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Continuous Commissioning® of Public Schools

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ABSTRACT

Continuous Commissioning® (CC®)[1] is a proven, highly cost-effective process that can improve building comfort and reduce energy consumption. This paper discusses the CC® of three public schools in Austin, Texas. These schools include one high school and two elementary schools, one of which also includes a community center. Major CC® measures implemented include resetting supply air temperature, duct static pressure, chilled and hot water loop ΔP setpoints, condenser water temperature, and reheat water temperature; optimizing economizer operation and heat recovery unit operation; improving equipment scheduling and staging sequence; and adjusting terminal box air flow settings. Also included are some minor retrofits that convert a few constant volume units to variable air volume units and adjusting the fan pulleys for units that are oversized. Even though all three schools are well maintained, the CC® project was able to achieve 10-14% energy reduction, which amounts to an annual cost saving of $80,000. With a total implementation cost of approximately $201,800, the simple payback is about 2.5 years.

INTRODUCTION

In June 2004, the Energy Systems Laboratory (ESL) performed an initial Continuous Commissioning® assessment on three schools at Austin Independent School District (AISD). These are the Pickle Elementary School and St. John's Community Center, Galindo Elementary School, and Akins High School. Two of the schools were relatively new and all three schools were well-run according to the original design intent. However, significant opportunities were identified for further improvement on energy efficiency. Continuous Commissioning® was recommended for all three schools and was subsequently funded by the school district.

Continuous Commissioning® of the heating, ventilating, and air-conditioning (HVAC) system at the three schools began in 2005 and was substantially completed by late 2006 with the assistance of the AISD Energy Management Department. All of the primary energy systems in the building were investigated to determine their existing conditions and operations. This paper discusses the key findings and major CC® measures implemented at these schools.

THE SCHOOLS

The Pickle Elementary School and St. John's Community Center was built in 1999. It is a single-story building complex with approximately 116,000 ft^2 of conditioned area. The school section houses Pre-K to grade 5 and includes classrooms, offices, a library, a cafeteria, a kitchen, and a gymnasium. The Community Center section includes the County Health Department, the City Library, the Parks and Recreation Department, and the Police Annex. The HVAC system includes ten single-duct variable air volume (VAV) air handling units (AHUs), 101 terminal boxes, one 400 ton centrifugal chiller and one 60 ton screw chiller, one dual-cell cooling tower, and 18 heating water heaters. Most of the AHUs operate from 6:00 AM to 7:00 PM, Monday through Friday.

Galindo Elementary School was built in 1986 with 83,000 ft^2 of conditioned area. It consists mostly of classrooms, offices, a cafeteria, a kitchen

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[1] The terms Continuous Commissioning and CC are registered trade marks of the Energy Systems Laboratory, Texas Engineering Experiment Station, Texas A&M University System.

and a gymnasium. The HVAC system includes two 250 ton chillers, one cooling tower, one 3.5 MBtu/hr boiler, eight single-duct VAV AHUs, and eighty terminal boxes. A heat recovery unit (HRU) is attached to each AHU at the inlet of the outside air intake. The HRU uses the building exhaust air to precondition the incoming outside air. The building HVAC system operates from 6:00 AM to 4:00 PM, Monday through Friday.

Akins High School was built in 2000. The school has approximately 300,000 ft^2 of conditioned area that consists of four parts: an education center, a cafeteria, a gym, and the Fine Arts building. The HVAC system includes twelve single-zone constant volume AHUs, thirty Roof Top Units (RTUs), eight HRUs that provide 100% fresh air to the classrooms, several fan coil units, two 300 ton chillers, and two 3.0 MBtu/hr gas boilers. The building HVAC system operates from 7:00 AM to 8:00 PM, Monday through Friday, with certain buildings/sections shutting down earlier.

The chiller plant at each site is arranged in a primary-secondary loop configuration with constant speed chilled water pumps in the primary loop and variable speed pumps in the secondary loop. Cooling tower fans are also equipped with VFDs. At Akins, the condenser water pumps and secondary hot water pumps are also equipped with VFDs. All three schools have a building automation system (BAS).

MAJOR CC® MEASURES

The CC® engineers performed extensive field investigations at each school for the chillers, boilers, cooling tower, water pumps, AHUs, RTUs, HRUs, and selected VAV boxes. Detailed in-house study on existing systems operations and control algorithms was also conducted through remote access provided by AISD. The HVAC systems overall are well-maintained and operated based on the original design intent. However, many savings opportunities were identified. Key findings and CC® measures implemented are discussed below.

