CONTINUOUS COMMISSIONING℠ RESULTS VERIFICATION AND FOLLOW-UP FOR AN INSTITUTIONAL BUILDING - A CASE STUDY

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ABSTRACT

The Kleberg Building on the Texas A&M University campus is a teaching/research facility consisting of classrooms, offices and laboratories, with a total floor area of approximately 165,030 ft^2. Continuous Commissioning (CC^{SM}) was performed on the building in August 1996 with additional follow-up in April 1999 and significant savings were achieved. Subsequently, the building chilled water and hot water energy consumption increased due to later building operational changes. This paper presents the verification and follow-up efforts, which identified control problems in air handling units and laboratory variable air volume (VAV) systems and provided recommendations currently being implemented to restore HVAC optimization.

INTRODUCTION

The Continuous Commissioning process is an advanced form of commissioning for new buildings and existing buildings. The CC process can yield substantial benefits, such as improved occupant comfort and indoor air quality, and provide solutions to chronic maintenance problems (Claridge, 1996; Liu, el. al, 1999; Deng Song, et al., 2000; Chen, et al., 2000). It also typically provides substantial operating savings. In 1996 Continuous Commissioning was started on the Texas A&M campus in a collaborative effort of the Energy Systems Laboratory (ESL) and the Physical Plant, Utilities Office of Energy Management (Claridge, et al. 2001a; Claridge, et al. 2000b;). et al. However, when savings degradation or other problems indicate changes in building operation, verification and follow-up are needed to determine whether CC measures are still in place, need changes, or whether repairs are needed.. If optimal building operations were changed or degraded due to changes in building use, control programming changes, component/sensor failure, or controls by-pass or override, the follow up activities and possible new CC measures will adapt the systems to these changes.

This paper presents the verification and follow-up efforts, which identified control problems in air handling units and lab variable air volume (VAV) systems, and provided recommendations currently being implemented to restore HVAC optimization for the Kleberg Building on the Texas A&M University campus. This case study also summarizes all CC activities and the resulting savings, which have been achieved in this building since it was first commissioned in 1996.

BUILDING AND HVAC SYSTEM INFORMATION

The Kleberg Building is a 4-story teaching/research facility with a basement; it includes classrooms, offices and laboratories, with a total floor area of approximately 165,030 ft^2. Two (2) single duct variable air volume (VAV) air handling units (AHU) each have a pre-heat coil, a cooling coil, one supply air fan (100 hp), and a return air fan (25 hp). . These two VAV AHUs serve 90% of the conditioned air area for the building. Two (2) single duct constant air volume (CAV) air handling units (1×5 hp; 1×10 hp) with pre-heat and cooling coils provide conditioned air to the teaching/lecture rooms in the building. A schematic diagram of the chilled water system in the building is shown in Figure 1. The campus plant provides chilled water and hot water to the building. In addition there are two (2) parallel chilled water pumps (2×20 hp) with variable frequency drive control. There are two parallel chilled water valves for each large AHU (AHU1 and AHU2) . and a chilled water valve for each small AHU (AHU3 & AHU4).

There are 120 fan-powered VAV boxes with terminal reheat in 12 laboratory zones and 100 fan-powered VAV boxes with terminal reheat in the offices. There are six (6) exhaust fans (10-20 hp, total 90 hp) for fume hoods and laboratory general exhaust.

The air handling units, chilled water pumps and 12 laboratory zones are controlled by a direct digital control (DDC) system. DDC controllers modulate dampers to control exhaust airflow from fume hoods and laboratory general exhaust.

CC ACTIVITIES

Continuous Commissioning measures were first implemented in the building from June - August 1996 with additional follow-up during the period from June 1998 through April 1999. The CC measures and design EMCS settings are shown in Table 2. From June 1996 to July 1999, the hot water savings were $482,600 and chilled water savings were $656,200 for total savings of $1,138,800. This corresponds to average annual savings of $360,000/yr. Figures 2 and 3 show chilled water and hot water consumption comparisons for Pre-CC and Post-CC periods separately. The Post-CC period shown is the first year after CC measures were implemented in the building.

