 53°F. The pumps run 10 minutes before the boiler starts.

Results: The improved schedule reduces natural gas consumption during summer season. The terminal box minimum primary airflow reset eliminates the need to operate the boiler while maintaining the room temperatures at normal levels, also resulting in significant reheat energy savings.

Hot water temperature

Existing schedule: The hot water supply temperature set-point is maintained at 160°F during the winter and 80°F during the summer season.

Improved schedule: The hot water supply temperature set-point is reset between 160°F and 120°F based on the outside air temperature.

Results: Figure 21 shows the trend data for hot water supply water temperature and outside air temperature after implementation of the new control sequence (post-CC) on January 7~10, 2007. Decreasing the hot water supply temperature minimizes the natural gas consumption.

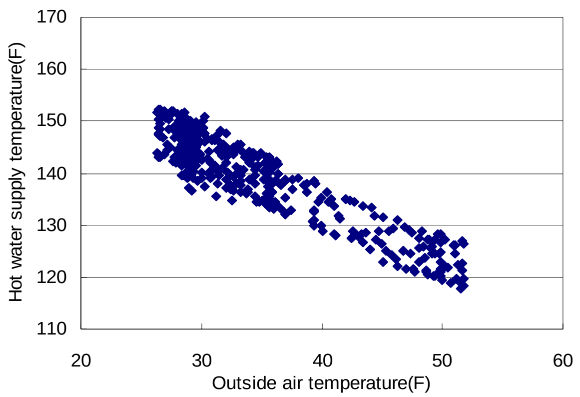

Figure 21. Post-CC hot water supply temperature and outside air temperature (January 7~10, 2007)

Energy savings

After implementation of optimal CC® control schedules in this building, the energy requirements are reduced. Figure 22 compares electricity consumption over a one-year period before CC® and after CC®. The electricity consumption savings was 1,328,832 kWh, a reduction of 26.8% in one year.

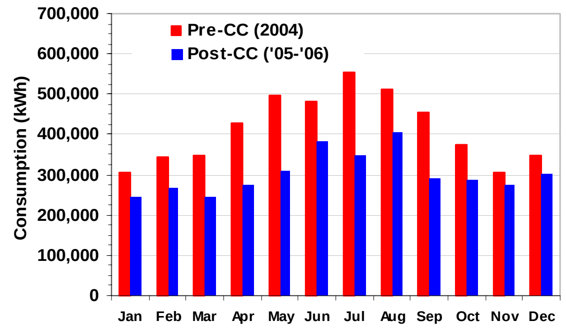

Figure 22. Comparison of Pre and Post-CC electricity energy consumption

Conclusion

The case study of CC® implementation in this office building shows that an improved control sequence can minimize energy cost and improve building comfort level based on effective measurements and operation analysis.

Acknowledgement

The cooperation and support from the building owner and Omaha Public Power District are greatly appreciated.

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