<u>Sensor Calibration</u>

Field measurements were taken of all the key temperature, humidity, and CO_2 sensors as well as the temperature and pressure sensors of the chilled and hot water systems. These measurements were then compared to what the BAS was reading. The readings of some sensors were found to be in error by unacceptable levels. The following are some examples of sensor-related issues found:

- The outside air relative humidity sensor reading at Pickle Elementary was observed fluctuating between 1% and 99% in short intervals during our field visit. Since this sensor is used in combination with the outside air temperature sensor to determine the economizer mode operation, it is critical to have this sensor repaired/replaced.
- At one school library, the space relative humidity sensor also failed and was giving a constant high relative humidity reading. This in turn caused the AHU and the chiller plant to be constantly energized in order to "dehumidify" the space.
- One AHU duct static pressure sensor failed and was showing -0.2 inch of static pressure, which caused the supply air fan to constantly operate at high speed.
- The discharge air temperature at one AHU was faulty and displayed a constant temperature of 250°F, causing the cooling valve to be open all the time.
- Many CO_2 sensors were reading higher than actual values, causing excess outside air to be drawn into the building.

These faulty sensors were repaired/replaced with funds set aside by AISD for deferred maintenance items.

<u>Time Scheduling</u>

An occupancy survey was conducted to determine when each area of the school was in use. The result of the survey was compared to the BAS schedule and the existing HVAC equipment operating time schedules were then adjusted accordingly to eliminate unnecessary runtimes.

<u>Economizer Optimization</u>

At the Pickle Elementary, the existing economizer mode was enabled when outside temperature was between 40 and 60°F, and if the outside air enthalpy was less than the return air enthalpy. After the outside air temperature and relative humidity sensors were replaced and calibrated, the program was modified to enable the economizer when the outside air temperature is below 70°F and the outside air enthalpy is less than 26 Btu/lbm. As a result of this decision, the return air enthalpy is no longer used in the equation, which prevents any faulty return air relative humidity sensor from disabling the economizer cycle.

For buildings with demand-based ventilation control, the economizer damper control was integrated with the CO_2 control. When the economizer mode is enabled, the CO_2 control sequence was disabled.

Reset AHU Discharge Air Temperature Setpoints

The existing discharge air temperature setpoint was a constant 55°F at Galindo Elementary. To reduce simultaneous cooling and heating because of this setting, the supply air temperature was reset to a higher value based on outside air temperature when the supply air fan speed is around 40%, which serves as a proxy for the building in a low cooling load or heating load condition.

At the Pickle Elementary School, the discharge air temperature had a base setpoint of 55°F. The actual setpoint varies by 5°F when the average VAV box load, which varies between -100% to 100%, is below 0% and the unit is in economizer mode. When the average box load is below -25%, the discharge air temperature setpoint will rise another 5°F. The "step" reset schedule was converted to a linear reset which makes the system work more smoothly without any sudden changes. A feedback signal from the supply air fan was also used to ensure that the supply air temperature reset only happens when the fan speed is less than a preset minimum.

At the Akins High School, the cold deck temperature was maintained at a constant 55°F for the constant volume reheat AHUs. The reheat valve at each unit modulates to maintain the space temperature. A reset schedule was added for the cold deck temperature so it modulates based on the space temperature whenever the outside air temperature is below 60°F. Cold deck air temperature is maintained at 55°F when the outside air temperature is above 60°F.

Reset Duct Static Pressure Setpoints

To ensure adequate airflow in all the boxes during high loads, airflow measurements were taken at the farthest box from each AHU. The box dampers downstream of the static pressure sensor location were commanded opened 100% to simulate high load conditions. If the airflow did not meet the design maximum flow for the most remote boxes, then the static pressure was raised until there was enough flow. If the flow was more than the design maximum, the static pressure was lowered until the flow reached an appropriate level. This method was used to determine the maximum static pressure needed for all AHUs. The static pressure setpoint was reset between the minimum and maximum based on outside air temperature or supply air fan speed to save fan power and reduce noise levels.

