Micro Level Data Analysis in Continuous Commissioning®: A Case Study

Saleem Khan1 and Mitch Bible1

1 Texas Energy Engineering Services, Inc.
1301 Capital of Texas Highway, B325
Austin, Texas 78746
Email: saleem@teesi.com

Abstract:
The overall efficiency of the Continuous Commissioning® (CC®) process relies on the interactions of the commissioning team, the building owner, and the building operators. At times the process may be hindered by the traditional "open loop" approach of planning, implementing, and presenting commissioning measures, then waiting for results based on analysis and availability of whole-building utility data. One way of closing this loop and providing instantaneous feedback to all parties is through "micro" level data analysis to evaluate individual measures. This paper presents a case study of a CC® project at Anderson High School in Austin, Texas. Measures for optimizing air and hydronic systems were implemented. Concurrently, building automation system trend data relevant to each measure were analyzed. Results of this analysis helped to improve response times for the commissioning team, reassure savings potential for the building owner, and instill confidence in proper equipment function for the building operators. These effects all in turn improved the CC® process efficiency, which was validated by the whole-building savings results following completion. Through six months, post-CC® utility bills show an estimated utility savings of $39,192 without sacrificing comfort, already exceeding pre-assessment projections for the entire year.

Keywords:
Building Automation System, Commissioning, Measurement, Utility Analysis Verification,

1. Introduction

As energy prices continue to rise in today's economy, utility costs are becoming an increasingly critical part of institutional budgets. As the budgets themselves are staying relatively stagnant, these costs cut into Operation and Maintenance (O&M) funds that could be used for equipment retrofits, further compounding the issue. Continuous Commissioning® can offer a solution to this problem, with typically faster payback than capital retrofit while also addressing existing O&M and comfort issues. The CC® process works within existing HVAC systems to continuously optimize operation, comfort, and energy use given the current, and not original design conditions (Verdict et al., 2004). It can also serve as a tool for achieving sustainability and emissions goals. The value of CC® to the client can be further improved when the efficiency of the process itself is optimized.

Continuous Commissioning® was developed by the Energy Systems Laboratory (ESL), and traditionally consists of sequential steps such as conducting system measurements, developing a CC® plan, implementing CC® measures, and documenting energy savings and
comfort improvements (Claridge et al., 2002). All of these steps involve interactions with building owners and operators to help identify problem areas, gain approval for proposed measures, and report results to validate the project. The efficiency of these interactions are crucial to the success of the project. Just as in control theory, introducing measured feedback throughout the CC® process can enhance its efficiency and its ultimate deliverables.

2. Closing the CC® process loop

The primary "output" of the CC® process used to measure its success – and potentially to feed back to improve the process – is energy savings. The least expensive method of CC® project savings measurement is using building utility data gathered over several months before and after implementation, as outlined in the International Performance Measurement and Verification Protocol (IPMVP) Option C (EVO, 2012). This may not, however, be the most effective method as its lengthy delay renders it essentially an open-loop approach. Accurate analysis with this approach can take up to 12 months or more of data (Sellers, 2001), long after quantifiable results are demanded by the owner, and too late for corrective action by the engineer. Moreover, whole building utility data encompasses interactions between all building equipment, and fails to demonstrate the success of individual measures as they are implemented. Using trend data within the Building Automation System (BAS) can be a cost effective way to improve the frequency and resolution of this feedback and close the process loop.

During the planning and implementation phase, baseline time series trend data can identify operational issues. Ideally, automated "dashboards" can monitor trends and notify operators when certain limits are exceeded (Seidl 2006). Such tools are currently in development by ESL and others. In addition to real-time troubleshooting, trends showing the success of "trial" measures can be useful to ease concerns of building operators over proposed sequence modifications. In the post-implementation phase, gathered data can be filtered to verify the functionality and efficiency of implemented measures. This information can be used by the CC® team to iterate the implementation phase as necessary and fine-tune CC® measures, as well as to give an early savings projection to building owners and justify the project sooner.

CC® was recently performed at Anderson High School in Austin, Texas by Texas Energy Engineering Services, Inc. (TEESI). ESL provided whole building M&V services following project conclusion. Throughout the project, TEESI engineers used the closed-loop approach and BAS trend data as described above to successfully improve the process efficiency and ultimately the end product.

3. Facility Description

Anderson HS has a total square footage of 265,180 ft² and is located in Northwest Austin, Texas. The school was originally constructed in 1973 with multiple renovations since that time. In particular, a new band hall and science building were added in 2009 with a separate satellite central plant.