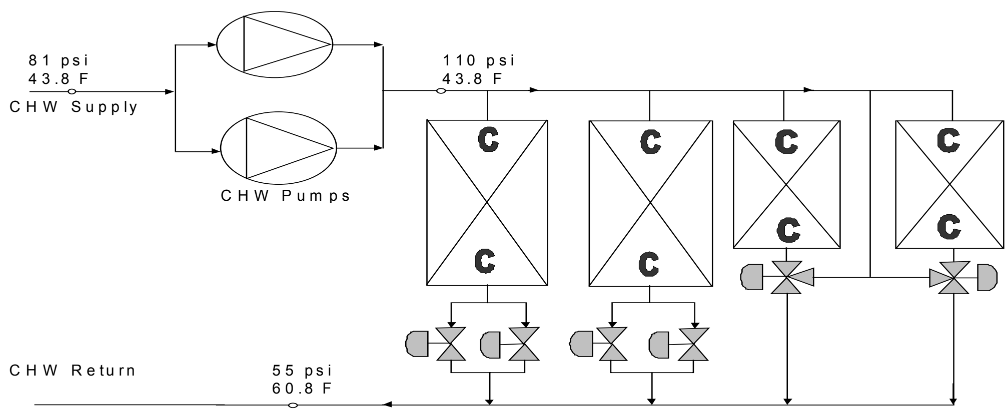

Figure 1. Schematic Diagram of Chilled Water System

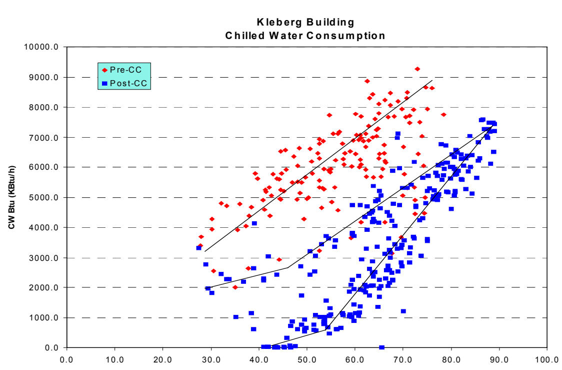

Figure 2. Chilled Water Consumption Comparison or Pre-CC and Post-CC Period

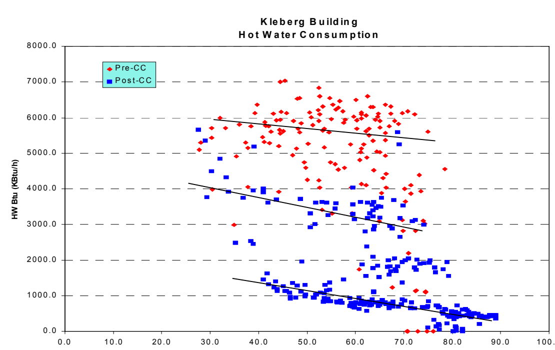

Figure 3. Hot Water Consumption Comparison for Pre-CC and Post-CC Period

It should be mentioned that the initial CC effort just focused on major CC measures at the AHU level due to time restraints. For example, the CC engineer optimized the reset schedules of supply temperature and static pressure for AHUs, improved the pump system operation, and solved existing simultaneous heating and cooling system problems and comfort problems. The CC follow-up effort mainly focused on air balance in the 12 laboratory zones, general exhaust system rescheduling, VAV terminal box calibration (including calibrating the controllers), adjusting the actuators and dampers, and calibrating fume hoods and return bypass devices to remote DDC control.

The TAMU Physical Plant, Utilities Office of Energy Management was called (July 2000 and May 2001) due to hot and cold complaints. The CC group of the Energy Systems Lab in collaboration with the Office of Energy Management performed not only troubleshooting, but also CC verification.

The CC group performed extensive field tests and analyses on two SDVAV AHU systems, two chilled water pumps, and the Energy Management Control System (EMCS) control algorithms. Several problems were observed, and most were related to building operational changes made since the CC follow-up effort.. These findings will be discussed later. The detailed findings of the CC verification process are shown in Table 2.

REASON FOR CC VERIFICATION

The persistence of savings from CC is related to many factors, but the most important factor seems to be the degree to which optimum control schedules are maintained (Turner et al. 2001). The savings from some buildings may slowly degrade over time, but these buildings are still saving large amounts of energy. The savings from other buildings may suffer significantly over the years. Comfort complaints from the building occupants may indicate that the building operation requires analysis. An obvious increase in whole building electricity, chilled water and/or hot water consumption definitely shows CC measure degradation. This is probably the best indicator that CC measure verification and follow-up is needed.

