

CONTINUOUS COMMISSIONING[®] OF THE MATHESON COURTHOUSE IN SALT LAKE CITY, UTAH

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ABSTRACT

The Utah Energy Office, located in the Department of Natural Resources (DNR), Utah Department of Facilities Construction and Management (DFCM), and engineers from the Energy Systems Laboratory at Texas A&M University teamed to perform Continuous Commissioning[®]¹ of the Matheson Courthouse in Salt Lake City, Utah. The Matheson Courthouse is a relatively new building, well-run, with a modern controls system. It is one of the most efficient buildings in Utah, averaging only \$1.08 per square foot per year prior to the building and thermal plant commissioning. The project started with a walk-through commissioning audit in February 2001, and the CCSM process began in January 2002. Details of the CC process and the measures implemented are included in this paper. The 2002 energy bills for Matheson dropped by \$116,000, down to \$0.77 per square foot per year. Approximately 80% of the reduction in bills can be attributed to the Continuous Commissioning process, with the remaining savings coming from lower gas and electricity prices.

\$1.08 per square foot per year is based on conditioned square feet. The Utah Department of Natural Resources (DNR) contracted with the Energy Systems Laboratory to conduct preliminary audits of seven state buildings in 2000 and to present a Continuous Commissioning workshop for facilities managers and operators. Metering and monitoring is an integral part of this process, and most of the initial state buildings audited did not have meters in place and did not have interval metering from the local utility, Utah Power. The decision was made by the State Energy Office to look for additional candidate buildings which had interval metering. The Matheson Courthouse did have an interval data recorder, and it was selected as a potential candidate building for Continuous Commissioning. In Utah, electricity is the dominant utility for most state buildings, generally representing from 75% to 100% of the building's energy requirements. A DNR program decision was made to use the interval electricity utility data and monthly gas bills for the savings analysis.

INTRODUCTION

The Matheson Courthouse in Salt Lake City is the main state courthouse, built in 1997. A photograph is noted in Figure 1. The multi-story building includes 37 courtrooms, offices, holding cells, and a three-level underground parking garage. The total square footage is 420,000, with 370,000 of conditioned square feet. The 2001 Energy Cost Index (ECI) of

The CC walk-through was conducted in February 2001. Despite the efficient building operation, the team identified sufficient measures to justify choosing Matheson as a viable candidate. The cost proposal estimated at least \$35,000 in savings, with a commissioning cost of roughly \$70,000, for a two-year simple payback. This was an acceptable savings and payback criteria, and a contract was established between DNR and the Laboratory, effective in October 2001. The commissioning team consisted of an engineer from DNR Energy Office, the building facility manager from DFCM, a controls specialist from DFCM, and two engineers from the Energy Systems Laboratory. The team was structured such

¹ The term Continuous Commissioning is a registered trademark of the Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, Texas.

that the CC measures would largely be identified by the ESL engineers, would be discussed with the team, and those measures accepted for implementation would then be carried out by the DFCM team. This approach has several advantages:

- 1) All team members are part of the CC process.
- 2) Overall costs are minimized since the ESL was not providing technician or programming support to the project, thus reducing both manpower and travel costs.
- 3) The DFCM would gain valuable first-hand knowledge of the commissioning process.

It should be mentioned that this approach also has a major disadvantage. While the CC work was important to the team, the two DFCM team members had major responsibilities other than commissioning of the Matheson Courthouse. Their other responsibilities had to be taken care of, and the CC work often did not get top priority, thus lengthening the process.

The Continuous Commissioning process was initiated in January 2002 and continued throughout much of the year. Over 30 separate Continuous Commissioning measures were identified, and most have been implemented. The measures can be roughly broken into:

- 1) Calibration issues
- 2) Operational changes
- 3) Maintenance issues
- 4) Optimization improvements

FACILITY DESCRIPTION

The courthouse was first occupied in 1997. It is a very modern facility, containing three levels of underground parking, six stories of offices, courtrooms, holding cells, library, cafeteria, etc. and a sixth floor, largely mechanical rooms. Some facts about the building include:

- 1) 420,000 square feet (covered); 370,000 square feet (conditioned)
- 2) One (1) 400 ton and one (1) 800 ton chiller
- 3) Six (6) single duct, VAV AHUs, with hot water terminal reheat
- 4) Two (2) 500-hp hot water boilers
- 5) Modern DDC building automation system
- 6) Annual utility bills of \$400,000 (\$300,000 electric; \$100,000 gas)

