Continuous Commissioning of A Central Chilled Water & Hot Water System

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ABSTRACT

A central chilled water / hot water system provides cooling / heating energy from central utility plants to multiple customers (buildings) through campus distribution loops. To effectively transport

used, including air handling unit coil bypass, pump bypass, building loop bypass, distribution loop bypass, and central utility plant decoupling. Most of the bypass schemes are designed to provide comfort to each building without regard for the loop pumping requirements. Continuous Commissioning of the building and campus loops is necessary to ensure adequate water flow to each building and reduce the overall pumping energy required for both the campus loops and the building loops. Some optimization of the plant chiller / boiler operation is also necessary and beneficial. In general, through Continuous Commissioning, chilled water and hot water loop temperature differences will be improved, leading to reduced chilled water and hot water flow rates. This will save pumping energy and improve chiller/boiler efficiency.

I. INTRODUCTION

Continuous Commissioning (CC) began as part of the Texas LoanSTAR program at the Energy Systems Laboratory (ESL) at Texas A&M University (Claridge, 1994; Liu, 1994). Continuous Commissioning (CC) emerged from a program of implementing operation and maintenance improvements following retrofits in buildings. This

used rather than implementing design intent.

Bypasses or decouplers are often used on building chilled water or hot water systems, central plant chilled water or hot water production systems, and campus distribution loops, to maintain constant water flow rate or achieve system supply temperature or differential pressure control. On the other hand, small chilled water or hot water building or campus loop temperature differences are common problems and present a challenge for most facility O&M (operation and maintenance) teams, facility managers and engineers.

There are various ways to improve the loop temperature differences and even achieve high differential temperatures (DT's) (Hattemer, 1996; Fiorino, 1999). Most of the time, bypasses and decouplers are key components to be studied and recommissioned in this process. For example, two-way control valves are highly recommended as a replacement for three-way bypass control valves in building AHU (Air Handling Unit) systems (Fiorino, 1999). In addition, variable-speed pumping is highly recommended and widely applied in new system construction designs (Fair, 1996) and existing system renovations (Karalus, 1997). Primary-secondary pumping configurations are also extensively adopted. All of the above provide further opportunities to convert bypassing-type control into a more energy-efficient control. System operation savings will be achieved along with improved pumping management and improved loop DT's (Hattemer, 1996).

This paper presents our efforts to improve the chilled water system and hot water system operation on the West campus of Texas A&M University, emphasizing our bypass recommissioning study and practices. With other loop operation optimizing measures, pumping power savings of over 50% are achieved (Deng, 1998). In addition we have reduced hot water consumption, improved chiller performance, and reduced the peak chilling capacity for the West campus buildings and central thermal loops.

II. FACILITY INFORMATION

The Texas A&M University (TAMU) West Campus has a total of 28 buildings on the central chilled water and hot water loops with a total of more than 3,500,000 ft^2 of conditioned floor area. All these buildings receive chilled water from two central plants: the West I Plant and the West II Plant, which together have a total installed cooling capacity of 14,000 tons. West Campus IV provides hot water only through heat exchangers, and West Campus I has a boiler that was also used for producing hot water.

With an installed capacity of 10,000 tons, The West I Plant sends out chilled water through two loops: the East loop and the South loop. Both loops are interconnected through common supply and return headers in the Plant and pipe connections over the west campus. The West II Plant has a capacity of 4,000 tons and is interconnected with the two campus loops. Except for the three steam-driven centrifugal chiller/single-effect absorption chiller tandem sets (with installed capacity of 2,000-ton each)at West I Plant, all the other chillers at West I & II Plants are electrical centrifugal chillers.

III. SCOPE OF WORK

To improve the performance of the West Campus chilled water and hot water loops, to determine the West Campus buildings' real cooling load, and to determine the available capacity of the West I & II plants, we balanced the West Campus chilled water and hot water loops in 1998. After determining that sufficient pumping power was available from the main distribution loops, we were able to turn off many of the individual building pumps. About 90 % of the West Campus building-side hot water pumps were turned off, and about 80 % of the building-side chilled water pumps were turned off. By turning off unnecessary pumps during our balancing work, 270 hp (200 kW) of electrical power was removed from the campus grid.