Figures 4-6 show time-series plots of whole building daily electricity, chilled water and hot water consumption for about five years, beginning in January, 1996. The energy consumption changes due to CC activity at different times may be observed in these plots. These plots, particularly the chilled water consumption plotted in Figure 5, show increases in energy use from 1999 and onward. The chilled water energy savings degraded about 15% during the 3 - 4 years after CC. The reasons for this increase will be discussed.

PROCEDURES

The CC group of the Energy Systems Lab and the TAMU Physical Plant Utilities Office of Energy management developed procedures for CC verification and follow-up for the investigation. The CC verification and follow-up is not simply a repeat CC process. Typical CC measures include field sensor verification or calibration (temperature, static pressure, and flow), optimization of the schedules for supply temperature (hot and cold deck temperature resets), static pressure of AHUs, reset schedules of airflow and temperature of terminal boxes, and pump operation. The investigation focuses on building EMCS control settings for before CC was implemented, after CC measures were implemented, control settings found at the time of the verification process and on the CC reports. The approach used was to: 1) retrieve hourly energy consumption data from the database and make time series plots of energy consumption and energy consumption versus temperature plots using the E-Model program; 2) review original design and renovation mechanical drawings and CC reports; 3) check current EMCS algorithm controls; 4) trend data and get the point data log if necessary; 5) conduct a field survey and make necessary field measurements; 6) talk with the building proctor and maintenance staff; and 7) verification of results and follow-up. The primary purpose of the procedure is to determine changes in CC savings over time, and find any differences between previously implemented CC measures and the current status of the building operation. Figure 7 shows the CC verification and follow-up procedures.

OPERATIONAL VERIFICATION AND PROBLEMS IDENTIFIED

Following the CC verification procedure described above, all the CC reports or CC documents were reviewed, and the field and control system surveys and energy data analysis were performed by the commissioning engineer. The HVAC operation was reviewed in detail by collecting the trend data from the EMCS and the field survey. Table 2 lists all the design control settings, initially implemented CC measures, and the measures implemented during the CC follow-up activities.

The data collected from the EMCS indicated that the majority of the VFDs were running at a constant speed and were not modulating with the load. Most of the AHU VFDs were running continuously between 90% and 100% speed, though the outside air temperature was below 40 F.