The main central plant at Anderson consists of two water-cooled centrifugal chillers totaling 600 tons with primary-secondary variable speed pumping. Four hot water boilers totaling 8,000 MBH in capacity also serve the main building. The satellite central plant for the
science and band addition consists of a 120 ton air-cooled chiller and two hot water boilers totaling 2,700 MBH in capacity.

On the air-side, most classroom areas at Anderson are served by variable volume Multizone (MZ) Air-Handling Units (AHUs). Single Zone (SZ) variable volume AHUs serve large areas such as the cafeteria and gymnasium. Finally, the new band and science hall are primarily served by Single Duct Variable Air Volume (SDVAV) units with terminal hot water reheat.

4. Pre-CC® Control

Prior to implementation, occupants could control space cooling setpoints between 67°F and 77°F. The majority of spaces were set at the lower end of this range. Heating/cooling deadbands were only 2°F if they existed at all. In the case of the classroom MZ units, no deadband was in effect. Zone mixing dampers were controlled to a single setpoint. On the MZ air-handlers themselves, Cold Deck (CD) setpoint was a constant 55°F, and both Hot Deck (HD) setpoint and VFD speed were reset based on outside air temperature alone. Although space temperatures could still be controlled with the zone dampers, this was often accomplished wastefully by mixing heated and cooled air to deliver ultimately neutral air to already-satisfied spaces. Moreover, although variable volume, the open loop nature of fan speed control led to minimum VFD speed being 70% of design in order to assure proper airflow in heating.

On SZ units, although Supply Air Temperature (SAT) and VFD speed were controlled based on space temperature feedback, both were controlled simultaneously. This created potential for overly high flows of neutral air, costing fan energy, as well as significant overshoot and hunting of space temperature.

SDVAV units at Anderson controlled fan speed based on maintaining a constant static pressure setpoint. These units are also equipped with pressure independent outside air control, which before CC® was set to deliver a constant volume of outside air.

On the water-side, secondary Chilled Water (CHW) pump speed was controlled to a constant "worst case scenario" Differential Pressure (DP) setpoint. Hot Water (HW) pumps were constant speed and were found by the CC® team to be in "Hand" position and running around the clock even with the boilers disabled.

In addition to control issues, TEESI also identified HVAC equipment and sensors that required repair or upgrade. All of these issues and more were addressed in the implementation phase with the aid of consistent micro level trend data analysis and feedback.

5. Implementation Phase and Micro Level Feedback

As part of the CC® planning process, BAS points relevant to the most significant measures were trended using the controls frontend. From this data, a baseline was established to use for feedback during implementation. To properly execute a closed-loop CC® approach, careful planning of BAS trends is critical. Ideally, trending every system point would ensure baseline data were available for areas found to be of interest following implementation. In reality, trending capabilities are limited by the time needed to set them up, the effort needed to filter results, and the network traffic created when downloading data to workstations. As such, a
certain amount of foresight is necessary to predict "heavy hitting" measures and their related BAS points prior to implementation.

After the planning and setup phase, the proposed measures were approved by the school district and implemented in the BAS. Implementation began with simple changes such as space setpoint limitations (72°F minimum in cooling) and widening deadbands to meet or exceed current energy code requirements. Operating schedules were also trimmed to reflect actual occupied hours. Next, modifications to actual unit control sequences were made by TEESI engineers. Finally, repairs were made to the outside air humidity sensor and Gym unit CO₂ sensor, and the hot water pumps (two in total) were retrofitted with Variable Frequency Drives (VFDs). The following sections describe the implemented control sequences and micro data analysis.

5.1. Multizone AHUs

Cooling/Heating demand based reset strategies have been shown to yield significant energy savings over those based purely off outside air temperature (Texas A&M, 2008). Ideally, the two should be combined so as to prevent "rogue zones" from ramping up the system unnecessarily (Wei et al., 2004). However, it should first be verified these zones do not have high internal loads that legitimately require more cooling. If well monitored, combined zone-demand and outside air based control can help to identify zones with relatively high internal heat gain so that other action may be taken. This combination control was implemented widely at Anderson HS, starting with MZ AHU fan speeds being reset to maintain the most open zone damper position (critical cooling zone) at 90%.

