Continuous Commissioning^{SM} in an Aged Office Building

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ABSTRACT

Continuous Commissioning^{SM} (CC^{SM}), "an ongoing process to optimize energy use, resolve operating problems, improve comfort, and identify retrofits for existing commercial and institutional buildings and central plant facilities", has been conducted in an aged office building. This paper presents the information of a building HVAC system and detailed CC^{SM} optimal control with particular examples in this building including original control schedules, operation analysis and CC^{SM} operation control schedules. The CC^{SM} energy savings of over 20% in this building conclude that optimal control reduces energy and improves indoor comfort.

INTRODUCTION

Continuous CommissioningSM (CC^{SM}), "an ongoing process to optimize energy use, resolve operating problems, improve comfort, and identify retrofits for existing commercial and institutional buildings and central plant facilities" [1] has proved in many facilities that cost-effective system control technologies and system trouble-shooting can be applied to improve building comfort and enhance the building energy performance. Continuous Commissioning^{SM} has produced typical savings of 20% with payback less than three years (often 1-2 years) in over 100 buildings [1].

As this case, CC^{SM} has been conducted in an aged office building. This paper presents briefly the facility and the HVAC system information. Focusing on the optimal systems control, this paper presents in detail the optimal control schedules implemented in some typical AHU systems and an integral AHU's control method to minimize energy and improve indoor air quality. The results of implementation of CC^{SM} are compared by control schedules, operation data, and utility bills before and after CC^{SM}.

The case study building, located at Omaha, Nebraska, was originally built in 1958, and renovated with additional area added in the 1980s. This office building, shown in Fig. 1, has three floors with the total conditioned floor area of about 140,000 square feet including the basement. The major office area includes Main Building area, Executive Wing area and Additional area. Main building and executive areas are the original office area, and an additional area was added in 1980's. Fig. 2 shows the major office areas in this building. Main Building consists of about 80,000 ft^2 with 3 floors and has occupancy density of about 140-160 ft^2/person. Executive Wing is a special area for the executive of this company with one floor about 5,000 ft^2 and occupancy density of about 500 ft^2/person. Other associated functions include cafe area and a board room. The typical office hours are from 8:00am to 4:30pm during the weekdays.

Fig. 1: Case Study Building

This building has a total of 11 Air Handling

Units (AHUs). Among these, 7 AHUs serve the Main Building and Executive Wing areas: one AHU, called Primary AHU, for the perimeter of the Main Building and Executive Wing areas, and six AHUs, called Interior AHUs, for the interior of Main Building. The remaining four AHUs serve the Additional Area and other auxiliary areas.

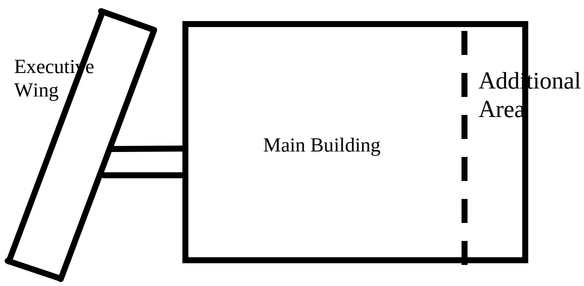

Fig 2: Layout of Major Office Area

Along the exterior glass walls of Main Building and Executive Wing, there are approximately 170 2-pipe induction terminal units installed.

One 375-ton water cooled chiller is installed. There is one old chiller as a backup. There were originally four constant speed chilled water pumps: one Primary Pump for Primary AHU cooling coil, one Main Pump for perimeter induction units, and two pumps for the additional area. One constant volume condensing water pump serves the 375-ton chiller. Two gas-burned steam boilers are installed with capacity of 5,830,000 Btu/hr for each. One steam-water heat exchanger provides hot water to the perimeter induction units and AHUs.

The HVAC systems operate from 5:00 a.m. to 7:00 p.m. generally during the weekdays and from 7:00 a.m. to 3:00 p.m. on Saturday.

After the CC^{SM} survey and study, this building was retrofitted with four VFDs: two for Primary AHU supply and return fans respectively; one for Primary pump and one for Main pump. No additional control sensors were recommended.

CC^{SM} activities in this building included optimal control implementation for all AHUs and two pumps with VFDs, solving operation related building comfort problems, identifying the malfunctioning HVAC devices, calibration of drifted sensors and fine-tuning control loops. As examples, this paper will focus on the optimal control implemented in Primary AHU and Interior AHUs to demonstrate the CC^{SM} effect.

