# Lessons and Measures Learned from Continuous Commissioning[SM] of Central Chilled/Hot Water Systems

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## ABSTRACT

As it has been proved repeatedly that commissioning is very necessary for new construction and renovation/retrofit projects, we found continuous commissioning[SM] (CC) is an effective and efficient way to manage and optimize existing central chilled water and hot water system operation. It can be performed before, during, or after building side continuous commissioning. Successful central chilled/hot water system CC not only results in improved production and distribution, but also achieves significant thermal and pump power savings. It quickly evaluates building HVAC (Heating, Ventilating, and Air-Conditioning) system performance for savings opportunities when carried out before building CC, or serves as a necessary and productive follow-up when performed after. Meanwhile, continuity is the key factor to achieve the persistence of savings and optimized performance.

## I. INTRODUCTION

Continuous Commissioning[SM] (CC) began as part of the Texas LoanSTAR (Loans to Save Taxes And Resources) program at the Energy Systems Laboratory (ESL) of Texas A&M University (Claridge, 1994). It emerged from a program of implementing operation and maintenance improvements following retrofits in buildings (Liu, 1994). This process identifies and implements optimal operating strategies for buildings as they are currently being used rather than implementing design intent (Claridge, 2000).

CC process was first developed and applied on the air/water sides of building HVAC systems, and later extended to central chilled/hot water distribution loops and utilities plants. Unlike building CC, central chilled/hot water system CC faces more challenges, since it "deals with" all major components - all the buildings, distribution loops and central plants; but also presents "bigger" opportunities, since it targets the performance of the entire system.

Central chilled/hot water system performance has always been a major concern for facility O&M (operation and maintenance) staff, engineers and managers. For example, low system differential temperatures (DT's) are a common problem and present a challenge for most facilities. Effective and efficient delivery of cooling and heating energy to all the buildings is another major concern for most campuses.

Efforts have been made continuously and various methods have been explored to improve the central chilled/hot water system performance: different ways were studied and presented to achieve high system DT (Hattemer, 1996; Fiorino, 1999), variable-speed pumping was recommended in new system construction designs (Fair, 1996) and existing system renovations (Karalus, 1997), and primary-secondary pumping configurations were also heavily discussed (Sabeff, 2001; Volpe, 2001). Meanwhile, the importance of commissioning has been more and more realized and emphasized as the effective way to ensure the system is working "right" from the very beginning (English, 2001), and some detailed commissioning recommendations have been provided (Sabeff, 2001).

As it has been proved repeatedly that commissioning is very necessary for new construction and renovation/retrofit projects, we found continuous commissioning$^{SM}$ (CC) is an effective and efficient way to manage and optimize existing central chilled/hot water system operation. Successful central chilled/hot water system CC not only results in improved production and distribution, but also achieves significant thermal and pump power savings.

In fact, it is always a good timing to perform central chilled/hot water system CC, either with small local area trouble-shooting based on comfort complaints or operation problems identified by monitoring, or well-planned building-by-building balancing. It can be performed before, during, or after building side CC. It can be started at the central plants, and continued on the building loops, or in the reverse order: perform building loop CC before utilities plant CC.

Continuity is the key factor to achieve the persistence of savings and optimized performance. Well-organized communication and documentation is very important when pursuing the long-term overall success of this process, as it “pieces up” information in all the dimensions. Facility O&M team’s involvement and training is essential, since they carry out the daily routine operation and maintenance. Following-up on the recommendation list identified during the initial CC process will protect the persistence of savings achieved by temporary equivalent CC measures.

This paper presents the lessons and measures learned during our efforts in developing and exploring the central chilled/hot water continuous commissioning$^{SM}$ (CC) process. This on-going process has been performed on the central chilled/hot water systems of the Main Campus and the West Campus of Texas A&M University (TAMU) (Deng, 1998; Deng, 2000a), and other campuses (Zhu, 2000). With central utilities plant CC, 1 MW (40%) pump power savings opportunities were identified (Deng, 1998) and largely realized in the following years. With combined central building loop and utilities plant CC, pump power savings of over 50% were achieved, with additional hot water consumption reduction, improved chiller performance, increased available cooling capacity and decreased peak cooling load (Deng, 1998).

## II. FACILITY INFORMATION

To provide an example, Texas A&M Main Campus central chilled water loop is shown in Figure 1, which supports more than 100 buildings with a total of 9 million $ft^2$ conditioned floor area. All these buildings receive chilled water from two central plants: the Main Plant and the South Satellite Plant, which together have a total installed cooling capacity of 24,700 tons.

With a cooling capacity of 21,400 tons, the Main Plant sends out chilled water through four loops: West, East, South, and Central. All these loops are interconnected through supply and return common headers in the Central Utility Plant and pipe connections over the campus. The South Satellite Plant is a complementary one with a capacity of 3,300 tons, connected to the South loop at about 2/3 of the way from the Central Utility Plant. Meanwhile, the Main Plant itself is a co-generation CHP (Combined Heat and Power) utilities plant.