As discussed, the pre-CC® MZ units were without heating/cooling deadbands because zone dampers controlled to a single setpoint. During CC®, an effective deadband was implemented by sequencing units to take no heating action until any zone actually needed heating (space temperature below separate heating setpoint). Rather than controlling off of outside air temperature, HD temperature and heating fan speed were reset to maintain all zones above their respective heating setpoints. This also had the effect of allowing for a lower minimum fan speed, since speed could be increased as necessary should any zone require heating. The existing resets based on outside air were used as upper limits.

Following implementation, trend data were downloaded and filtered to ignore unoccupied periods. Because fan laws relate fan power to the speed cubed, the root-mean-cube VFD speed was calculated for each day and plotted against the corresponding daily average outside air temperature. Figure 1 shows the results of this analysis. The data confirmed that the new sequence was working properly and saving energy while in general improving comfort.
5.2. Single Zone AHUs

The existing SZ AHU sequences at Anderson were already using a demand based reset of SAT and fan speed, but not to optimal capacity. Both supply temperature and air flow were reset at the same time in response to space temperature, causing issues for both energy consumption and occupant comfort. During CC, the sequence was modified to split the sensor signal and respond to cooling or heating demand with warmer or colder air, respectively, first before ramping up fan speed. The fan speed was allowed to modulate from its minimum setting only once SAT reached its lower or upper limit. Figure 2 shows normalized fan speed trend data. The data once again confirmed to the CC® team that the sequence modification had the desired effect.

The existing simultaneous control of supply temperature and flow also caused the units to overreact to space cooling or heating demand and overshoot the setpoint. This resulted in large, potentially uncomfortable temperature oscillations in the space. The oscillatory behavior was identified from time series trend data directly within the BAS and remedied immediately with the new sequence. Splitting the thermostat signal had the secondary effect.
of softening the AHU response to space temperature, thus tuning and tightening the control. Figure 3 shows the pre-CC® issue observed from trend data and the subsequent correction resulting from the modified sequence.

![AHU-15 Room Temperature](image)

Figure 3. Single Zone AHU space temperature oscillations corrected during CC.

### 5.3. SDVAV Units

Implementation on SDVAV units provided examples of using micro level trends analysis and feedback to enhance other areas of CC® in addition to savings results. Like MZ and SZ AHUs, it was recommended that the SDVAV units use a demand-based reset, in this case for static pressure setpoint (reset to maintain most open terminal unit damper at 90%) rather than keeping it constant. This was met with some skepticism from building operators worried about undercooling and increasing hot calls. It was agreed that the proposed sequence be implemented on a trial basis and monitored by the CC® team. Figure 4 shows the results of this trial; the most open damper was successfully maintained at 90%. Being pressure independent boxes, the system still necessarily receives the exact same amount of cooling as before CC® – only at a more efficient system pressure – provided all dampers are less than full open. Figure 4 also depicts the most open damper position on a typical pre-CC® day, when the constant static setpoint was too high and forcing all zones to throttle airflow needlessly. The resultant decrease in fan speed after implementation is also shown, along with the outside temperature profiles on both days for comparison. After presenting the trial results to the District, the reset was approved and implemented for all SDVAV units. Figure 5 shows the weather-normalized fan speed data confirming long-term savings in addition to functionality.
A demand based reset was also proposed and tested for SDVAV SAT. In this case, trend analysis identified short-cycling in the satellite chiller. This was attributed primarily to the chiller being oversized for the present load, i.e. already occurring before CC. Nevertheless, corrective action was taken by the CC team as a result of the discovery. The District was notified and the reset was removed to avoid complicating the issue.

SDVAV-served spaces at Anderson HS are equipped with motion sensors whose signals are tied into the BAS. The system was previously using these signals to set back or set up the space temperature setpoint when no occupancy was sensed. Building on this, and extending the concept of demand based resets, the CC team implemented a reset of the outside air volume setpoint based on the number of occupied zones. A sequence was written to poll all motion sensor signals and decrease the setpoint as necessary assuming zones with no motion

SDVAV Fan Speed

Figure 4. SDVAV static pressure reset trial results.

Figure 5. SDVAV fan speed trend pre and post CC.
were completely unoccupied. Following implementation, pre and post CC® trended outside air CFM measurements were filtered for hours of operation only and sorted into hourly time bins. The average for each bin was computed and plotted in Figure 6. It was discovered that some occupant diversity was always present, that is, at least one zone was almost always unoccupied. As expected, significant ventilation setback was possible during shoulder periods before and after school, without violating ventilation codes.