PRIMARY AHU

Primary AHU was originally a single duct constant volume AHU. The schematic diagram of Primary AHU is shown in Fig. 3. Supply fan and return fan power are 60 hp and 7.5 hp respectively. There are two supply air ducts branches, providing primary air to the induction units in Main Building and Executive Wing. Each branch has a steam reheat coil after the supply fan. Each induction unit has no air modulation, but has a 2-way valve to modulate water flow rate based on individual space thermostat set point.

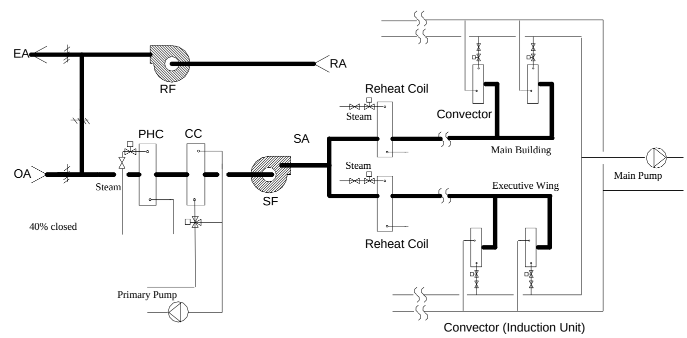

Fig 3: Schematic of Primary AHU

There are two pumps for this AHU and terminals: Primary Pump dedicated for the cooling coil, Main Pump for the terminal induction units.

Original Control

In the original control scheme, fans operated at 100% speed. Mixed air dampers, preheat and cooling coil valves were modulated to maintain supply fan discharge air temperature at 55^{o}F year around. Economizer was used when the outside air temperature is lower than 60^{o}F. When the outside air temperature was higher than 60^{o}F, the outside air damper position was set at 10%.

Since 2-pipe induction units provide heating in the winter and cooling in the summer, both WINTER and SUMMER modes were set up. WINTER and SUMMER modes were defined when the outside air temperature was lower or higher than approximately 55°F respectively.

In WINTER mode, Primary AHU provided 55°F primary air to induction units. Hot water circulates in the induction units and was modulated to warm up induced room air according to the space temperature.

In SUMMRER mode, the AHU cooling coil valve was modulated to provide 55°F air to the steam reheat coils. Two steam reheat coil valves were modulated to maintain supply air temperature set points between 90°F and 55°F and between 75°F and 55°F respectively for the two duct branches inversely proportional to the outside air temperature between 55°F and 80°F. The schedule is shown in Fig. 4. In the induction units, chilled water circulated to cool down the induced room air according to thermostat's call. "Cold" induced air was mixed with "warm" primary air and sent to office space.

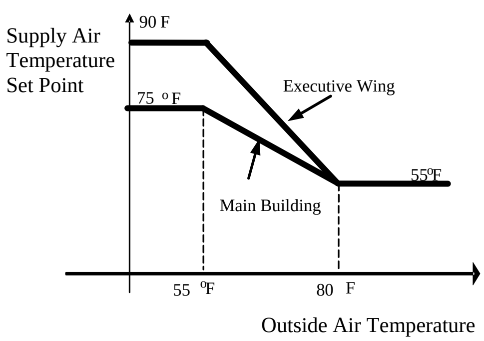

Fig. 4: Supply Air Temperature Set Point for Main Building and Executive Wing

CC^{SM} Control

The CC^{SM} study indicated that the original performance and control schedules have the following problems: (1) Intense simultaneous reheat and cooling is wasted by the above WINTER/SUMMRER operation when the outside air temperature is between 55°F and 80°F in SUMMER mode; (2) Considerable heating is consumed by supply air temperature set points at 55°F in the winter since the exterior zone needs heating in the winter; (3) Fan power, and heating and cooling energy is wasted by excessive supply airflow rate for this AHU; (4) Free cooling is not maximized due to the low economizer enabling set point.

After conducting measurements and building load analysis during CC^{SM}, the optimal control schedules were developed and implemented to solve the above problems and optimize energy use.