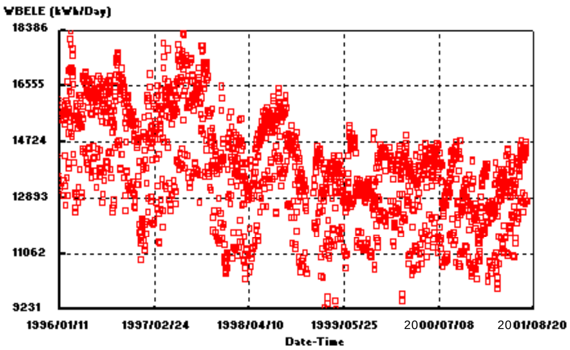

Figure 4. Electricity Consumption

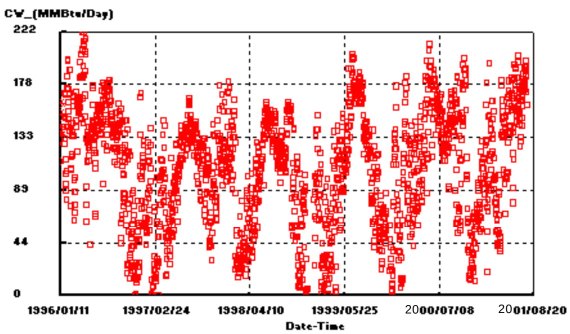

Figure 5. Chilled Water Consumption

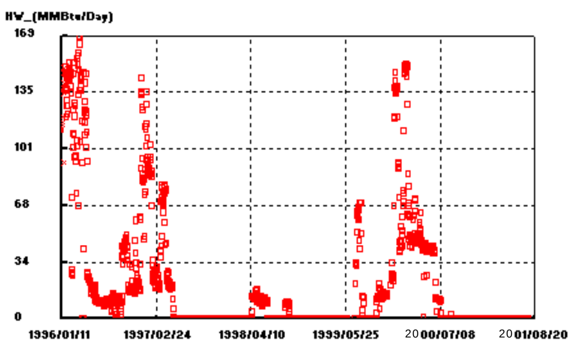

Figure 6. Hot Water Consumption

The two chilled water control valves of AHU2 could not fully shut off the chilled water flow due to valve leakage. Figure 1 shows two parallel chilled water valves for AHU2. Unfortunately the leaking valves at AHU2 made the discharge air temperature decrease to 50.4 F when the two chilled water valves were fully closed. Figure 8 shows the discharge temperature data for August 8, 2001 and August 9, 2001. Observations from facility personal indicated that the discharge temperature of AHU2 was sometimes as low as 48 F during cold weather.

It was found that two parallel chilled water pumps with VFD control were by passed to run at full speed. The CC measures implemented earlier called for sequential operation based on demand. The manual pump control at full speed was worse than the initial design specification for control of simultaneous operation of both pumps.

Water loop measurements showed that the differential pressure of the secondary loop had pressures as high as 55 psi during the time when the two chilled water pumps were by-passed to full speed, and differential pressure of the primary chilled water loop was at 26 psi. The chilled water pumps serve AHUs only and have 70 feet head on the pump nameplate. The differential pressure of 26 psi from the primary water loop is adequate to ensure flow through the building loop, and it is not necessary to run the building pumps. The detailed primary and secondary chilled water loop measurements are summarized in Table 1. The Figure 1 also presents the measured results.

The previously implemented CC measure for preheat control set the valve controls based on a cold deck temperature difference of -10 F because there is no temperature sensor between the preheat coil and the cooling coil. This means the preheat valve will try to prevent the cooling coil discharge temperature from dropping below 55 F if the cooling deck setpoint is 65 F. The leaky cooling valve, plus high chilled water differential pressure and failure of an electronic to pneumatic control component decreased the discharge air temperature to around 50 F as noted earlier. This in turn caused the preheat coil to remain on, regardless of the outside air temperature value, since the preheat control loop control program tries to prevent the discharge temperature from dropping below 55F when the setpoint is 65F.

Two failed CO2 sensors put the outside air dampers to the full open position in AHU3 and AHU4. These two AHUs with coupled control also exhibited 5-10 F swings in discharge air temperature due to a delay between the feedback between the discharge temperature and the action of chilled water and hot water valves. This can be corrected by inserting a deadband between the heating and cooling setpoints. In addition to this problem, the discharge temperature for AHU3 oscillated for a period of about a minute due to incorrect PI gain settings.

