

Integrated Commissioning for A Large Medical Facility

Yeqiao Zhu, Ph.D.
Project Manager
Texas A&M University

Mingsheng Liu, Ph.D.
Associate Professor
University of Nebraska

Tommy Batten
Researcher
Texas A&M University

John Zhou, Ph.D.
Control Engineer
Trane Company

Dan Turner, Ph.D.
Professor

David Claridge, Ph.D.
Professor
Texas A&M University

Tim Giebler
Research Associate

Chuck Cameron
Lead UCS Operator
Johnson Controls, Inc at BAMC

Ben Keeble
Project Manager

Roy Hirschak
Chief
BAMC Facility Management

ABSTRACT

The energy costs of heating, ventilating and air conditioning usually represents a large portion of the utility bills for a medical facility. One large, modern medical center located in the hot and humid region of southern Texas includes clinic areas, inpatient areas, critical areas, diagnostic areas, and pharmacy and a research center. An integrated commissioning of the HVAC system was performed for this building. The commissioning activities improved the building comfort conditions and reduced the utility costs by \$225,000 for seven months during the commissioning periods and four months following the major commissioning completion. Some unique optimized control strategies were developed and implemented in the control system. This paper describes the commissioning activities and the results.

INTRODUCTION

Continuous Commissioning has become a very important conservation topic for buildings in the commercial sector. Even newly built buildings with modern EMCS control systems are candidates because Continuous Commissioning (CC) can still reduce the energy consumption further and also can improve the building comfort level [Zhu, et al., 1997; Liu, et al., 1998; Claridge, et al., 1996; Haas and Edmunds, 1997; Lawson, 1997]. For the large medical center, the HVAC system and building system are often complex. The commissioning will take the form of integrated process for such systems and will be both in air side and water side [Zhu, et al., 1998; Liu, et al., 1997; Zhu, et al., 2000]. This paper presents a case-study of an integrated commissioning process applied to a building, which was built in 1996 as an energy

efficient, large modern medical facility in south Texas.

BUILDING AND HVAC SYSTEMS

The Brooke Army Medical Complex is a large, multi-functional medical facility. It consists of a medical center (main hospital), a research building (R) and a central energy plant (CEP). The medical center consists of the C building (4 stories), an M building (6 stories), an A building (6 stories) and a B building (8 stories) with a total floor area of 1,349,707 ft². The research building is a 3-story building with a floor area of 118,886 ft².

Figure 1 is the typical floor layout of the complex.

The complex primarily consists of outpatient clinic rooms, nuclear medicine, pharmacy areas, ICUs, CCUs, surgical areas, inpatient beds, emergency rooms, diagnostic areas, research labs, offices, animal holding areas, cafeteria, computer rooms, training class rooms and an auditorium.

The complex is equipped with a central plant, which has four 1,200 ton water-cooled electric chillers. The chilled water is distributed to the complex through primary, secondary loop and building riser pumps with a total of 1357 hp. Four primary pumps (75 hp each) are used to pump water through the chillers. Two secondary pumps (200 hp each), equipped with VFDs, supply chilled water from the plant to the building entrance. A total of 14 chilled water risers equipped with 28 pumps totaling 557 hp are used to pump chilled water to all of the AHUs and small FCUs. All of the chilled water riser pumps are equipped with VFDs.