CONTINUOUS COMMISSIONING PROCESS

Continuous Commissioning is defined as the process of analyzing and optimizing the HVAC energy systems in a building or central plant to reduce energy consumption, improve comfort, and increase productivity of the occupants. The process can also

identify potential capital retrofits that may be needed to further improve energy efficiency. CC can be performed as an existing stand-alone measure, which has been documented in a number of papers [1, 2, 3, 4, and 5]. It can also be conducted after major capital retrofits, such as the Texas LoanSTAR program [6 and 7], which is where the CC process began. It can also be included as an Energy Conservation Measure as an integral part of a major capital retrofit program for energy efficiency [8, 9, and 10].

The major steps of the process are as follows:

- 1) Conduct a commissioning walk-through of the building. This preliminary audit is targeted at identifying operational problems that are preventing optimum operation. This audit may take several days in a large or complex building and involves detailed measurements of air handler operation, central plant operation, and a review of the building automation system (BAS) operation. If trend logs are available, they will be reviewed. If BAS trend logs are not available, key trend logs may be set up to help with the preparation of the initial commissioning plan.
- 2) Prepare a commissioning implementation report, describing measures identified, potential savings, and cost for the Continuous Commissioning of the facility. The cost may include several options, ranging from a "turnkey" quote, where the ESL engineers and technicians will do all the CC work, including purchase of sensors and valves, and minor repairs, to providing primary CC project management services, with the receiving entity doing most of on-site implementation.
- 3) Initiate a contract to do the work. Include in the statement of work the division of responsibilities for the various parties involved, i.e., the team.
- 4) Conduct an initial team meeting to go over the CC process, the various roles of the team members, and the schedule. Utility bills should have been provided and reviewed at this stage, as well as metered data or trend logs from the building automation system.
- 5) Conduct the detailed CC audit, identifying the potential measures to be implemented. Quantification of savings by measure should be made to the extent possible.
- 6) Discuss the potential measures with the team and determine which measures can be implemented, who is going to implement them, and the schedule. There are some measures which can be implemented immediately, while others may require purchase of sensors, recalibration, or equipment repair. Prepare a detailed implementation plan.
- 7) Implement the measures. Over the course of the implementation process, additional measures may be identified.

- 8) Track the building operation from building meters, the BAS, and/or utility metering. Make sure the measures are performing, and fine tune, if necessary.
- 9) Determine savings and write a report to the client, documenting the operational and **comfort improvements** and energy/dollar savings.
- 10) Continue to work with the client to ensure savings persist, i.e., the “continuous” portion of the Continuous Commissioning process.

At the Matheson Courthouse, approximately 30 CC measures were identified. Some were major, while others were minor improvements. The measures, by category, are listed below:

SENSOR CALIBRATION

1) Three of the six CO₂ sensors controlling outside air were out of calibration. Two were reading low, which did not have energy implications, but one sensor had failed with a reading of 2000 ppm, which resulted in 100% outside air being used for that air handler all year long. Several duct static pressures were reading high, and several supply air temperature sensors were off 1-3°F.

2) Outside air temperature and relative humidity sensor calibration and location were problems. The outside air temperature sensor was found to be reading as much as 6°F too high during some parts of the day, and the relative humidity was reading high by 35-40%. The RH sensor had failed (it would saturate in wet weather or when snow was on the building roof), and the temperature sensor was out of calibration.

- 1) The delta pressure (ΔP) sensor on the chilled water loop was out of calibration. Later it was found to be a static pressure from the supply line rather than a ΔP signal. A recommendation was made to install a ΔP sensor in order to optimize the operation of the chilled water loop.
- 2) The building static pressure sensors were out of calibration and were re-calibrated, as discussed later in the paper.
- 3) Major problems were found with the VAV box calibration. Over 70% of the boxes were providing erroneous readings. Boxes were showing large amounts of flow even when AHUs were off, flow stations were broken, or dampers were not functioning properly. As a result an outside firm was hired by the State of Utah to re-calibrate the boxes. This slowed the CC process until the boxes were completed, but it was absolutely necessary to carry out the commissioning.

