LESSONS LEARNED FROM THE CONTINUOUS COMMISSIONING OF A MULTI-FUNCTIONAL COMMERCIAL BUILDING

Chenggang Liu
Research Associate

Song Deng
Project Manager

David E. Claridge, Ph.D., P.E.
Professor & Associate Director

W. Dan Turner, Ph.D., P.E.
Professor & Director

Energy Systems Laboratory
Texas A&M University
College Station, TX

ABSTRACT

A multi-functional institutional building often has ventilation and comfort requirements that vary widely from zone to zone. When we commissioned the Reed McDonald building on the main campus of Texas A&M University (TAMU), efforts were made to control its environment according to the zone functions so that occupants can be satisfied with the comfort, and provided with a healthy and safe teaching and working environment. This paper presents a case study of the problems encountered and solutions implemented when commissioning a multi-functional institutional building.

INTRODUCTION

The Reed McDonald building is a 4-story building with a basement. The total floor area of the building is 77,130 ft^2. The basement has offices, computer lab, and classrooms in it. The 1st through 3rd floors are mainly offices. The 4th floor houses a chemistry lab.

Air Handling Units (AHUs) AHU-1, AHU-2, and AHU-3 are dual-duct variable air volume (DDVAV) systems with terminal boxes and direct digital control (DDC), serving the 1st floor through the 3rd floor respectively. AHU-4 serving the 4th floor is a single-duct system with reheat terminal boxes. AHU-5 serving the basement is a single-duct system without terminal box. Both of AHU-4 and AHU-5 are constant air volume systems with local pneumatic control. There is one chilled water pump with a variable frequency drive (VFD) and one constant speed hot water pump in the basement. There are 38 exhaust fans on the roof. Thirty-six there are used for exhaust of laboratories on the 4th floor, and two are for rest room exhaust. These AHUs and exhaust fans run 24 hours per day, 7 days a week.

Major Continuous Commissioning (CC) activities started on 6/20/1999 and ended on 10/25/1999. These activities included identifying and solving problems of the HVAC (Heating, Ventilating, and Air Conditioning) system, modifying the control program, performing an air balance, and analyzing savings. Several optimized operation schedules will be applied in the near future after some system retrofit and upgrade are implemented, and more savings will be achieved.

AHUs OPERATION AND ISSUES

When the building was built in 1967, the air-handling systems were installed with pneumatic control. In 1996, control systems for AHU-1, AHU-2, AHU-3 and chilled water system were retrofitted with DDC.

The problems and issues identified when we commissioned this building are listed in Table 1.

EXISTING SCHEME OF DDC AND ISSUES

The building is cooled with chilled water and heated with hot water distributed by the campus power plant. Chilled water and hot water pumps were installed in the basement of the building. The constant speed hot water pump is turned on/off manually. The chilled water pump was always on. The speed of VFD chilled water pump was varied to maintain building differential pressure (DP) at its setpoint. The setpoint was set according to chilled water flow, indicated in Table 2. There is one control valve on the building chilled water return side and one control valve on the building chilled water bypass. The bypass control valve was modulated to maintain a minimum flow of 200 GPM of the building. That is if the flow rate is lower than 200 GPM, the bypass control valve will be open to maintain the chilled water flow rate at 200 GPM.

Chilled water valves of AHU-1, 2, and 3 were modulated to maintain cold duct temperature at their setpoint. The setpoint was set according to cold duct static pressure, indicated in Table 3.

Hot water valves of AHU-1, 2, and 3 were modulated to maintain hot duct temperature at their setpoint. The setpoint was set according to hot duct static pressure, indicated in Table 4.

Fan speeds of AHU-1, 2, and 3 were varied to maintain cold duct and hot duct static pressure at their setpoint of 3.0 in WG.