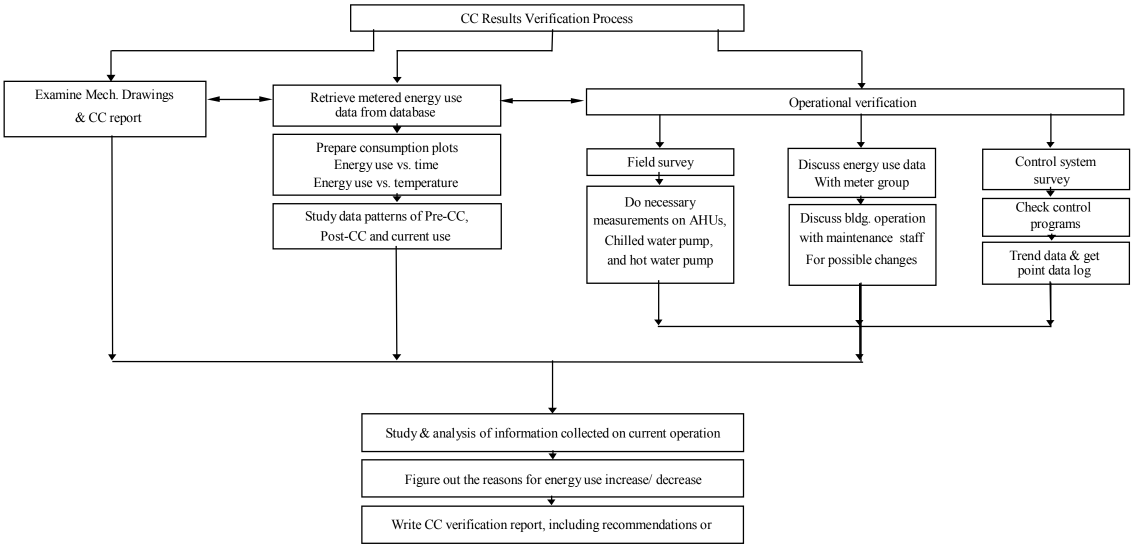

Figure 7. CC Verification and Follow-up Procedure

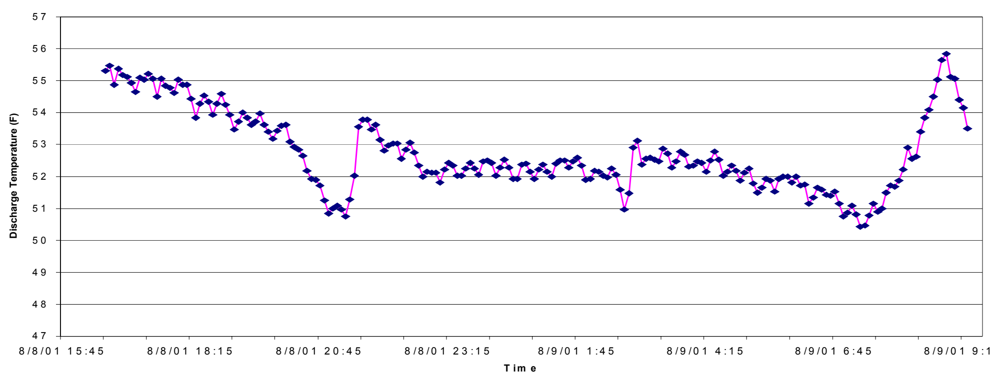

Figure 8. Discharge Air Temperature of AHU2 (the two Chilled Water Valves were fully closed)

Table 1. Primary & Secondary Loop Measurements

8/3/2001	Building Loop		Primary Loop	
	P (psi)	T (F)	P (psi)	T (F)
Supply	110	43.8	81	43.8
Return	55	60.8	55	60.8
DP or DT	*55*	17	*26*	17
Field Note	• Pump : 650 GPM, 70 ft head • CHW pumps serve AHUs only			

This building pressurization setpoint was based on the average of static pressure readings from 3 sensors. One of the three sensors had failed and caused the outside air dampers to open fully all of the time.

The CC engineer also discovered that the damper actuators were leaking and unable to maintain pressure in some of the VAV boxes. This caused the actuators to remain open in some instances. Cold air was going through the boxes even when they were in the heating mode, resulting in simultaneous heating and cooling. Furthermore some of the reheat valves were malfunctioning. This caused the reheat to remain on continuously, or the valve would open before the damper actuator had shut.

Air balance problems in the 12 lab zones were also noticed. Lab supply airflow was too large for some labs and was insufficient in others. The measured differential pressures of the labs showed that some had negative values, and some had values too high for chemical labs.

A few of the problems identified from the field survey were the following: 1) high air resistance from the filters and coils, 2) errors in the temperature sensor and static pressure sensor, 3) high static pressure setpoints in AHU1&AHU2.

The previously implemented CC measures and the status at the time of verification are summarized in Table 2 for comparison. Table 2 also shows the CC verification findings and recommendations.

CAUSES FOR INCREASED ENERGY CONSUMPTION AND COMFORT COMPLAINTS

According to the facility personnel, there were a high number of hot call complaints during the summer and cold call complaints during the winter, beginning in 1998. Figures 9 – 10 show about five years of monthly electricity consumption and chilled water consumption beginning shortly before the initial CC measures were implemented. Figure 10 shows increased chilled water consumption starting during the last half of 1999. Metering problems have limited the amount of hot water consumption data available during this period, but the data available are consistent with an increase in hot water consumption since 1999 as well (see Figure 6). The reasons are as follows:

- Two chilled water pumps by-passed to full speed not only wasted electricity, but also increased chilled water & hot water consumption due to high pressures in the water loops.
- Leaking chilled water valves and the failed electronic to pneumatic control component resulted in lower air discharge temperatures and caused not only terminal reheat to activate in labs and offices, but also caused the preheat valves to come on when outside air temperature was higher than 40 F.
- Failed CO2 sensors and building static pressure sensors resulted in excessive outside airflow.
- Loose-coupled controls and hunting valves also resulted in simultaneous heating and cooling.