OPERATIONAL PROBLEMS IDENTIFIED

1) Boiler operation—Two large boilers were used to provide heating hot water to the courthouse. Both boilers were being used, each starting up on high fire, which resulted in large swings in hot water temperature and pressure. One boiler can easily carry the courthouse hot water needs, starting on low or medium fire.

2) Pump operation—The Matheson Courthouse was regularly using two pumps for operation of their glycol, chilled water, and hot water loops, when one-pump operation will carry the load much of the time.

3) Glycol loop operation—A glycol loop is used to melt snow on the garage ramp. A programming error turned the de-icing system on when the outside air temperature was below 38°F or the outside relative humidity was above 80%. This turned on the de-icing system anytime, fall, spring, summer or winter, when the outside RH exceeded 80%. When this measure is combined with a faulty RH sensor discussed in item 1 under Sensor Calibration and item 2 above on two-pump operation, this meant the two small glycol pumps and the glycol loop were operating far too much.

- 1) Chiller start-up procedures in spring—A review of the 15-min load data from the electric utility indicated an electrical “spike” of several hundred kW in the spring. This was attributed to a refilling of the chilled water systems and turning on the chillers, pumps, and condenser equipment for operational verification. By changing the normal start-up procedures to make sure the equipment is not run at the same time during a weekday, this will save several thousand dollars. It is not an energy saving measure, but an electrical demand management measure.
- 2) Early morning building warm-up/cool-down measures—Prior to CC the building was generally started up sometime after midnight on Monday mornings and somewhere between 2 a.m. and 4 a.m. on other mornings, depending on the season. Although the Building Automation System has a feature called Optimum Start (or O-Start), it was not starting under optimal conditions. For example, in the winter the building start-up conditions would typically be as follows:
 1. Temperature inside AHU might reach 120°F when AHU was off and hot water was being circulated for freeze protection.
 2. AHU would start for building warm-up but would try to maintain occupied

discharge air temperature typically around 55°F.

3. When the stagnant air inside the air handling unit reached the discharge air temperature sensor, the temperature would be too high, and the signal would be sent to fully open the economizers.

4. Opening the economizers now meant that very cold air would enter the AHU, and the DAT would drop rapidly.

5. The now low DAT would cause the heating valve to open and would also drive the economizer dampers to start to close.

6. This extreme instability of temperature conditions required more than an hour to achieve equilibrium and wasted a lot of energy in the process.

The result of this operation was to devise/create a semi-occupied start-up mode which reduced the warm-up/cool-down period dramatically.

MAINTENANCE ISSUES

1) Damper adjustments. Several of the outside air dampers were out of adjustment and required adjustment for proper operation and control. This is particularly important for economizer operation, minimum air settings, and early morning start-up.

2) Building static pressure sensors and damper maintenance. During the initial CC phase, the building static pressure sensors could not be located or verified, but from the BAS readings, they were known to be off calibration. None of the sensors, for example, read zero when all the AHUs were off. The static pressure sensors were later recalibrated from the BAS to read zero when the AHUs were off. Sensors not capable of being rescaled were replaced. There was also a failure of the program logic which allowed the exhaust dampers to remain open on some of the building core shafts when the exhaust fans were off. This allowed outside air to be "sucked" into the building when the exhaust fans were off. Since most of the core shafts exhausted into the parking garage, this also created an indoor air quality issue because exhaust fumes from the garage were entering the building. Some programming logic was changed for this measure as well.

3) Leaking control valves. Maintenance was not a big issue at Matheson, as the building was well maintained. However, two control valves were leaking and were repaired/replaced.

4) Small chiller isolation valve. There was a problem with the isolation valve on the small chiller, which was handled manually by the Matheson maintenance staff. This sticking valve would prevent the proper

sequencing of the large (800-ton) and small (400-ton) chillers.

5) Missing insulation on one AHU. During the sensor calibration/verification phase, one return air sensor was reading several degrees lower than the other return air sensors. A careful investigation revealed missing seal insulation around some outdoor access areas which was allowing outside air to be mixed with return air prior to the mixed air chamber. These areas were insulated by the Matheson maintenance staff.

OPTIMIZATION MEASURES

1) Hot water and cold deck reset schedules. An optimized cold deck reset schedule was developed for Matheson, resetting the cold deck temperature as a function of outside air temperature and enthalpy. The AHU discharge air, mixed air, and return air temperatures were measured, and the optimum schedule was established. Temperatures were also reset in accordance with ambient air temperature.