Optimize Air Handler Operations

At the Akins High School, variable frequency drives were installed on several large constant volume AHUs. After this small retrofit was completed, the existing control sequence was modified to improve the unit performance. The chilled water valves were modulated to maintain discharge air temperature at the setpoint, while the supply air fan speeds were controlled from 70% to 100% during the cooling mode to maintain the space temperature. During the heating mode, the fan speed remains at 70% (adjustable) while the cooling and heating valves modulate to maintain the space temperature at its setpoint.

Optimization of Terminal Boxes

At Galindo Elementary School, excessive heating in the terminal boxes was observed during the cooling season. When the outside air temperature was above 85°F, around 40% of the boxes were in the heating mode. Most of the classrooms had cold complaints since the boiler was out of order periodically during the pre-commissioning period. During times when the outside air temperature is high, there should not be any need for heating, unless the space is over-cooled. Unfortunately, this is exactly what happened; it was found that the box minimum airflow setpoint was too high. The flow sensors of the terminal boxes were inspected and calibrated as needed. After that, the terminal box minimum airflow settings were adjusted lower based on actual space needs.

Relief Air Fan Control

At the Pickle Elementary School, the relief fan speed was controlled based on AHU economizer damper position and supply air fan speed. Unfortunately, this control strategy does not necessarily ensure proper building pressurization since the outside air damper position and fan speed have a non-linear relationship with the outside air flow rate. Therefore, outside airflow is not proportional to those two parameters. Since each AHU has its own space static pressure sensor, the relief fan speed control was modified to maintain space (building) static pressure at the set point of 0.05 inch water column.

Optimize the Heat Recovery Units' Operation

At the Galindo Elementary School, it was determined from field measurements that the outdoor air and relief air flow rates were approximately twice as much as the amount required. To create proper building pressurization, the outside air and relief air were reduced to the required levels by adjusting the fan pulleys. Similar issues were found at Akins High School. In addition, field measurement suggested that the relief air fans released more air than the supply air fans supplied, which could lead to potential moisture problems in the building. To remedy this, the air flows were adjusted and properly balanced.

The HRUs are designed to provide enough outside air intake when the school is occupied. These units were enabled and disabled based on the same schedules as the other HVAC systems. If the HRUs can be shut off when the students are dismissed from school, five hours of operation can be reduced and significant outside air fan and return air fan power, as well as thermal energy, can be saved. To accomplish this, each HRU's operating schedule was shortened so that it only turns on from 7 AM to 2 PM, when the building is occupied. The heat wheel inside each HRU was also disabled during economizer season to reduce the energy penalty. This measure was implemented at both Galindo Elementary School and Akins High School.

Chiller Enable/Disable Sequence

At the Galindo Elementary School, the chillers were enabled all the time and were set to maintain the 44°F supply water temperature even though the AHUs were off at night. This was identified from trend data review as shown in Figure 1. Unfortunately, the lack of cooling load resulted in frequent chiller on/off cycling at night, which not only consumed excessive energy, but can also potentially reduce the chiller life span and increase the maintenance costs. As a result, the control program was modified so that the chillers, cooling tower and pumps are switched on/off based on both time schedules and AHU status.

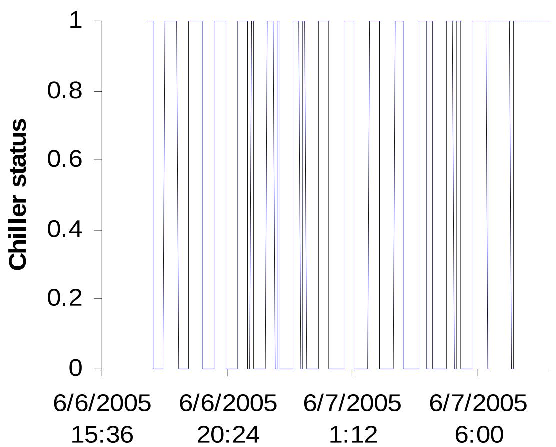

Figure 1: Chiller frequent on/off cycling

Secondary Chilled Water Loop

The ΔP setpoints for the secondary chilled water loop were generally higher than necessary at all three schools, even for peak load operating conditions. These high ΔP settings can require excessive pumping energy. With the high ΔP, the chilled water valves at the AHUs did not have to open more than halfway even during hot weather conditions. Tests were conducted on the system to determine the ΔP required and a ΔP reset schedule based on outside air temperature or maximum chilled water valve position was implemented at each school.