The central chilled/hot water systems on the TAMU Main/West Campuses are large in size and complicated in nature, supporting building HVAC systems of various types and ages, which provides huge challenges as well as opportunities to explore the complete CC process and measures.

## III. LESSONS, MEASURES AND DISCUSSIONS

Lessons and measures learned from CC of central chilled/hot water systems are presented

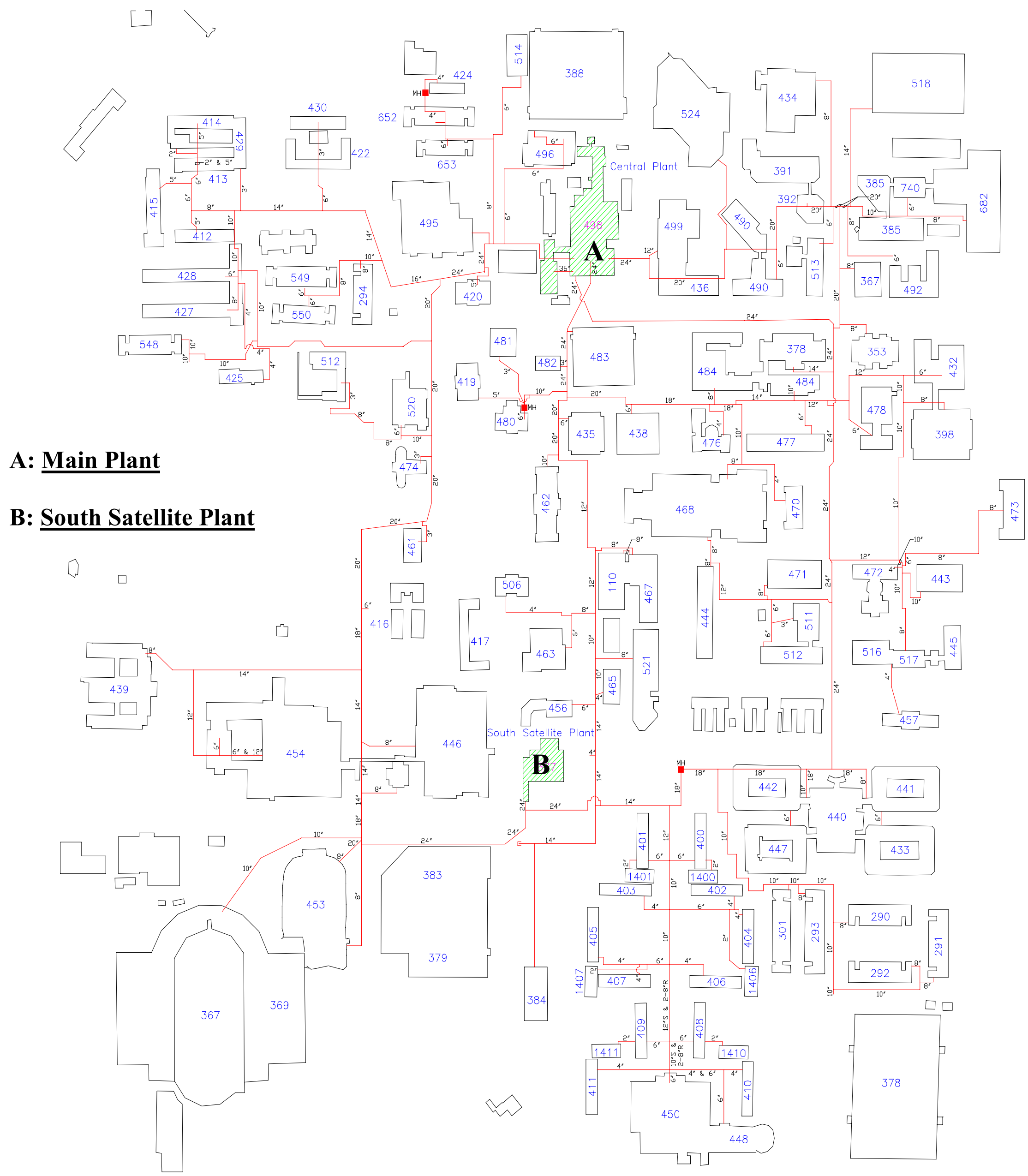


Figure 1. TAMU Main Campus Central Chilled Water Loop

below in detail. They are prepared in four categories: thermal energy sources, chilled/hot water delivery, operation assistance, and operation management.

1. *THERMAL ENERGY SOURCES*

Chillers: electric-driven chillers are frequently used for individual building energy plants.

1. Chillers need to be sized wisely so that the combinations of chillers will not only be able to support peak cooling loads with redundancy, but also handle partial-load and

low-load conditions with high efficiency. Mismatch of cooling capacity during low-load conditions will result in power waste, short cycling of chillers, and even damage of compressors (Deng, 2000b).

2. Individual chiller chilled water isolation valves are needed for consistently cold chilled water supply. Without them, during partial-load conditions, warm chilled water supply due to bypassing (through "dead" chillers) and mixing potentially causes humidity problems.

3. Chillers can be operated with variable chilled water flow rates allowed by manufacture to provide operation flexibility. Rapidly changed flow setpoints are not recommended (Deng, 1998).