2) Duct static pressures were also reset in accordance with outside air temperature. A semi-occupied mode was devised, and duct static pressures were reset also depending on occupied vs. semi-occupied modes.

3) Air flow adjustments on VAV boxes. The minimum air flow was reset for VAV boxes in accordance with a semi-occupied mode. Also, the semi-occupied mode reduced total outside air flow since the building occupancy was lower.

4) Lower hot water supply temperature. The boilers were both running, supplying nominal 180°F water to the building year round. The water temperature was lowered to 155°-160°F, which was as low as the boiler controls would allow.

5) Add a new boiler controller and turn off boiler in summer. These two recommendations are still pending, awaiting boiler maintenance, additional VAV box maintenance, and the installation of a new controller for the boiler.

6) Improve the chiller sequence. Prior to CC, the BAS program allowed both chillers to run while switching from the small chiller to the larger chiller. The sequence was changed to eliminate two-chiller operation and reduce demand costs.

COMMISSIONING RESULTS

Except as noted above, all the commissioning measures identified were implemented. Sensors were recalibrated or replaced, operational changes were implemented, and maintenance issues were handled by the Matheson staff.

The analysis group within the Energy Systems Laboratory developed baseline models from monthly

utility bills and determined the savings from commissioning to be in the range of \$75,000 to \$80,000 per year, based on 2001 energy prices. Sixty percent of the savings were from natural gas, resulting from changing the boiler operation, reducing the hot water temperature, changing the winter early morning start-up requirements, and reducing the amount of simultaneous heating and cooling required. The savings models for electricity consumption, demand, and natural gas were 3-P regression models based on monthly average outdoor air temperature.

Monthly bills were used for the savings analysis for electricity because the interval electric utility data was erroneous for several months during the 2001 baseline period. The electric demand monthly model could not accurately predict the savings from the chiller spring start-up and chiller reprogramming changes, which saved approximately 400 kW at \$8.01 per kW. The monthly demand model only predicted about 200 kW in demand savings for the entire year.

Because of lower gas and electricity prices in 2002 vs. 2001, the utility bill at Matheson reduced from about \$400,000 (\$300,000 for electricity, \$100,000 for natural gas) to \$284,000 (\$249,000 for electricity, \$35,000 for natural gas). The ECI for Matheson reduced from an already low \$1.08 per square foot per year to \$0.77 per square foot per year, based on the conditioned square feet. More than 700 hours of AHU operation were eliminated by optimizing the start-up and shut-down sequence of the HVAC system. Figure 2 is a plot in natural gas usage for 1999, 2000, 2001, and 2002 vs. the model-predicted consumption for 2002. The 2002 usage is clearly lower than any previous year and the model.

CONCLUSIONS

The Continuous Commissioning of the Matheson Courthouse was a team effort and a resounding success. The utility bills were reduced approximately 20% from the CC process, and, because of lower energy prices, actually dropped nearly 30% from the 2001 baseline year. A second building commissioning at the Salt Lake Community College is now underway, and a recommendation has been made to DFCM to form a state retro-commissioning team to continue this work at various other state buildings in Utah.

In summary, the CC process can save energy, reduce the number of comfort complaints, and improve worker productivity, if the tenants are happy with the building.

The simple payback for the ESL charges, the TAB firm, and parts purchased by DFCM, was roughly 1.2 years; therefore the project was paid back in the spring of 2003, and the state is now experiencing a positive cash flow from the project.

Since several of the recommended changes have not been implemented to date, i.e., shutting off the boiler in the summer, further reducing the hot water supply temperature, and adding a ΔP sensor for the chilled water supply loop, additional savings will result when these measures are implemented.

ACKNOWLEDGMENTS

The Continuous Commissioning of the Matheson Courthouse was funded by contract #66200 between the Utah State Department of Natural Resources and the Texas Engineering Experiment Station, Energy Systems Laboratory. The contract monitor for DNR was Mr. Jim Hood, P.E.