Cooling Tower Operation

At the Pickle Elementary School, the condenser water temperature setpoint was modified from a constant setpoint to a reset based on ambient web-bulb temperature. This modification was performed after the outside air temperature and relative humidity sensors were replaced and calibrated. The outside air wet-bulb temperature was calculated using outside air temperature and relative humidity. The condenser water setpoint was set at 6°F above the outside air wet-bulb temperature with a minimum of 70°F and a maximum of 81°F.

For the schools that do not have outside air relative humidity sensors, the condenser water temperature setpoint was reset based on the outside air dry-bulb temperature instead of using a constant setpoint. This measure will increase chiller's efficiency. The reset schedule is shown as follows:

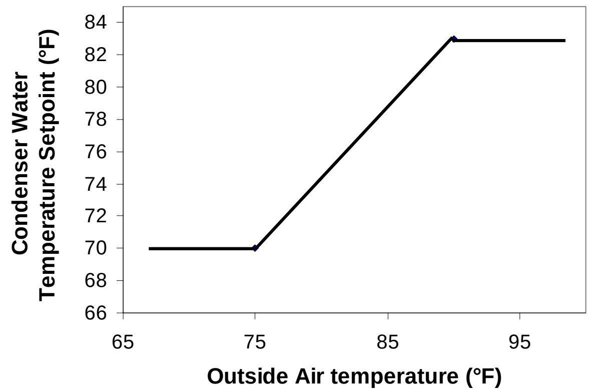

Figure 2: Condenser water temperature reset

Hot Water Heater Operation

At the Pickle Elementary School, the existing outside air temperature enable setpoints for the hot water heater and hot water pumps ranged from 75°F to 115°F. Consequently, some of the heaters and hot water pumps were running whenever the corresponding AHUs were operating. These set points were lowered to 65°F for all the heaters and hot water pumps. This stopped them from running during the cooling season when they are not needed.

Secondary Hot Water Loop

At the Akins High School, the ΔP setpoint for the secondary hot water loop was 27.5 psi. This set point was unnecessarily high for most of the operating season, as it caused simultaneous heating and cooling since some hot water valves could not completely close under such high ΔP. To remedy this, a ΔP reset schedule based on outside air temperature was implemented.

RESULTS AND ENERGY SAVINGS

The CC® process started in June 2005. Most of the CC® measures were implemented a year later. To evaluate the impact of the CC® process on energy consumption, baseline models of electricity, electric demand, and gas usage at each of the schools were created using utility bills prior to CC® implementation. Figures 3 and 4 show the baseline models for the building electricity and gas usage at Pickle Elementary School. The electricity baseline used a 3-parameter change point model, and the gas baseline used a 4-parameter change point model. Also shown on these two figures are the post-CC® period daily average energy usage.

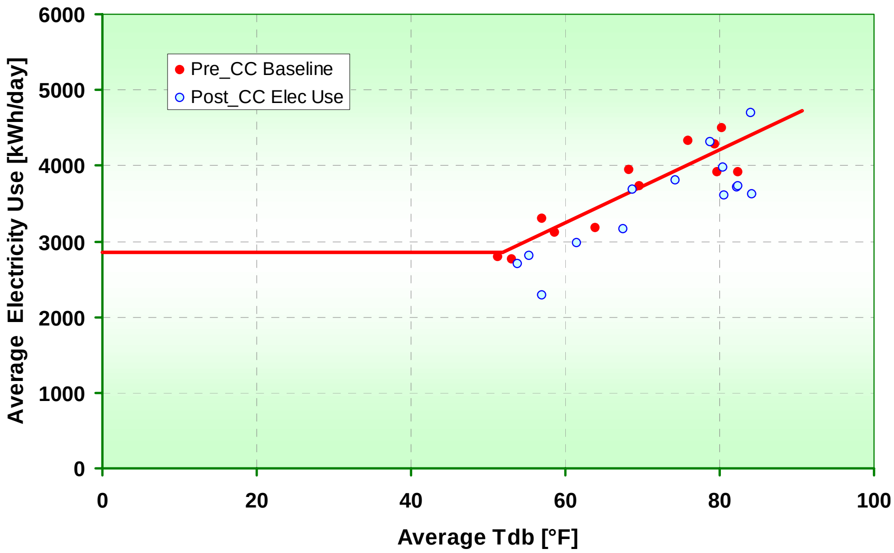

Figure 3: Electricity baseline model for Pickle Elementary School.