We then worked with plant operations staff and gradually increased each (West I & West II) chiller's chilled water supply temperature setpoint from 42°F to 45°F. By doing this: 1) a high loop differential pressure problem was solved for nighttime low-load operation, and 2) steam and electricity are saved with the chiller operations.

Meanwhile, we recommended, all gas boilers and the loop hot water pumps be turned off at West I. Plant hot water supply and return lines were also isolated. The West Campus hot water is now supplied by the West IV plant only, with a reduced supply temperature of 140°F. Later, we worked with plant operations staff and tested operation using one pump and one heat exchanger to serve the West Campus instead of two heat exchangers, each with dedicated hot water pumps. The test results were successful in that the hot water needs could be met with one exchanger and its dedicated pump. This allowed TAMU to operate only one heat exchanger and one pump from West Campus IV to provide hot water to the campus.

IV. CONTINUOUS COMMISSIOING PROCEDURES

1. *ORIGINAL CONTROL SCHEMES*

Chilled Water Systems

The TAMU Physical Plant personnel were concerned that peak loads on the West Campus would exceed available capacity, and rental chillers were ordered for the summer of 1998. The normal operation was to run two tandem sets (1,800-ton each), Ch-23 (1,600-ton), Ch-21 & 22 (1,000-ton each) at West I, and one or two of Ch-31, 32 & 33 (electrical chillers, 1,200-ton each) at West II. Portable chillers with a total capacity of 1,600 tons were rented and connected. The chilled water supply temperature setpoints of all chillers were 42°F.

Heating Water Systems

The West Campus hot water was supplied by West I & IV. Gas boiler(s) and hot water pump(s) were run at West I and heat exchanger(s) and their hot water pump(s) at West IV. The supply temperature setpoint of the heat exchangers was originally 180°F.

2. OPTIMIZED CONTROL SCHEMES

We recommended the following control sequences at the West I, II & IV Plants to insure optimized operation:

Chilled Water Systems

During Summer Peak Load Periods (Ambient T_o > 85°F)

For nighttime and early morning operation, operate two (2) tandem sets (1,800-ton each) and Ch-23 (1,600-ton) at West I, and one (1) chiller (1,200-ton) at West II. For hot days use the loop return temperature to turn on additional chillers if more cooling production is needed. The recommended control strategy is:

1) When the chilled water return temperature is greater than 59°F, or when the chilled water supply temperature equals to 46.5°F, turn on another chiller.
3) Try to maintain the loop differential pressure (DP) around 15 psi at West I and around 10 psi at West II. Turn on one chiller when the loop ΔP is 4 psi lower than the desired value, and turn off one chiller when the loop ΔP is 5 psi higher than the desired value.
4) Keep all chillers' chilled water supply temperature setpoints at 45°F.

During Fall & Spring Transition Periods (Ambient 85°F > T_o > 65°F)

We recommend operating two (2) tandem sets (1,800-ton each) at West I, and one (1) chiller (1,200-ton) at West II as the initial operation, and adjust operation based on the loop return temperature:

1) Turn on another chiller at West II if the chilled water return temperature at West I exceeds 59°F.
2) Turn off a chiller in West I if the chilled water return temperature drops below 56°F.
3) Keep all chillers' chilled water supply temperature setpoints at 46°F.

During Winter Low Load Periods (Ambient T_o < 65°F)

We recommend operating one (1) tandem set (1,800-ton) at West I, and one (1) chiller (1,200-ton) at West II as the initial operation, and adjust operation based on the loop return temperature:

1) When West I return temperature exceeds 59°F, another electrical chiller needs to be turned on.
2) When West I return temperature is less than 56°F, turn off one electrical chiller.
3) Keep all chillers' chilled water supply temperature setpoints at 47°F.

Heating Water Systems

Keep gas boilers and hot water pumps off at West I, and isolate the plant hot water supply and return lines. Use the West IV plant only to serve the West Campus with hot water.

During Winter High Load Periods

Run two of the three heat exchangers at West IV along with their dedicated pumps. Maintain the supply water temperature setpoint at 150°F.

During Other Periods

Run one of the three heat exchangers with its dedicated pump, and maintain the supply water temperature setpoint at 140°F.