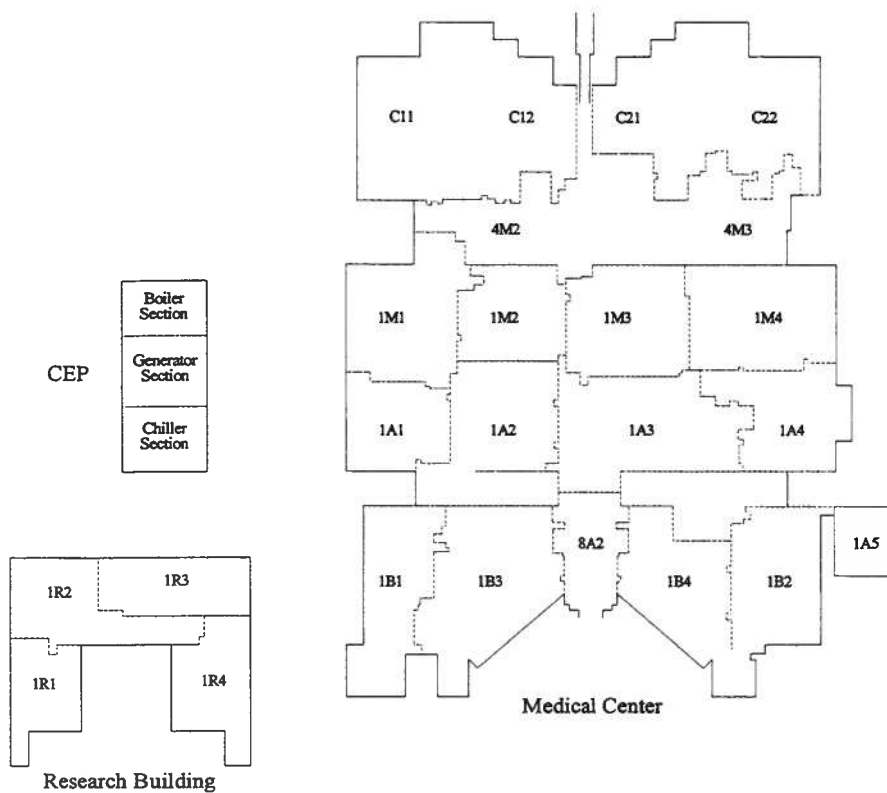


Figure 1. Typical Layout of BAMC Complex

There are 4 natural gas fired steam boilers in this plant. The maximum output for each boiler is 20 MMBtu/hr. Steam is supplied to each building where heating water is generated. The steam pressure setpoint for the boilers was 125 psi.

There are 90 major AHUs serving the whole complex with total of 2,570 hp. VFDs are installed in 65 AHUs while the others are constant volume systems.

In the complex there are 2,700 terminal boxes in which 27% are dual duct variable volume (DDVAV) boxes, 71% are dual duct constant volume (DDCV) boxes, and 2% are single duct variable volume (SDVAV) boxes. There are no terminal boxes for warehouse and auditorium.

The HVAC systems (chillers, boilers, AHUs, pumps, terminal boxes and room conditions) are

controlled by a York DDC control system and operated by a contract company. Individual controller-field panels are used for the AHUs and water loops located in the mechanical rooms, which are also accessed to the central control system through an interface-Procommplus and Facility Manager. The program and parameters can be changed either by the central computers or by the field panels.

When commissioning began, it was discovered that the EMCS control system was being used to perform the following control items.

1. hot deck reset control for AHUs
2. cold deck reset during unoccupied periods only for some units
3. static pressure reset between high and low limit for VAV units
4. hot water supply temperature control with reset schedule

- 5. chilled water pumps VFD control with ΔP setpoint (no reset schedule)
- 6. box level control and monitoring

This facility is maintained by an outside contractor, who does a good job of maintaining the facility in accordance with the original design intent. This building is considered energy efficient for a large hospital complex. Nevertheless, significant energy savings can still be achieved through the commissioning process.

COMMISSIONING ACTIVITIES

Because the case study hospital is such a multi-functional complex, the authors performed a detailed investigation and performed the commissioning at the terminal box level, AHU level, loop level and central plant level. Several different types of improved operation measures and energy solutions have been implemented in different HVAC systems due to the actual function and usage of the areas and rooms.