AHU-1 — First Floor — DDVAV	
1	The outside air damper linkage was broken. The outside air couldn't be balanced.
2	Diffusers in room 106 were blocked and two dampers were installed incorrectly.
3	Most diffusers and filters were dirty. It blocked the air.
AHU-2 — Second Floor — DDVAV	
4	Some rooms needed an air balance, such as rooms 221A, 221B, 228A, and 228B.
5	Most diffusers and filters were dirty. It blocked the air.
6	The hot water control valve was allowing water to flow even when the valve was shut. It wasted energy, because the hot duct temperature was higher than its setpoint with the leakage valve.
AHU-3 — Third Floor — DDVAV	
7	Air ducts in room 316 were blocked.
8	Room 319 needed an air balance.
9	The hot water control valve was allowing water to flow even when the valve was shut. It wasted energy too.
AHU-4 — Fourth Floor — SD w/Reheat	
10	The cooling coil is restricting flow (18 psi DP on the coils, even after being back-flushed several times). This caused the high chilled water building DP setpoint.
11	There was no supply air to room 403A, because the reheat coil was entirely blocked by insulation.
12	Several bad reheat coil thermostats were identified.
13	The static pressure of lab 401, 417, 429 and 430 was positive, instead of negative.
14	The reheat coil control valves for room 401, 402, 405, 415, 423, and 425 were bad. These valves are normally open. When the air pressure was changed from 20 psi to 0 psi, the valves didn't move or moved very little.
15	Many of the hot water balance valves of the terminal boxes were leaking when adjusted.
AHU-5 — Basement — Single Duct	
16	The airflow rate is 10,300 CFM, about 64% of the design flow. The design supply airflow is 16,200 CFM.
17	The hot water control valve was allowing water to flow even when the valve was shut. It wasted energy too.
18	It's not necessary that the AHU-5 had its own chilled water pump. 12 psi pressure dropped through the pump when it was free rolling.
19	There is no fresh air duct for this unit. According to the design, the fresh airflow rate should be 10% of the supply airflow.
20	The cooling capacity isn't high enough. Although the coils have already been back-flushed and cleaned on the airside, we only measured a discharge air temperature of 55.8 °F with the 64% design supply airflow. Room temperature was still too high.
Exhaust	
21	There was no exhaust fan for hood B in room 403A.
22	The make-up air fan for hood A in room 403A is rusted, and has holes in it. Its connection with the duct is damaged.
23	There is no exhaust fan for hood B in room 417. It made the room static pressure positive.
24	There is no drain on the exhaust fan for hood B in room 418, and a significant amount of rust could be seen.
25	There is some rust on the exhaust fan for hood C in room 418.
26	The connection is damaged between the exhaust fan for hood C in room 419 and its duct.
27	The connection is damaged between the exhaust fan for the new hood in room 423 and its duct.
28	The make-up air fan for hood B in room 426 needed a fan belt.
29	The case of the exhaust fan for hood C in room 426 is rusted with holes on it.

Table 1. The problems and issues identified.

GPM	0	125	250	375	500	625
DP (psi)	15.0	15.6	17.5	20.7	25.2	31.0

Table 2. Chilled water building DP set schedule.

CD Static pressure (in WG)	1.0	3.0
CD setpoint (°F)	52.0	58.0

Table 3. The cold duct temperature set schedule.

HD Static pressure (in WG)	2.0	3.0
HD setpoint (°F)	110.0	75.0

Table 4. The hot duct temperature set schedule.

The problems and issues of the existing control scheme are listed in Table 5.

1	The chilled water pump was always turned on. We recommended that the pump be on, when the chilled water lop DP is lower than the building DP setpoint.
2	The building DP setpoint was too high. For example, in the winter, the chilled water pump was still turned on and run at high speed to keep building DP setpoint. But the AHUs didn't need so much chilled water during that time, so that their control valves were shut to kill the pressure.
3	Bypass valve was opened in order to maintain the minimum flow. We recommended that it be not necessary to keep the minimum flow, so that the bypass valve can be shut.
4	The fan speed is varied to maintain static pressure at its setpoint and the setpoint is a constant value of 3.0 in WG. The cold duct temperature setpoint is always around 58 °F, because it's set according to static pressure. A setpoint of 55.0 °F was manually set in summer and 58 °F in winter. We commended that the cold duct temperature setpoint be varied based on the cooling load.
5	Similarly with cold duct temperature setpoint, the hot duct temperature setpoint was always about 75 °F. We commended that the hot duct temperature setpoint be also varied based on the cooling load.
6	The static pressure setpoint of 3.0 in WG is too higher than what is needed. We commended that the static pressure setpoint be also varied based on the cooling load.

Table 5. The issues of existing control scheme.