3. LOOP PROBLEMS ENCOUNTERED AND CONTINUOUS COMMISSIONING MEASURES PERFORMED

Chilled Water Systems

Campus Chilled Water Loops

We followed the West Campus chilled water loop map and checked every manhole on the loop to investigate the pipe conditions and valve positions. We found:

1) A valve leading to one of the building complexes was 70% closed. This caused a huge pressure drop in this line and reduced the chilled water flow. We opened this valve.

2) Chilled water pipes going to another complex were not connected to the pipe coming from the West II Plant as the map showed. Also, in the manhole beside the complex, the chilled water supply line was connected to the return line with a ΔP control valve, which needed to be checked for leakage or removed from the system.

3) Eight manholes were found to be filled with hot water, which significantly increased the heat loss of the chilled water lines and hot water lines. It was reported to the Utilities shop. Some hot water leaks were found and repaired, and water was pumped from the manholes. A sump pump is needed in each manhole in order to keep the manholes and pipes dry.

Building Chilled Water Loops

We worked through each West Campus building connected to the chilled and hot water loops and balanced their building loops over a four-week period. Work performed during the field visits is listed below:

1) Bypasses of the building chilled water and hot water systems were checked and shut.

2) Wrong pipe connections, malfunctioned valves and sensors, water leakage, VFD (Variable Frequency Drive) problems and controls problems were identified and documented for repair.

3) For buildings where the building chilled water differential pressure provided by the central plants was higher than 20 psi, chilled water pumps were shut off. For those buildings where pumps cannot be turned off, the building loops were balanced. Building hot water loops were also balanced at the same time. About 90 % of the West Campus building hot water pumps were turned off, and about 80 % of the building chilled water pumps were turned off. By turning off these unnecessary pumps during our balancing work, 270 hp (200 kW) electrical power was removed from the campus grid.

Improved Chiller Operation Schedule at West I & II Plants

Loop differential pressure increased significantly under the old operation schedules, but the new operation scenario (presented in "O&M Procedures" section under "During Summer Peak Load Period") has been implemented instead. As shown in Table 1, only 60 % of the current West I&II plants' capacity is required to carry the West Campus through the daily peak load when the outside air temperature is 100^{+} °F. Another 3,000 tons electrical chillers would be ready to be put on line at any time.

At the West I plant, 58°F has been taken as the new critical chilled water return temperature to turn on another chiller instead of 56°F, because field investigation found that buildings around the West I plant are relatively new and have better HVAC (Heating, Ventilating, and Air Conditioning) systems and control. The chilled water return temperature from these buildings can be 58°F or even higher while still maintaining satisfactory discharge air temperatures from the air handling units.

At the West II plant, the maximum chilled water return temperature has increased from 51°F to 56°F. The available plant capacity has increased from 1,200 tons to 3,000 tons, because of the large loop ΔT. More capacity can now be contributed by the West II plant.

To verify that the new chiller operation schedule at West I & II plants was adequate, we responded to hot calls from the West Campus buildings. HVAC problems were solved locally in the problem buildings, and extra chillers have not been turned on at the plants to meet the summer loads.

Chiller Chilled Water Supply Temperature Adjustment

We gradually increased West I & II chilled water supply temperature setpoints from 42°F to 45°F. By doing this, 1) a high loop differential pressure problem was solved for the nighttime low-load operation, and 2) steam and electricity were saved with the chiller operations. The savings are presented in Table 2.

Table 1. West Campus Chilled Water System Performance after Loop Balancing

Date & Time	Plant	Ps (psi)	Pr (psi)	Ts (°F)	Tr (°F)	Tonnage	Chillers on line
11:35 am 07/17/98	West I	92	41	43.3	55.3	6,300	A, B sets, Ch-23, Ch-22
	West II	85	39	43.2	51.3	700	Ch-31
11:50 am 07/17/98	West I	74	41	44.0	55.7	5,300	A, B sets, Ch-23
	West II	67	39	44.0	51.9	760	Ch-31
15:33 p.m. 07/17/98	West I	62	42	45.7	57.8	5,250	A, B sets, Ch-23
	West II	56	39	44.3	53.7	1,080	Ch-31
15:00 PM 07/22/98	West I	76	41	44.9	57.0	5,200	A, B sets, Ch-23
	West II	70	38	43.2	53.6	2,000	Ch-31, Ch-33

Note:
1. Westinghouse control system data.
2. All rental chillers were off, and West I data was from West I east section.
3. Outside air temperatures were 100^{+} °F.