1. AHU LEVEL

Optimize the Operation of VAV AHUs

There are a total of 54 VAV AHUs serving the clinic areas, diagnostic areas, pharmacy, research laboratory, food services areas, offices, lobby areas, maintenance areas and storage rooms. The cold deck (CD) temperature setpoints were operated with a constant setpoint, ranging from 55°F to 57°F and were occasionally adjusted by the operator during occupied periods. The hot deck (HD) temperature setpoints were modulated between a low limit and a high limit according to the box requirement. If there is no calling for heat from the box, the hot deck will be maintained at low limit. If there is a calling for heat from a box, the hot deck will be increased until the high limit unless stop calling.

The actual measured results from the site measurements and short-term data loggers showed that HD temperatures ranged from 75°F to 93°F during hot summer. The static pressure setpoints were modulated between the low and high limit according to the box conditions. The supply fan ranged from 55Hz to 60Hz for different AHUs during the site visit period.

Table 1 shows the control schedules before commissioning.

Table 1: Typical Setpoints for the HD and Static Pressure before Commissioning

Limit	HD Setpoint	Static Pressure Setpoint
High limit	110°F if Toa<30°F, 90°F if Toa>70°F	1.8”H2O (fixed value)
Low limit	90°F if Toa<30°F, 70°F if Toa>70° F	1.4”H2O (fixed value)

The outside air intakes were constant for both day and night. The relief and return air dampers were 100% open for all units.

Through our investigation, it was found that the high hot deck temperature caused excessive heating and cooling consumption and caused hot calls during the summer. The cold deck setpoints with a reset schedule can better satisfy the building load under different weather conditions and reduce simultaneous cooling and heating consumption during the winter condition. The

actual required static pressure setpoint should be much lower than the original value based on the box and main duct static pressure measured results. The higher static pressure caused more fan electricity consumption and excess cold and hot air to the building. The authors performed detailed calculations for the hot deck and static pressure setpoints [Zhu, et al., 2000]. The post-commissioning control schedules are presented in Tables 2-1, 2-2, and 2-3.

Table 2-1. Post-CC HD Temperature Reset Schedules for DDVAV AHUs

Limit	HD Setpoint
High limit	94~98°F if Toa<30°F, 75°F if Toa>78°F
Low limit	74~76°F if Toa<30°F, 70°F if Toa>78°F

Table 2-2. Post-CC CD Temperature Reset Schedules for DDVAV AHUs

Time	CD Setpoint
Occupied period	60°F if Toa<45°F, 56°F if Toa>80°F
Unoccupied period	Keep existing reset schedule 80°F if Tret<55°F, 55°F if Tret>80°F

Table 2-3. Post-CC Static Pressure Setpoint Limits for DDVAV AHUs

Limit	C building Inch H2O	M building Inch H2O	A building Inch H2O	B building Inch H2O	R building Inch H2O
High limit	0.9~1.3	1.0~1.8	1.0~1.8	1.0~1.8	1.5~1.8
Low limit	0.5	0.5~0.7	0.5~0.7	0.5	0.5

Note: The static pressure setpoint limits are determined based on the duct condition, box condition, damper condition, special resistance factors such as HEPA filter.

Prior to CC, the preheat setpoints were 2~5 degrees below the cold deck setpoints, which caused some simultaneous heating and cooling if the temperature sensors had some bias. The new preheat setpoints after CC are 40°F for all the AHUs.

Before commissioning, twelve AHUs in the C building had 2-hours of shut down at night and the control philosophy allowed the indoor temperature to swing from 65°F to 85°F. In order to reduce the swing for the indoor air condition, the AHUs are running 24 hours a day after the commissioning.

As one of the commissioning measures at unoccupied periods, in order to reduce the outside air intake after hours, the relief air dampers will be closed for all the units. To maintain the building pressure, some of the exhaust fans will be shut down also.

The optimized operation schedules were tested and implemented in all 54 VAV AHUs. The commissioning team also performed

Table 3: The Typical Setpoints for HD before Commissioning

Limit	HD Setpoint
High limit	110°F if Toa<30°F, 90°F if Toa>70°F
Low limit	90°F if Toa<30°F, 70°F if Toa>70°F

troubleshooting and fine-tuning on the AHUs and associated terminal boxes. The indoor conditions were improved and the fan power consumption, as well as thermal energy consumption, was reduced significantly.