NEW CONTROL SCHEME RECOMMENDED FOR DDC CONTROL

To begin with, we recommended that the chilled water pump speed very to maintain the building DP at its setpoint. Thus, the building DP setpoint is reset according to the flowing equation

$$DP=(69.4) \times (Q^2)+7$$

In this equation the DP is building differential pressure (psi) and Q is the chilled water flow rate (kGPM). Table 6 shows samples of chilled water building DP setpoints.

GPM	100	200	300	400	500
DP s.p. (psi)	7.7	9.8	13.2	18.1	24.4

Table 6. The chilled water building DP setpoints.

When the chilled water loop DP is higher than the building DP setpoint, the return control valve should be controlled to maintain the building DP at its setpoint. When the chilled water loop DP is lower than the building DP setpoint, the return control valve should be always fully open before the VFD chilled water pump on. In order to protect the VFD chilled water pump, the pump is turned on with minimum speed of 25% after control valve is fully open. The chilled water bypass valve is always shut.

The chilled water valves of AHU-1, 2, and 3 should be modulated to maintain cold duct temperature at their setpoint. The cold duct temperature setpoint is reset according to outside air temperature, instead of static pressure. The setpoint is shown in Table 7.

OA Temp (°F)	55.0	60.0	70.0	85.0
Cold duct s.p. (°F)	60.0	58.0	58.0	55.0

Table 7. Reset schedule of cold duct temperature setpoint.

The hot water valves of AHU-1, 2, and 3 should be modulated to maintain hot duct temperature at their setpoint. The hot duct temperature setpoint is reset according to outside air temperature, instead of static pressure. The setpoint is shown in Table 8.

OA Temp (°F)	30.0	50.0	70.0
Hot duct s.p. (°F)	95.0	85.0	70.0

Table 8. Reset schedule of hot duct temperature setpoint.

The duct static pressure setpoints are reset from 1.5 in WG to 2.5 in WG according to outside air temperature, instead of 3.0 in WG constant value. The setpoints are shown in Table 9.

OA Temp (°F)	40.0	60.0	75.0	90.0
Duct static pressure s.p. (in WG)	1.5	2.0	2.0	2.5

Table 9. Reset schedule of duct static pressure setpoint.

COMMISSIONING ACTIVITIES

The control program was modified. AHU-1, 2, and 3 are dual duct VAV air-handling units with terminal boxes and direct digital control (DDC), serving the 1st through 3rd floor respectively. According to the existing control scheme, the fan speeds of AHU-1, 2, and 3 were varied to maintain the duct static pressure at their setpoints and the setpoints were a constant value of 3.0 in WG. The cold duct temperature setpoint was always around 58 °F, because it was set according to static pressure. That was why the cold duct temperature setpoint of 55.0 °F was manually set in the summer and the hot duct temperature setpoint of 110.0 °F in winter.

In the new control scheme, the cold duct and hot duct temperature setpoints are reset according to outside air temperature. The fan speeds are varied to maintain the duct static pressure at their setpoints and the setpoints are also reset according to outside air temperature. Lower static pressure reduces air leakage in the terminal boxes. Lower chilled water building DP setpoint and shutting down bypass valve reduces energy consumption. Other commissioning activities for AHU-1, 2, and 3 are diffuser cleaning and air balancing. Since commissioning, the occupants on the 1st through 3rd floors have received improved comfort.

The 4th floor houses the Texas State Chemist's Laboratory served by AHU-4 and 36 exhaust fans. A negative pressure differential between indoor and outdoor air is required for the chemistry labs. The recommended value is from -0.01in WG to -0.10 in WG, but typically is -0.05 in WG. The major problem on the 4th floor was that room negative pressure was out of control, e.g. some rooms were too negative and some rooms were positive.

There are three common room pressure control schemes in use today: 1) direct pressure, 2) flow tracking, and 3) cascaded control. The supply airflow rate is used in all three schemes. In the direct pressure method, the aim is to maintain a desired negative room pressure. In flow tracking, a differential between the exhaust and supply airflow rates is maintained, and the differential flow is related to the negative room pressure. The cascaded loop method is used in a VAV system, measuring differential pressure to reset the differential flow setpoint and control the flow-tracking loop. The AHU-4 on 4th floor is a constant air volume system with pneumatic control. Therefore the direct pressure method was recommended to balance the airflow.

Before balancing, there was the positive pressure in rooms 404, 417, 420, 421and 422, because the supply airflow was larger than the exhaust. The pressure in rooms 402, 423 and 427 was too negative. Table 10 shows the room pressure data, before and after the air balance. A negative pressure of 0.03 in WG between the 4th floor and 3rd floor hallway was also recommended.