Table 2. Chiller Operation Savings by Increasing Chilled Water Supply Temperature Setpoint from 42°F to 45°F at West I & West II Plants

Plant	Chiller	Capacity (tons)	Operation (tons)	Pre- Elec or 600-psi Steam Consumption (kW/ton or lbs/h.ton)	Post- Elec or 600-psi Steam Consumption (kW/ton or lbs/h.ton)	Savings (kW/1,000ton or lbs/h.1,000ton)
West I	Set A	1,800	1,000-1,200*	12	12	0
	Set B	1,800	1,000-1,200	11	11	0
	Set C	1,800	1,000-1,200	13	13	0
	Ch-21	1,000				
	Ch-22	1,000				
	Ch-23	1,600	1,500-1,700	0.77	0.77	0
West II	Ch-31	1,200	800-1,000	0.70	0.64	60
	Ch-32	1,200	800-1,000	N / A	0.64	N / A
	Ch-33	1,200	800-1,000	0.71	0.65	60
Total		12,600				60-120**

* Steam-driven centrifugal chillers only. Data for absorption chillers are not available.
** Depends on how many (one or two) chillers are on at the West II Plant.

Based on the operation logs, the steam consumption has not changed significantly for the West I steam-driven centrifugal chillers, tandem Sets A, B, and C, since their chilled water supply temperature setpoints were adjusted from 42°F to 45°F. No change in performance was noted for the Ch-23 (1,600-ton) chiller. A possible reason is that the data records used are not accurate enough to show the effects. This comparison can be made for Ch-21 & 22(1,000-ton each) because they have rarely been turned on. But for West II Ch-31 & 33 (1,200-ton each), the electricity consumption decreases are obvious, about 0.06 kW/Ton reduction for each chiller. Total savings are from 60 kW to 120 kW, depending on how many chillers are on line at the West II Plant.

Hot Water Systems

West Campus hot water was supplied by the West I and West IV plants. At West IV, the hot water supply temperature was 180°F, which was unnecessarily high for building heating and caused some problems for building hot water pump maintenance. At West I, one gas boiler was kept on line during the summer mainly to supplement hot water to heat exchangers in two buildings.

The first stage of the CC process was to balance the hot water loops in each building. This was done during the balancing of the chilled water loops. Then we turned our attention to the plant optimization.

First, after a discussion with the Power Plant operations staff, all gas boilers were turned off at West I. The hot water pump was also turned off, and the plant hot water supply and return lines were also isolated. Since that time, the West Campus hot water has been supplied by the West IV plant only, with a reduced supply temperature of 150°F. The buildings farthest from the West IV Plant are receiving adequate amounts of hot water at this temperature. Two heat exchangers with dedicated hot water pumps were initially in operation at the West IV Plant.

We then worked with plant operation staff to reduce the hot water production. We were able to reduce to one hot water pump and one heat exchanger. This improved operation has been maintained at the West IV plant. After operation without problems with a supply temperature of 150°F, the hot water supply temperature from the West IV plant was further decreased to 140°F to save energy. The lower temperature operation has been used without complaints since 1998.

V. RESULTS AND CONCLUSIONS

After the chilled water and hot water loop balancing and plant chiller and heat converter operation optimization, the West Campus Plants (West I & II) have enough cooling capacity to serve the west campus through its peak loads (with an extra 3,000 tons of electrical chillers ready to be put on line at any time). All of the 1,600 ton rental chillers were returned in 1998. More chilled water production has been provided by the West II plant than before because of improved loop and building conditions. Buildings at different points of the loops have been balanced and are supplied with the necessary chilled water and hot water supplies, and significant pumping power has been saved.

All of the gas boilers have been kept off at the West I plant. At the West IV plant, only one of the three heat converters is being operated, at a decreased hot water supply temperature of 140°F.

The West Campus chilled water hourly consumption data measured by the ESL meters during the summer peak loads are presented in Figure 1. The first day we changed the chiller operation schedule at the West I & II Plants was July 17, 1998, and the chilled water consumption data are presented as pre-CC and post-CC data, based on this date. However, the building chilled water and hot water loop balancing work had been started on 06/22/98, and finished around the middle of July; the gas boiler was turned off at the West I Plant and the hot water temperature supply temperature was reduced from 180°F to 150°F near the West IV Plant at the end of June; so some of the energy conservation efforts had been achieved before our pre-CC and post-CC separation date of 07/17/98.