Optimize the Operation of Dual Duct Constant Volume AHUs

There are total of 9 constant volume AHUs serving the diagnostic areas, pharmacy, offices, and classroom areas and health promotion center. Seven constant volume AHUs serve inpatient areas, which have special requirements such as indoor temperature for burn patients.

The cold deck temperature setpoint was operated with a constant setpoint, ranging from 55°F to 57°F, and was occasionally adjusted by the operator during occupied period. The hot deck (HD) temperature setpoints were modulated between the low limit and the high limit according to the terminal box requirements. The limits were almost the same for the AHUs and can be seen in Table 3.

The outside air intakes were constant day and night. All dampers stayed in the same position day and night. The relief and return air

dampers were 100% open for all units.

The post-commissioning control schedules are presented in Table 3-1, 3-2. ESL-HH-00-05-08

Table 3-1. Post-CC HD Temperature Reset Schedules for DDCV AHUs

Limit	HD Setpoint
High limit	94-98°F if Toa<30°F, 75°F if Toa>78°F
Low limit	74°F if Toa<30°F, 70°F if Toa>78°F

Table 3-2. Post-CC CD Temperature Reset Schedules for DDCV AHUs

Time	CD Setpoint
Occupied period	60°F if Toa<50°F, 56°F if Toa>80°F
Unoccupied period	Keep existing unoccupied schedule 80°F if Tret<55°F, 55°F if Tret>80°F

The new preheat setpoints after commissioning are 40°F for all the AHUs and the relief air dampers will be closed for all the units. To maintain the building pressure, some of the exhaust fans will be shut down also.

Due to the special inpatient requirements, there was no modification for seven AHUs. After the implementation, the hot calls were reduced and the thermal energy usage was reduced.

Optimize the Operation of VAV Multi-zone AHUs

There are two unique and large VAV multi-zone AHUs serving large storage areas and newly renovated office areas in the C building. The operation schedules before the commissioning can be seen in Table 4. The outside air and relief damper are always open. The preheat setpoint is 2 degrees lower than the CD temperature setpoints. There are no terminal boxes for the system, only duct supply.

Table 4: The detail schedules for HD, CD and Static Pressure before Commissioning

Item	HD Setpoint	CD Setpoint	Static Pressure Setpoint
Occupied	90°F to 100°F if Toa<30°F, 70°F if Toa>70°F	56 to 57°F	0.9"H2O
Unoccupied	90°F to 100°F if Toa<30°F, 70°F if Toa>70°F	80°F if Tret<55°F, 57°F if Tret>80°F	0.9"H2O

Through field measurements and analysis, the authors identified the following opportunities to improve the operation of the two VAV multi-zone AHUs.

- (1) Zone air balancing and obtain new static pressure setpoint for VFD
- (2) Optimize the cold deck temperature setpoints with reset schedules
- (3) Optimize the hot deck temperature reset schedules

- (4) Control of outside air intake, relief damper during unoccupied period
- (5) Optimized time schedule for fans to improve room condition
- (6) Improve the preheat temperature setpoint to avoid unnecessary preheating

Table 5-1. Post-CC HD Reset Schedules

Time	HD Setpoint	ESL-III-00-05-08
Occupied period(5:00 to 18:00)	76°F if Min(damper%z1;damper%z2)<10%, 70°F if Min(damper%z1;damper%z2)>50%	
Unoccupied period (18:00 to 5:00)	72°F if Min(damper%z1;damper%z2)<10%, 68°F if Min(damper%z1;damper%z2)>50%	

Note: damper%Z1: zone 1 damper control output. 0% means full open for the hot damper and full close for the cold damper; 100% means full open for cold damper and full close for hot damper.