Figure 1. Matheson Utah State Courthouse

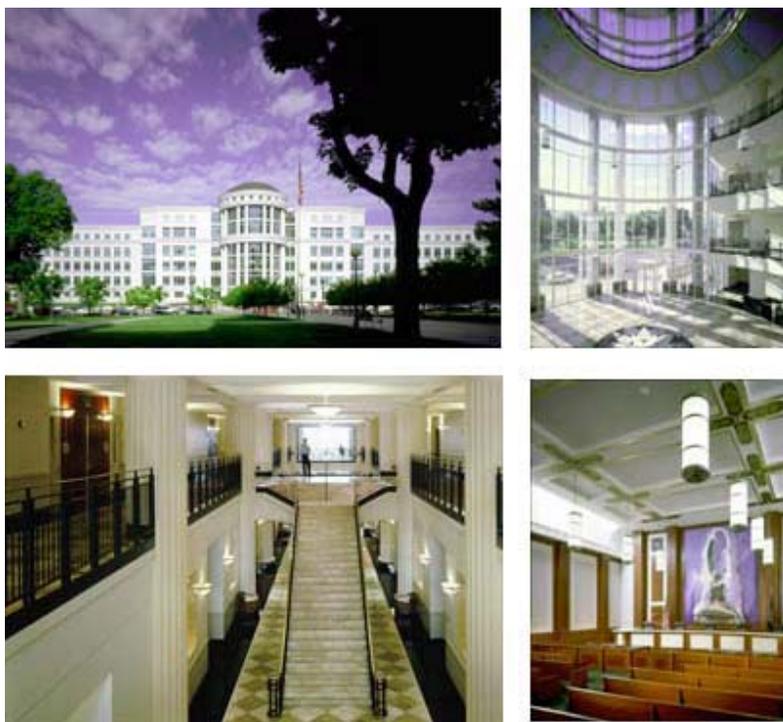
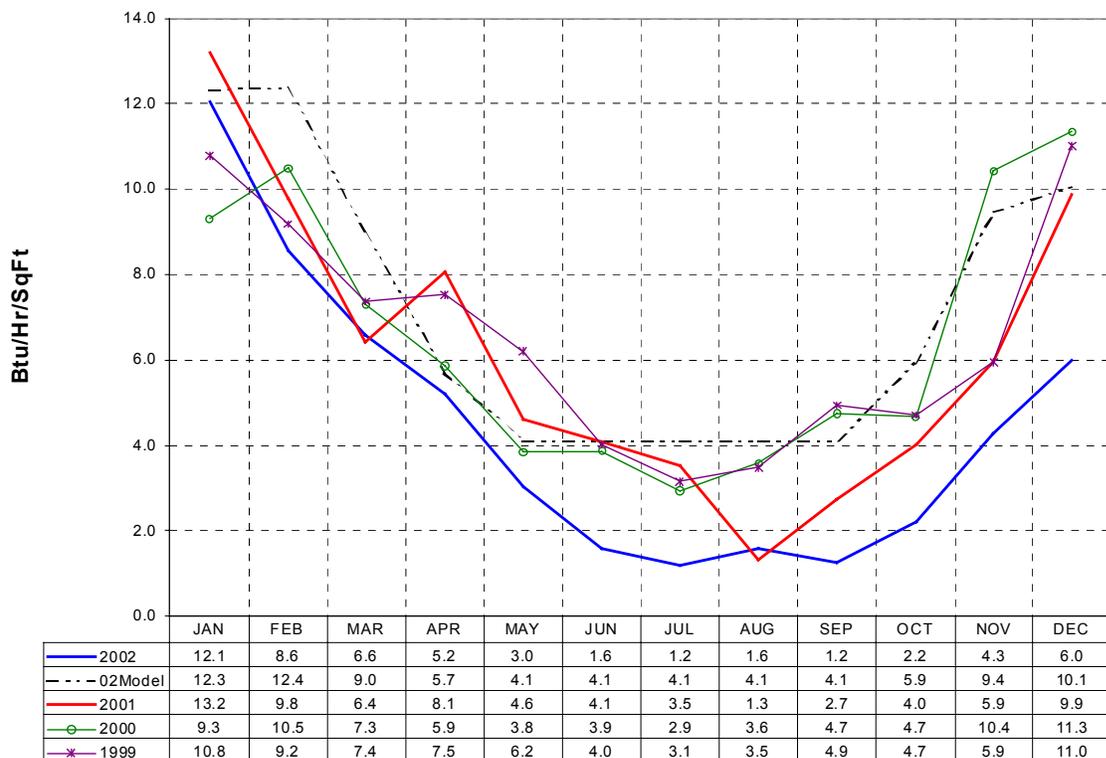


Figure 2. Matheson Courthouse Natural Gas Usage



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