Room No.	402	404	417	420	421	422	423	427
Pre (in WG)	-0.11	0.0	0.02	0.01	0.03	0.01	-0.10	-0.11
Post (inWG)	-0.04	-0.05	-0.07	-0.06	-0.07	-0.07	-0.05	-0.05

Table 10. 4th floor lab pressure data.

Other commissioning activities for AHU-4 and exhaust fans are: 1) replacing all of 24 reheat coil thermostats, 2) closing manual valves on the reheat coil bypasses and 3) fixing three exhaust fans.

AHU-5, serving the basement, is a single duct, constant volume air-handling unit, without reheat. The major problems for AHU-5 were inelegant cooling capacity, no fresh air and inelegant airflow. The temperature of some computer labs was also still too high. It was recommended that a fresh air duct for AHU-5 be installed and that the number of rows of cooling coils be increased. The fan speed was then increased to suit the design flow rate. Other commissioning activities for AHU-5 are diffuser cleaning, replacing hot water control valves and taking out its chilled water pump.

SAVINGS ANALYSIS

Major Continuous Commissioning activities started on 6/20/1999 and ended on 10/25/1999. Daily whole-building chilled water and hot water consumption data were retrieved from the LoanSTAR database. All the data comparisons are between pre—CC, from 1/1/1999 to 5/31/1999, and post—CC, from 3/1/2000 to 3/27/2000. The data for chilled water and hot water consumption are shown separately in Figures 1 and 2. They show that the chilled water consumption reduced by an average of about 8 MMBtu/Dy and the hot water consumption reduced by an average of about 5 MMBtu/Dy. According these data, the chilled water consumption will reduce annually by 2,920 MMBtu and the hot water consumption by 1,825 MMBtu. Annual saving will be about $22,305.

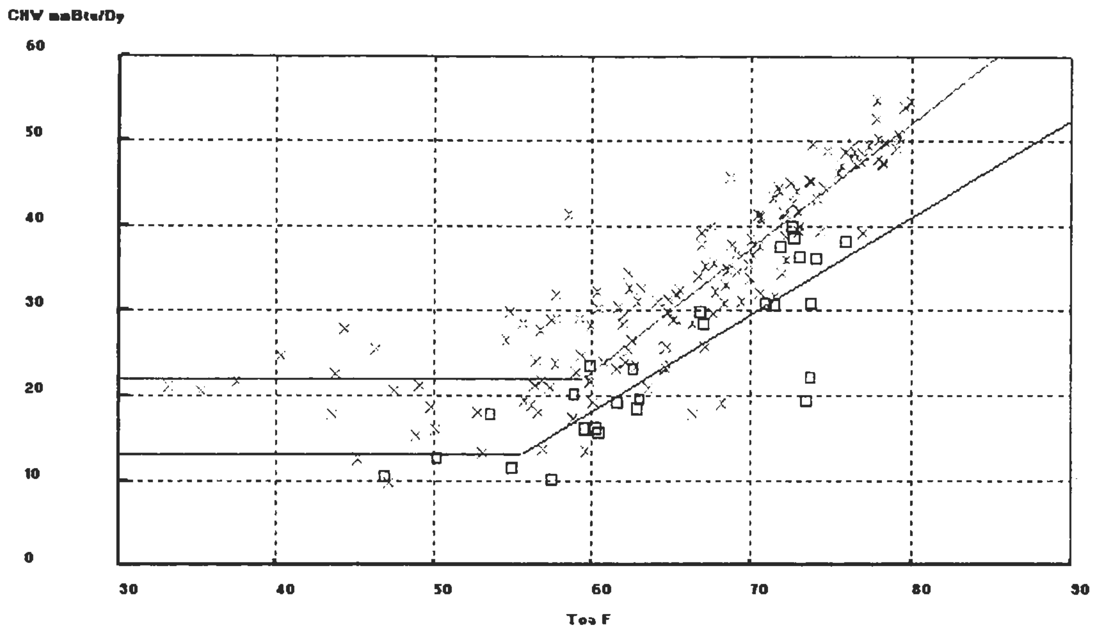

Figure 1. Chilled water consumption (x-- pre CC, □--post CC,).