Table 5-2. Post-CC CD Setpoints

Time	CD Setpoint
Occupied period (5:00 to 18:00)	57°F if Max(damper%z1;damper%z2)>90%, 60°F if Max(damper%z1;damper%z2)<50%
Unoccupied period (18:00 to 5:00)	Keep existing reset schedule 80°F if Tret<55°F, 55°F if Tret>80°F

Note: damper%Z1: zone 1 damper control output. 0% means full open for the hot damper and full close for the cold damper; 100% means full open for cold damper and full close for hot damper.

Table 5-3. Post-CC Static Pressure Setpoints

Time	LC11	LC12
Occupied period (5:00 to 18:00)	0.8	0.9
Unoccupied period (18:00 to 5:00)	0.5	0.5

The preheat setpoint changed to 40F for two units. The OA and relief dampers will be closed during unoccupied period.

2. TERMINAL BOX LEVEL

There are a total of 2700 terminal boxes supplying the conditioned air to the rooms in which 27% are DDVAV boxes and 71% are DDCV boxes and 2% SDVAV boxes.

Improve the DDVAV Box Control Logic

The original control logic of the DDVAV boxes were the same as constant volume terminal box operation except there were different CFM settings at minimum and maximum conditions. The minimum air flow CFM setting for the VAV boxes were the same both day and night and ranged from 30% to 90% with an average of 60% of maximum air flow for the box. It consumes excess heating and cooling air under normal room load condition. Also, the heating capacity was limited for some boxes due to the existing box design setting. In some case, the

boxes supplied a limited amount of hot air even in the full heating mode even though the hot duct of the boxes could allow more flow through. To meet the minimum air flow requirement, the boxes had to use more cold air than was necessary.

The authors developed a new control logic and made the box run as a VAV operation schedule. As a result, the simultaneous cooling and heating were reduced significantly during normal load conditions for the box. The hot air capacity was increased by 30% on average, under full heating mode. The minimum supply air flow was satisfied also.

Unoccupied Period Setback for VAV Boxes

The setback control is as follows:

1. The room temperature setpoints will be kept same as occupied period.
2. Reduce total flow minimum value to 0. The box can provide enough air when the load increased.

Unoccupied Period Setback for the CV Terminal Boxes

The setback control is as follows:

1. The room temperature setpoints will be kept the same as occupied period (based on existing setpoints).
2. Reduce total flow to a certain percentage of the design flow. The percentage is determined based on the building pressure analysis. Generally, the percentage is from 30% to 70% for different AHUs.

Troubleshooting

During the commissioning period, it was found that some terminal boxes could not provide the required air flow before and after the control program modification. The major reason is due to higher flow resistance from the flexible and kinked ducts to the terminal boxes. The authors performed detail checks for every box on the computer first, then conducted field measurements for all the trouble boxes. The specific problems were identified for about two hundred boxes. The operation & maintenance personnel fixed the problems following our recommendations.

Unoccupied Override Button

The purpose of an override is when the boxes go to setback mode, if an individual box needs normal AC, that individual box can get normal AC, but other boxes can still remain in the setback mode. The ESL team modified the control program for every box, which has setback mode. Now, every setback box has an override function. If someone needs normal air conditioning, they just push the button on the thermostat.

3. LOOP LEVEL

There are 14 chilled water risers equipped with 28 pumps providing the chilled water to the entire complex. The authors developed a new approach to quickly and simply balance the chilled water risers for pumps equipped with VFD [Zhu, et al., 2000].

After the balancing, the cold deck temperatures are maintained as required and the total pumps power consumption dropped by 40%.