ENERGY CONSUMPTION LOSS ESTIMATE

Significant energy savings were achieved through Continuous Commissioning and the additional follow-up performed on the building. Figures 9 – 10 clearly show the results of the Continuous Commissioning.

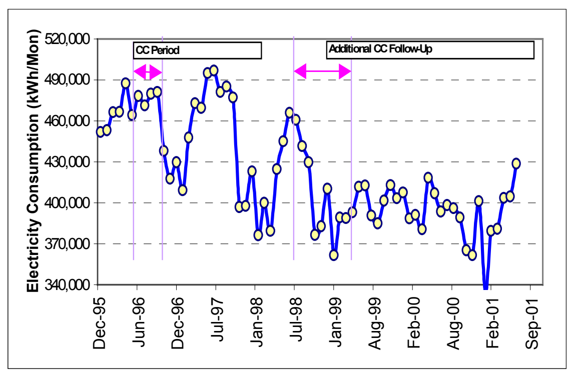

Figure 9. Monthly Electricity Consumption

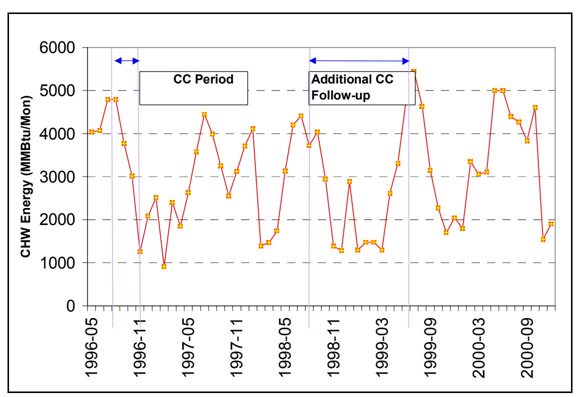

Figure 10 Monthly Chilled Water Consumption

The following shows estimated increase in energy consumption since 1999 due to these problems:

- Electricity consumption increase for two chilled water pumps:
  260,000 kWh/yr. for 2 pumps (~ $10,600/yr for 2 pumps).

Unknown increases when terminal fans are over-active due to low discharge temperature.

- Increased chilled water consumption of more than $20,000 per year (average 362 MMBtu/month).
- Increased hot water consumption cannot be accurately determined from the measured data because of the limited reliable data since 1999. The hot water consumption increases from problems of this type are generally comparable to chilled water increases.
- Total increased cost: $51,400/yr.