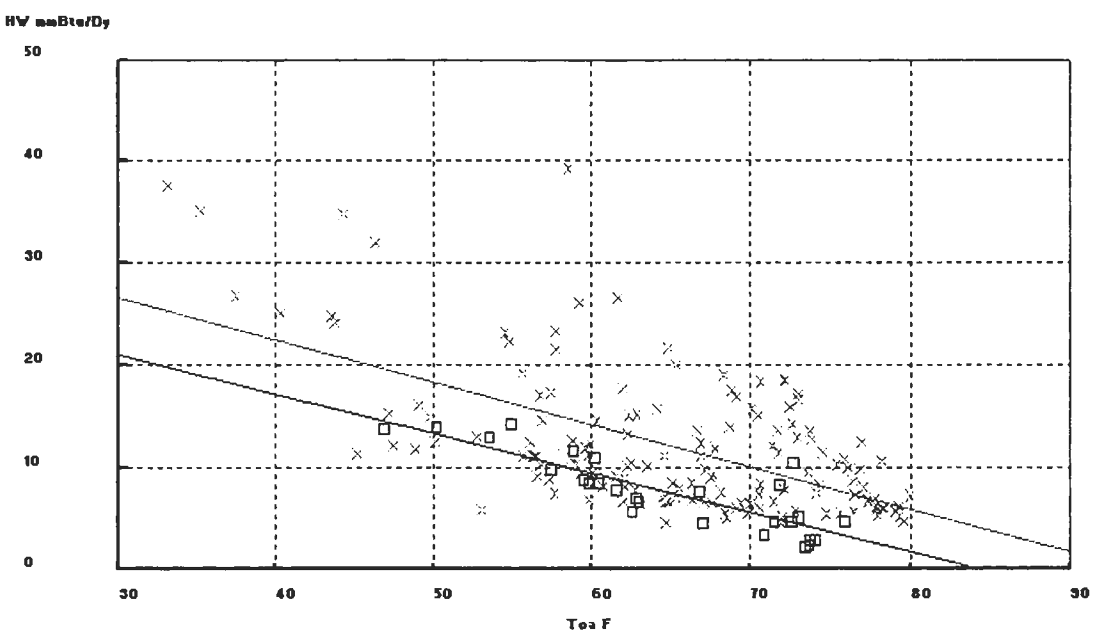

Figure 2. Hot water consumption (x-- pre CC, □--post CC,).

These savings are the direct result of the CC activities such as a new control scheme, air balancing, fixing leaking valves, replacing bad thermostats and shutting bypass valves. Several optimized operation schedules will be applied in the near future after some system retrofit and upgrade are implemented, and more savings will be achieved.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Mingsheng Liu, P. E., Associate Professor at University of Nebraska for his kindly help in HVAC system balance and controls. We would like to thank Mr. Carlos Juan and Mr. Jim Sweeney for their help in the saving analysis and data process. And we also would like to thank Mr. Homer L. Bruner Jr., CEM and Mechanical System Specialist of Texas A&M university for his cooperator and support in commissioning activities.

REFERENCES

1. Shan K. Wang. 1994. "Handbook of Air Conditioning and Refrigeration", Chapter 19, p.23.

2. O. Ahmed, J.W. Mitchell and S.A. Klein. 1993. "Dynamics of Laboratory Pressurization", ASHRAE Transactions 94(2), p.223—229.

3. C.W. Marsh. 1988. "DDC Systems for Pressurization, Fume Hood Face Velocity and Temperature Control in Variable Air Volume Laboratories", ASHRAE Transactions 94(2), p1947—1968.

4. McDiarmid, M.D. 1990. "Variable-volume fume hoods: User Experience in a Chemistry Research Lab", ASHRAE Transactions 96(2).

5. Y. Zhu, M. Liu, D. E. Claridge, W. D. Turner, T. Powell. 1998. "A Novel Procedure to Determine Optimal Air Static Pressure Set-points and Reset Schedules in VAV Air Handling Units", the 11th Symposium on Improving Building Systems in Hot and Humid Climates Proceedings. P294—301.

6. Mingsheng Liu, David E. Claridge. 1998. "Impacts of Optimized Cold & Hot Deck Reset Schedules On Dual Duct VAV Systems-Theory and Model Simulation", the 11th Symposium on Improving Building Systems in Hot and Humid Climates Proceedings. P146—152.