4. CENTRAL PLANT LEVEL

Boiler Setpoint Pressure

The original steam pressure was set to 125 psi.
The new steam pressure was set to 110 psi

according to our recommendations. The boiler efficiency is increased after the implementation of new steam pressure setpoint. ESL-HH-00-05-08

Chilled Water Loop

Before the commissioning, the blending valve was 100% open to separate the primary and secondary loops at the plant. The primary and secondary pumps were both running. The manual valves were partially open for the secondary loop although the secondary loop pumps are equipped with VFDs. After the investigation, the commissioning team and Mr. Ron Bettinazzi, the plant supervisor implemented the following changes:

1. Open the manual valves for the secondary loop
2. Close the blending stations
3. Shut down two secondary loop pumps

As a result, the primary loop pumps can provide required chilled water flow and pressure to the building entrance, and most of building riser pump speeds are reduced. The cold air temperatures are maintained as required. Meanwhile the secondary pumps stay offline for most of the time. The operator drops the online chiller numbers according to the load conditions and the minimum chilled water flow can be maintained to the chillers. At the same time, the chiller efficiency is also increased.

RESULTS

The major commissioning activities were completed by April, 1999. The actual measured energy cost savings, based on the utility bills, for seven months during the commissioning period and four months following the major commissioning measures implementation, are over \$ 255,000. The utility bill savings are \$165,000 for the first four months after major commissioning completion.

CONCLUSION

Integrated commissioning for a large medical center improved the building comfort level and reduced the energy costs significantly. The estimated payback period is less than one year after the CC. This experience shows that a modern facility, operated with modern EMCS and a good operating staff, can still show significant energy savings through the continuous commissioning process.

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REFERENCES

- Y. Zhu, M. Liu, D. E. Claridge, D. Feary, T. Smith, 1997, *A Continuous Commissioning Case Study of A State-of-the-Art Building*, Proceedings of 5th National Conference on Building Commissioning, Huntington Beach, California, session 13.
- M. Liu, Y. Zhu, D. E. Claridge, 1997, *Use of EMCS Recorded Data to Identify Potential Savings Due to Improved HVAC Operation & Maintenance (O&M)*, ASHRAE Transaction-Research, Vol. 103, part 2, pp. 122-129.
- D. E. Claridge, M. Liu, Y. Zhu, et al., 1996, *Implementation of Continuous Commissioning in the Texas LoanSTAR Program: "Can You Achieve 150% of Estimated Retrofit Savings" Revisited*, Proceedings of ACEEE, Vol 4, pp 4.59 - 4.67.
- Y. Zhu, W. D. Turner, D. E. Claridge, 1999, *Report of Energy Efficiency Study and Metering/Utilities Profile for Electricity Deregulation at Texas A&M International University, Laredo, Texas, ESL-TR/99-12/03*.
- Y. Zhu, M. Liu, D. E. Claridge, W. D. Turner, et al., 1998, *A Novel Procedure to Determine Optimal Air Static Pressure Set-points and Reset Schedules in VAV Air Handling Units*, Proceedings of 10th Symposium on Improving Building Systems in Hot and Humid Climates, Fort Worth, pp. 294-301.
- T. Haas, D. Edmunds, 1997, *The Role of Existing Building Commissioning in the State of Tennessee's Energy Management Program*, Proceedings of 5th National Conference on Building Commissioning, Huntington Beach, California, session 13.
- C. Lawson, 1997, *Commissioning the Modern Hospital for Modern Technology*, Proceedings of 5th National Conference on Building Commissioning, Huntington Beach, California, session 4.
- Y. Zhu, M. Liu, T. Batten, J. Zhou, et al., 2000, *Continuous Commissioning Report for Brooke Army Medical Center, ESL report*.
- M. Liu, Y. Zhu, D. E. Claridge, et al., 1999, *Airflow Reduction to Improves Building Comfort and Reduce Building Energy Consumption-A Case Study*, ASHRAE Transaction-Research, Vol. 105, part 1.
- Y. Zhu, M. Liu, J. Zhou, T. Batten, et al., 2000, *Optimization Control Strategies for HVAC Terminal Boxes*, Proceedings of 12th Symposium on Improving Building Systems in Hot and Humid Climates, San Antonio, Texas.
- Y. Zhu, M. Liu, T. Batten, et al., 2000, *A Simple and Quick Chilled Water Loop Balancing for Variable Flow Systems*, Proceedings of 12th Symposium on Improving Building Systems in Hot and Humid Climates, San Antonio, Texas.