Table 2. CC Verification for Kleberg Building

Item	Design Information	CC (6/1996~8/1996)	Additional Follow-up (6/1998~4/1999)	CC Verifications	Solutions and Recommendations
Two CHW pump control	Pumps were originally programmed to operate simultaneously at identical speeds depending on the maximum chilled water demand of AHU1 & AHU2.	Based on chilled water demand, one pump is modulated to full speed and then the second pump comes on	Calibration action taken on: • temp sensors • static press sensors • VFD	Two pumps are manually controlled at full speed. DDC control bypassed. PXP component failed.	Reactivate VFD control Replace PXP component
OA damper control (AHU 1 & 2)	OA, RA & EA dampers are initially fully opened. OA, RA & EA dampers are modulated for economizer cycle	RA damper fully opened all the time, OA damper modulates building pressure	Same as CC	Outside air dampers were always fully opened	Replace or calibrate bad static pressure sensor and modulate OA damper to maintain building press
Economizer mode (AHU 1 & 2)	When OA temp. is less than 55°F, OA, RA & EA dampers are modulated to maintain mix air temp. at 55°F.	Operates if OA air temp. falls below 60°F to maintain mix air temp. at 57°F	Same as CC	Same as CC	
Supply static pressure control (AHU 1 & 2)	Static press setpoint for supply fan is 0.75" WG.	Night time set back was developed to reset down to 0.5"WG	N/A	Static press setpoint for supply fan is 1.8" WG. No night setback	Reschedule static pressure setpoint. Install night setback (0.5"WG)
Pre-heating valve control (AHU 1 & 2)	Coupled control based on discharge temp.	Pre-heating valve will be opened if the mixed air temperature drops below 40 °F. Valve parameters (slope intercept) were corrected	Pre-heat will come on if the mixed air temperature drops below 45 °F.	Pre-heating valve functioned when outside air temp was 65°F.	Need to install temp. sensor between pre-heat coil & cooling coil for pre-heating valve control. Fix leaking chilled water control valves
CHW Control Valve (AHU 1,2,3 & 4)	Valve control was based on the discharge temperature	Dead band control introduced for AHU 3 & 4 due to valve hunting	N/A	Two chilled water control valves of AHU-2 are leaking badly. Dead band control was missing	Replace two bad control valves. Restore dead band control for two AHUs
OA damper control, Cold deck schedule and Pre-heating valve control (AHU 3 & 4)	• The CO_2 sensor controls the OA damper. $CO_{2\ setpoint}$ 1000 ppm • Temp. Sensor in the return air controls chilled water valve and Pre-heating valve to maintain RA temp. at 70°F for the coupled control AHU 3 & 4	• Return air damper fully opened all the time • A dead band was introduced in all chilled water and hot water valves	Same as CC	• OA dampers are fully opened all the time for AHU 3 and AHU 4 • Outside air damper of AHU-4 was in bad condition. • The two CO_2 sensors need to be calibrated • Loose control (wide temp swings)	• Calibrate or replace two CO_2 sensors • Fix outside air damper for AHU 4 • Restored dead-band (4 F) for coupled control AHUs

Table 2 (cont.). CC Verification for Kleberg Building

Item	Design Information	CC (6/1996~8/1996)	Additional Follow-up (6/1998~4/1999)	CC Verifications	Solutions and Recommendations
Cold deck schedule (AHU 1 & 2)	55°F fixed	Based on ambient temp. (62°F –57°F for ambient 40°F-60°F)	Based on ambient temp. (65°F –55°F for ambient 40°F-70°F)	Same as additional CC	
VAV box, terminal reheat & control, General exhaust system control, Fume hood VAV control	Fan powered VAV box with reheat. In response to the signal from thermostat terminal damper modulates to maintain the space set temperature	N/A	• Fixing of main air problem, faulty damper and actuator. • Calibration of thermostat • Calibration of controller • Verify flow sensor • Modify the control program for the lab & office • Calibration for fume hoods • Air balance for lab & office	Some damper actuators were leaking. Some reheat valves were malfunctioning	Fix leaking actuators and malfunctioning reheat valves. Air balance for some labs & offices
Building press control	Building static pressure was 0.05" WG	Building static press reduced to 0.03" WG	N/A	Building pressure setpoint still was at 0.04"WG. Trending and measurement show 0.01 – 0.02"WG One of the static pressure sensors malfunctioned	Calibrate or replace malfunctioning static pressure sensor.
Exhaust Fan	CV exhaust fans with modulating RA dampers to maintain suction press in exhaust duct at a setpoint of 1.75"WG	Same as design condition.	Static press in the exhaust duct is reset to 0.75 "H2O (it was 3.0" WG Calibrated pressure sensor	N/A	

CONCLUSIONS

This paper describes follow-up to the original Continuous Commissioning measures implemented at the Kleberg Building and more recent verification activities initiated in response to increased consumption and comfort complaints. The verification results show that the CC team initially was able to optimize control scheme-reset schedules on the air-side (AHU) and water-side (pump) systems in the building and improve operations for the terminal boxes by implementing CC measures during initial CC implementation and follow-up. Subsequently, some previously implemented CC measures were changed by a combination of facility personnel actions and HVAC quipment failures. Evidence suggests that implementation of changes and repairs recommended by the CC verification activities will restore HVAC optimization and return savings to earlier levels when completed. This restoration requires the following actions:

- Reactivate VFD DDC control for chilled water pumps.
- Modify pump programming operation schedule.
- Fix or replace the two leaking chilled water valves for AHU2.
- Calibrate or replace building static pressure sensor, electronic to pneumatic control component and the two CO_2 sensors for AHU3 and AHU4
- Separate cooling and heating setpoints for coupled control AHU3 and AHU4.

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