Measurements indicate that the dependency of the cooling load on the outside air temperature is different for Main Building and Executive Wing due to different occupancy and building structure. The Main Building needs cooling when the outside air temperature is 45°F to 50°F for different orientations while the Executive Wing needs cooling when the outside air temperature is around 67°F. Therefore, when the outside air temperature is between 55°F and 67°F, the Main Building needs cooling and the Executive Wing needs heating. Steam reheat coil valves are disconnected to minimize simultaneous heating and cooling in CC^{SM} control. WINTER and SUMMER mode is switched when the outside air temperature is at 64°F with a 3.0°F dead band. Induction units provide heating in WINTER mode and cooling in SUMMER mode according to the space temperature. When the outside air temperature is between 55°F and 67°F, the Primary AHU provides 55°F air to both areas. Different load requirements in the Main Building and Executive Wing are both able to be maintained by modulating the induction unit valve from 0% to 100%. As the result, this control minimizes both heating and cooling energy.

An AHU supply air fan discharge temperature reset was developed. Instead of being constant, supply air temperature set point increases when the outside air temperature decreases in the winter since heating is needed in both areas. Fig. 5 shows the CC^{SM} control schedule. Mixed air temperature set points take an offset of the supply air temperature set point. Economizer is used to modulate mixed air dampers to achieve the mixed air set point when the outside air temperature is lower than 65°F instead of 60°F.

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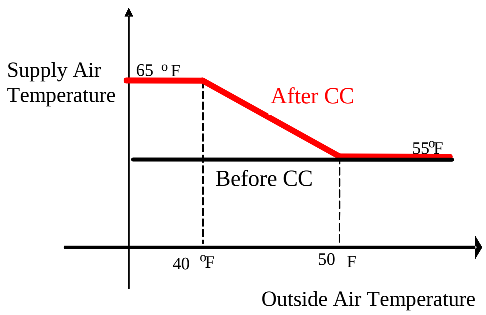
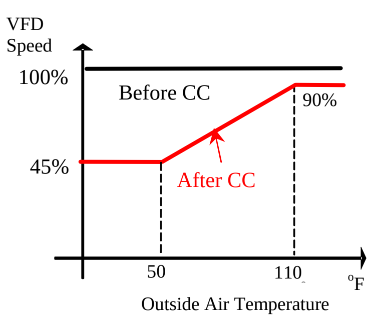
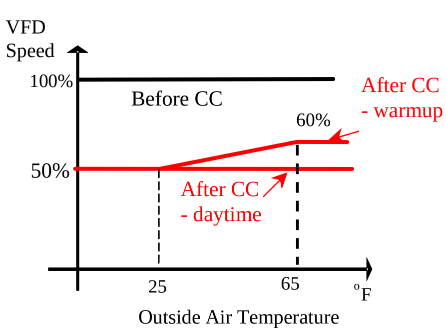


Fig 5: Supply Air Temperature Reset Schedule

The AHU fan speeds are reset as building load changes. The supply fan VFD speed is controlled based on the outside air temperature in SUMMER and WINTER modes according to the schedules in Fig. 6. Return fan speed is controlled at 9.5% lower than the supply fan speed. This return fan schedule is due to the following considerations: (1) Maintain a stable positive building pressure control; (2) Create a relatively positive space air pressure of the exterior relative to the interior area. Relatively "fresh" air is provided to interior for IAQ, which is to be discussed in the next section.



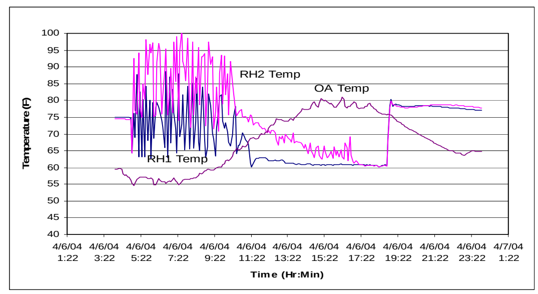
(a) SUMMER Mode



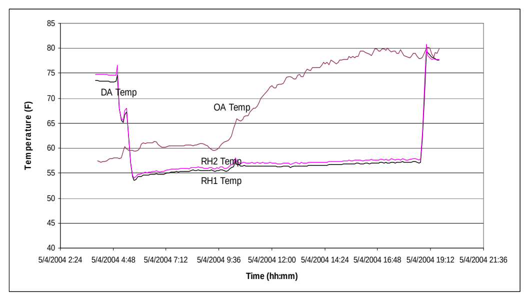
(b) WINTER Mode

Fig 6: Supply Fan Speed Reset

Some operational data with these above controls implementation are demonstrated in Fig 7. and Fig. 8. Fig. 7 compares supply air temperature before and after CC^{SM} in the branches of the Main Building and Executive Wing. Fig. 8 compares the Primary AHU supply fan and return fan power before and after CC^{SM}. Fig. 7 and Fig. 8 demonstrate that reheat, simultaneous cooling, and fan power can be optimized with optimal CC^{SM} control.