![Figure 6. Outside air intake time bin analysis.](image)

5.4. HW Plant

Control of Anderson's boilers within the BAS was limited to enable/disable functionality only, and thus fell outside the scope of the project. However, as mentioned, it was discovered the HW pumps were running around the clock. This issue was remedied in the field and the pump statuses continued to be monitored by the CC® team in the BAS. The data were again sorted in to time bins and the fraction-of-time-found-running in each bin was calculated for both pumps. Figure 7 shows the results of this analysis. After automatic control was restored, after-hours operation was limited to night setback calls only, and the pumps staged as intended with HWP2 rarely coming on.
5.5. CHW Plant

As with the HW boiler control, setpoint reset functionality was limited within the BAS. Thus, no direct changes to the chiller sequence was made. However, the cooling supplied to the building was trended in the BAS to monitor the indirect effects of changing setpoints, widening deadbands, reducing reheat, etc. Figure 8 shows the average daily loads during operation plotted against corresponding average daily outside air temperatures. Sequence changes related to CHW load were successful in reducing the CHW consumption as expected.

A demand based reset scheme was also applied to the CHW secondary pumping system. The DP setpoint for the secondary CHW pump VFDs was reset in order to maintain the most open
AHU CHW coil valve at 90%. Pump speed trend data were analyzed and plotted in Figure 9. It was suspected prior to implementation that the existing constant DP setpoint was far higher than necessary under most conditions. Post implementation trend data confirmed this suspicion. Resetting based on actual demand made the system more dynamic and self-balancing, allowing the pumps to slow significantly.

![Secondary CHW Pump VFD](image)

Figure 9. Secondary pump speed trend pre and post CC.

6. Savings Summary

The preceding sections demonstrate the value of analyzing trend data *during* the CC® process to assess individual measures and fine tune or take corrective action where necessary. The information can also be used following implementation to form an early savings projection for each measure and for the entire project, long before a meaningful result is available from monthly utility data. At Anderson HS, basic assumptions of efficiencies and baseline equipment equivalent-full-load-hours were combined with the compiled trend data to yield early savings projections. These projections were compared with savings estimates from the assessment phase before CC® used to secure funding. It is interesting to note that pre-CC® predicted savings resulting from reduced equipment runtime were overestimated in most cases, while savings calculations involving demand based resets and sequence modification were overly conservative. In this way, information gained from micro-level analysis is also useful for reviewing pre-project assumptions and advising future projects in the proposal/funding stage.

From the early micro-level analysis, TEESI projected savings of approximately 18% over the base year. Macro-level M&V provided by ESL, through six months following implementation, validates and even exceeds this projection, showing 21% electricity savings with an additional 17% natural gas savings over the base year. This corresponds to $39,192 in total utility cost savings thus far using prevailing rates, already surpassing total first year pre-project projections. Figure 10 shows the cumulative cost savings during the post CC® period (Courtesy ESL).
7. Conclusion

Continuous Commissioning® is a process intended to improve the efficiency of a building, but the efficiency of the process itself can be improved as well. CC® at Anderson High School in Austin, Texas has saved the school district nearly $40,000 in just six months since implementation began. This success was due in part to team efforts to enhance the CC® process through analysis of trend data relevant to individual measures. These data were critical for quality control of sequence modifications, supporting evidence for measure approval, and early justification of the project. They may also prove useful in fine tuning assessment-phase savings estimates for future projects.

Using "micro" level data analysis and feedback throughout the CC® process, in concert with "macro" level whole building M&V down the line, can be a valuable tool. Automated tools such as dashboards are being developed to help streamline this process. However, for best results, they should be used as a supplement to – and not replacement for – sound engineering practice and experienced hands-on analysis. In addition to potentially increasing project savings, micro analysis can also increase building owner and operator confidence in the CC® team and process. This confidence helps beget more cooperation and success in future projects, a snowball effect that ultimately maximizes savings and reduces the strain on institutions' ever tightening budgets.

Acknowledgements:

The authors would like to express appreciation for the assistance provided by the Austin Independent School District (AISD) facility department, maintenance staff and Anderson High School staff. We would also like to thank, in particular, Farshad Shahsavary, Ken Rebberger, Jim Dillard, Stuart Miller and Jess Williams for their time and assistance throughout the project. Our complements go to AISD top management for their foresight in
undertaking this project. Finally, thanks to the Energy Systems Lab for whole-building savings figures and input during the commissioning process.

References:


Texas A&M Campus Building CC® Team (2008), Simulated Energy Savings Comparison Between Two Continuous Commissioning® Methods Applied to a Retrofitted Office Building, ICEBO 2008 Proceedings, Berlin, Germany.