Comparing the West Campus chilled water consumption data before and after July 17 in Figure 1, we can see the peak load dropped about 800 tons (from pre-CC's 7,700 tons to post-CC's 6,900 tons), and the average load during the summer also decreased about 800 tons (from pre-CC's 6,500 tons to post-CC's 5,700 tons).

Before the West Campus chilled water loop balancing work, the available cooling capacity at the West II Plant was about 1,200 tons, no matter how many chillers were turned on because of the low return water temperature, and the cooling capacity at the West I Plant was about 7,200 tons (5,600 tons firm capacity considering Ch-23's 1,600 tons); therefore the combined available capacity was about 8,400 tons (6,800 tons firm capacity).

After the West Campus chilled water loop balancing work, the available cooling capacity at the West II Plant improved to 3,000 tons, and the combined available cooling capacity of the West I & II Plants is 10,200 tons (8,600 tons firm capacity). Meanwhile, the measured peak load dropped to 6,900 tons, which is 68 % of the combined available capacity (80 % compared with the firm capacity). It shows the plants have more than enough cooling capacity to serve the West Campus.

This paper clearly demonstrates the importance of considering the buildings and thermal loops as a "system", instead of looking at each individual building and serving that building's needs regardless of the loop conditions. Pumping power has been reduced, chiller capacity has been increased, hot water temperature has been reduced, and energy requirements (electrical and thermal) have been reduced on the West Campus with no sacrifice in comfort.

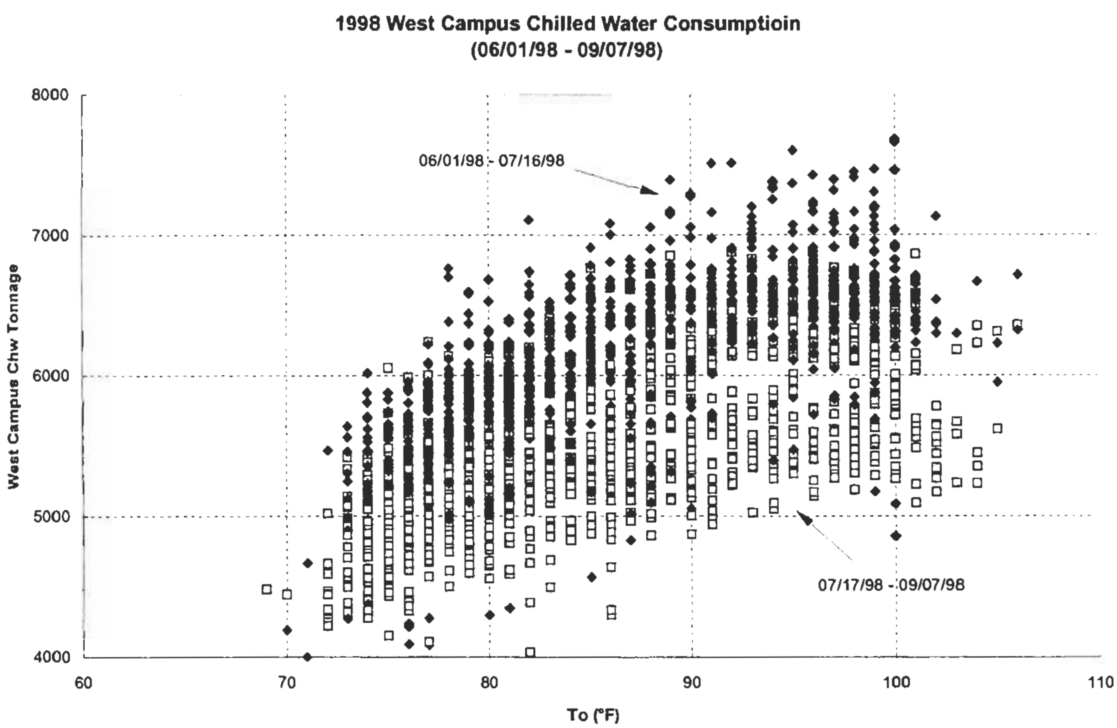

Figure 1. Scatter Plot of 1998 Summer West Campus Chilled Water Consumption

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