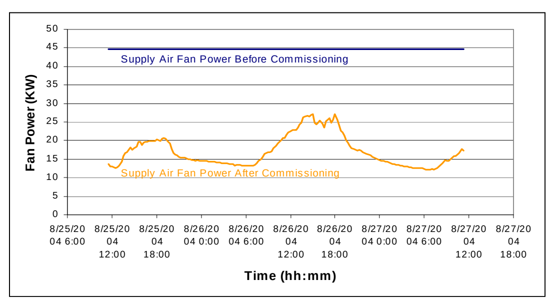


(a) Before CC^{SM}

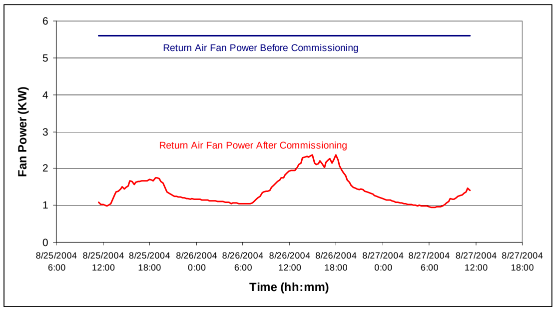


(b) After CC^{SM}

Fig 7: Primary AHU Supply Air Temperatures of Two Branches



(a) Supply Fan



(b) Return Fan

Fig 8: Primary AHU Fan Power Before and After CC^{SM}

INTERIOR AHUS

There are six single zone Interior AHUs serving the entire interior of the Main Building, two on each floor. The general schematic diagram of AHU systems is shown in Fig. 9.

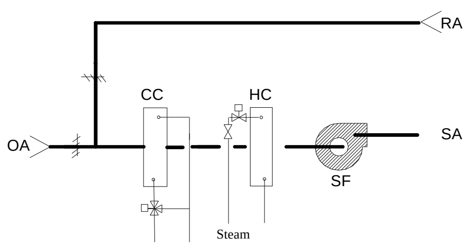


Fig 9: Schematic of Interior Zone Units

Original Control SChedules

Before CC^{SM}, the AHU discharge air temperature was set from 110°F to 55°F based on space average temperature according to the schedule in Fig. 10. The mixed air temperature set point is reset at the discharge air temperature set points with offsets. Steam or cooling valves are modulated to maintain the discharge air set point. The mixed air damper is modulated to maintain the mixed air temperature set point when the outside air temperature is lower than 60°F, and maintained at 10% when the outside air temperature is higher than 60°F.

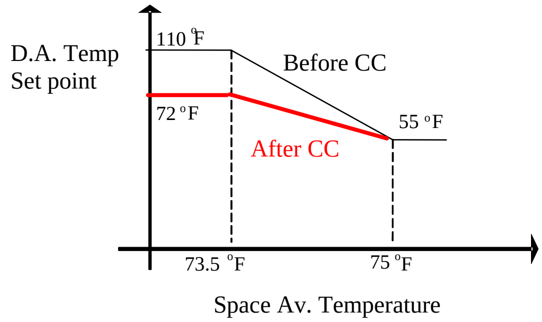


Fig 10: Discharge Air Temperature Set Points

CC^{SM} Control Schedules

Energy analysis indicates the existing performance and control schedules waste energy waste and have potential comfort problems in that (1) these schedules have to use simultaneous heating and cooling since only cooling load occurs for interior area, which wastes heating and cooling energy; (2) the economize setup also does not take full advantage of free cooling by using up to 60°F outside air; (3) The existing control schedule could not maintain relatively appropriate room humidity levels since the cooling coil discharge air humidity level maybe high in hot and humid summer.