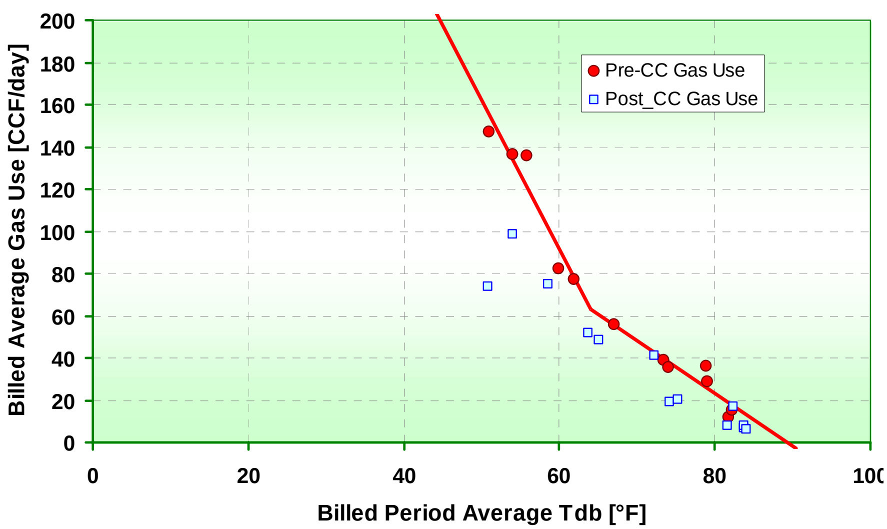

Figure 4: Natural gas baseline model for Pickle Elementary School.

The baseline models were used to predict post-CC® period energy consumption and compared with actual utility bills. The difference between the prediction and actual use is the energy saving. Although the three schools are all well-run, savings of 10-14% of total utility bills are achieved at these schools. Annual cost savings of $80,200 were calculated for the first year after CC® was completed. With total implementation costs of approximately $201,800, including minor repair costs and a few VFD installations, the simple payback is about 2.5 years. Figure 5 shows the cumulative cost savings of approximately $110,000 since June 2005.

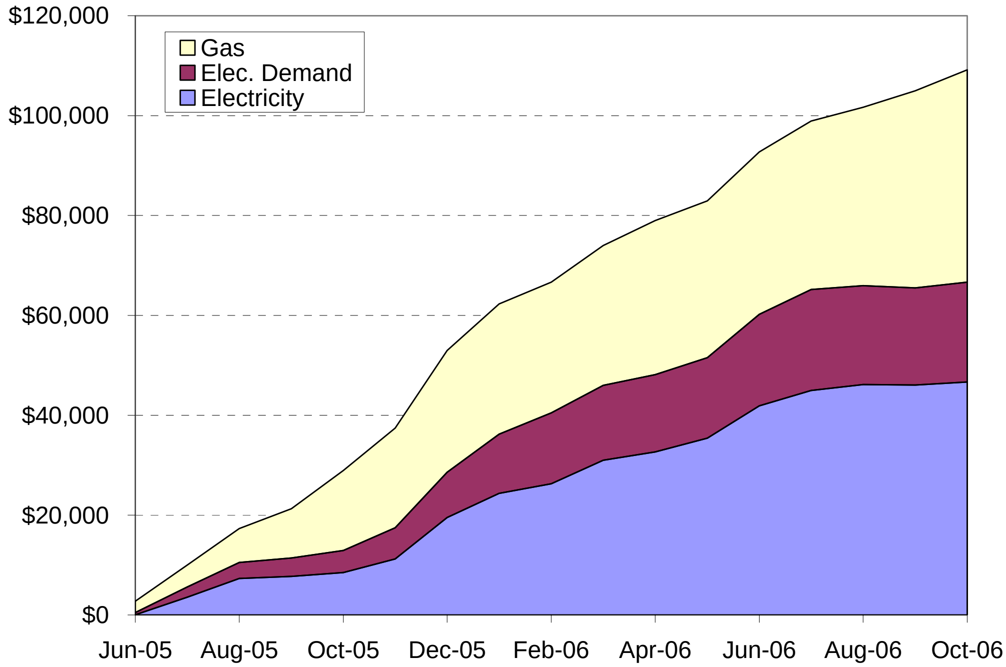

Figure 5: Cumulative cost savings from June 2005 to October 2006

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