The optimal control schedule is developed and implemented to optimize energy use and improve indoor comfort. Manual heating valves of all six interior AHUs are totally shut down to prevent heat usage or leakage since there is no heating load requirement in the interior. In the meantime, the AHU discharge air set point is reduced from 72°F to 55°F based on the room air temperature as shown in Fig 8 to avoid heating demand in the control schedule. The economizer is enabled when the outside air temperature is lower than 65°F instead of 60°F to take full advantage of Omaha, Nebraska weather conditions. To maintain a comfortable room humidity level, the outside air damper is programmed fully closed for six Interior AHUs when the outside air temperature is higher than 65°F.

In order to maintain "freshness" in the interior when the AHUs outside air damper is fully closed, the method of integral AHUs operation is implemented in this building. The outside air intake of Primary AHUs is modulated to satisfy ventilation requirement for both exterior and interior area of entire Main Building. By using the optimal Primary AHU supply and return fan speed control as discussed before, a relatively positive space air pressure of the exterior relative to the interior area is created so that the "fresh" return air moves from the exterior area to the interior area. The interior area can still maintain the freshness by indirectly introduced outside air. After the implementation of this control, CO_2 level of interior area was measured to be lower than 800ppm.

The results of the optimal control implementation are demonstrated in Fig. 11 and Fig. 12, where the H/C command of 50% to 100% and 0% to 50% indicates heating and cooling call, respectively. This data show that there is stable cooling demand when the building is occupied after CC^{SM} implementation. Room temperature is stable and at a comfortable level.

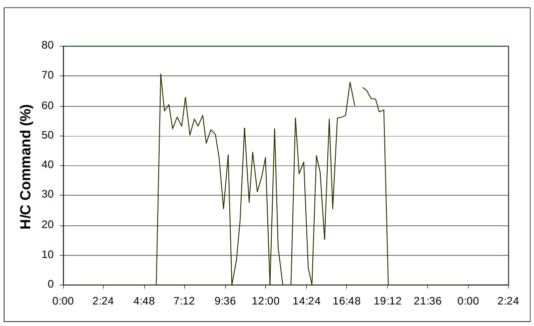


Fig 11: Interior AHU Heating/Cooling valve Command before CC^{SM}

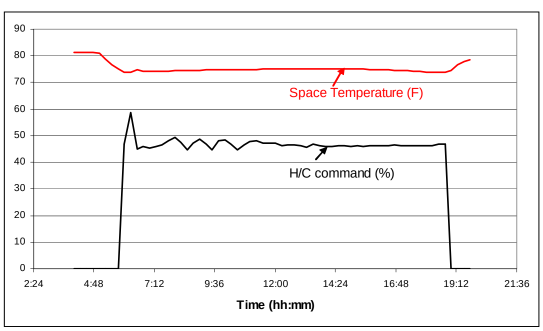


Fig 12: Interior AHU Heating/Cooling valve Command after CC^{SM}

RESULTS OF CC^{SM}

After implementation of optimal CC^{SM} control schedules and other CC^{SM} activities in this building, energy requirements are reduced and the building comfort is improved. Resulting annual heating and electricity energy cost of this old building should be reduced by 20%, based on utility bill and trended operation data. Figure 13 compares gas consumption (including heating and cooking usage) in the seven months before CC^{SM} and after CC^{SM}, with a total gas cost savings of $11,116 or 28%.

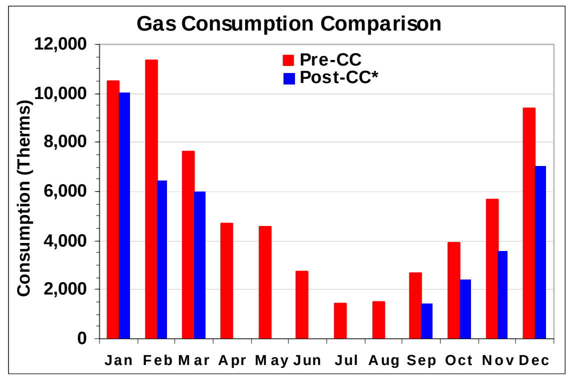


Fig 13: Gas Bill Before and After CC^{SM}

CONCLUSION

The examples of CC^{SM} implementation in this aged office building demonstrate that optimized control sequences can be developed to minimize energy cost and improve building comfort level based on effective measurements and operation analysis.

ACKNOWLEDGEMENT

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REFERENCE

[1] Liu, M., D. Claridge and D. Turner, 2002, *Continuous Commissioning^{SM} Guidebook: Maximizing Building Energy Efficiency and Comfort.*