4. Redundancy is necessary even with rental chillers/boilers.

In co-generation central plants, steam-driven chillers (centrifugal chillers or absorption chillers) are often used.

1. When both steam-driven and electric-driven chillers present, optimized operation schedules should be developed that steam chillers are used as base-load machines, and electric chillers as "add-on" (Deng, 2000a).

<u>Boilers and heat exchangers</u>:

1. Heating hot water or domestic hot water only needs low-pressure steam to produce through heat exchangers. Source steam pressure can be reduced to save energy.

Case study: TAMU West IV Plant uses 600-psig source steam to reduce to 20-psig to generate campus heating hot water. Availability of high-pressure steam is wasted, and performance of PRV (Pressure Reducing Valve) is unstable. A hot water boiler is being planned for replacement.

2. High heating hot water supply temperatures (160 °F and above) potentially damage pump seals and control valves, and result in more heat losses.

3. When isolating heating hot water flow to buildings in summer, pumps need to be run periodically to protect seal. Heating hot water should not be isolated for buildings where reheat is required for humidity control.

<u>Distribution planning</u>:

1. Satellite plants and loop interconnections provide operation flexibility and savings opportunities.

Case Study: hot water east/west loop connection at TAMU South Satellite Plant automatically balances hot water flows through both loops.

<u>CC measures</u>:

1. Develop optimized chiller/boiler operation schedules/sequences based on individual plant conditions and load profile.

2. Develop chilled/hot water supply temperature reset schedule based on the ambient temperature.

3. Develop chilled/hot water plant differential pressure (DP) reset schedule based on the ambient temperature or total flow rate.

4. Develop condensing water supply temperature reset schedule based on the ambient temperature.

5. Flooded manholes need to be drained and maintained dry, and leaks need to be searched and fixed.

Case Study:

1. TAMU West Campus central plant CC (Deng, 2000a).

2. TAMU Main Campus Main Plant heating hot water system CC. Table 1 recorded all the major actions, and Figure 2 presents the energy consumption relative savings. It was estimated that just by isolating heating hot

Table 1. Observed Heating Hot Water System Operation Conditions before and after Implementation of Improved Operation Schedule

| Date | To (°F) | Ts (°F) | DT (°F) | Ps (psi) | DP (psi) | Total Flow (gpm) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 12/16/97, 2:06 pm | 69 | 181 | 17 | 77 | 50 | N/A |
| 12/17/97 | Decreased supply T from 180 °F to 155 °F | | | | | |
| 12/17/97, 11:50 am | 58 | 155 | 12 | 74 | 49 | N/A |
| 01/29/98,11:00 am | 61 | 149 | 16 | 74 | 49 | 8,000 |
| 02/06/98 | Started to adjust loop DP every morning according to the improved reset schedule | | | | | |
| 02/06/98, 9:35 am | 43 | 149 | 22 | 61 | 35 | 7,250 |
| 02/27/98, 11:15 am | 62 | 142 | 17 | 60 | 35 | 7,100 |
| 03/13/98 | Stopped following the improved reset schedule, and raised loop DP back to 40 psi because of the problems at the Chemistry Complex | | | | | |
| 05/06/98, 10:20 am | 75 | 140 | 9 | 69 | 40 | 6,700 |
| 05/09/98 | Adjusted loop DP to 31 psi, since weather had been getting really warm | | | | | |
| 05/18/98, 12:03 am | 84 | 140 | 9 | 60 | 31 | 5,800 |
| 05/18/98 | Started isolating heating water supply to the dorms | | | | | |
| 05/20/98, 4:50 pm | 89 | 145 | 10 | 62 | 35 | 5,500 |
| 05/21/98 | Turn off electrical pump no. 5, and slowed down turbine pump No. 4 to maintain 31 psi loop DP, loop DP had increased from 31 psi to 35 psi because of the dorm heating water isolation | | | | | |
| 05/21/98, 10:10 am | 78 | 140 | 8 | 57 | 30 | 5,200 |
| 07/06/98 | Slowed down turbine pump No. 4 to maintain 30 psi loop DP, loop DP had increased from 31 psi to 34 psi because of less campus heating load, and decreased supply T from 140 °F to 130 °F | | | | | |
| 07/21/98, 3:00 pm | 98 | 135 | 11 | 58 | 29 | 5,100 |

water supply to all of the 40+ dormitories during the summer un-occupied period, the combined pump power savings and heating hot water energy savings exceeded $100,000.

*2. CHILLED/HOT WATER DELIVERY*

Driving force: Pumps are the driving forces for chilled/hot water delivery, including primary pumps, secondary pumps and building tertiary pumps. Meanwhile, condensing water pumps and cooling tower fans also falls into this category.

For the supplementary satellite central plants, sometime the primary-secondary pump system can be converted to secondary-only pump system to save pump power (Deng, 1998).

Common O&M problems identified during CC are: 1) pump impellers have been worn out, and are not able to deliver the specified flow and head; 2) check valves are either not installed or failed, causing water to flow in short-circuit; 3) pump deadhead due

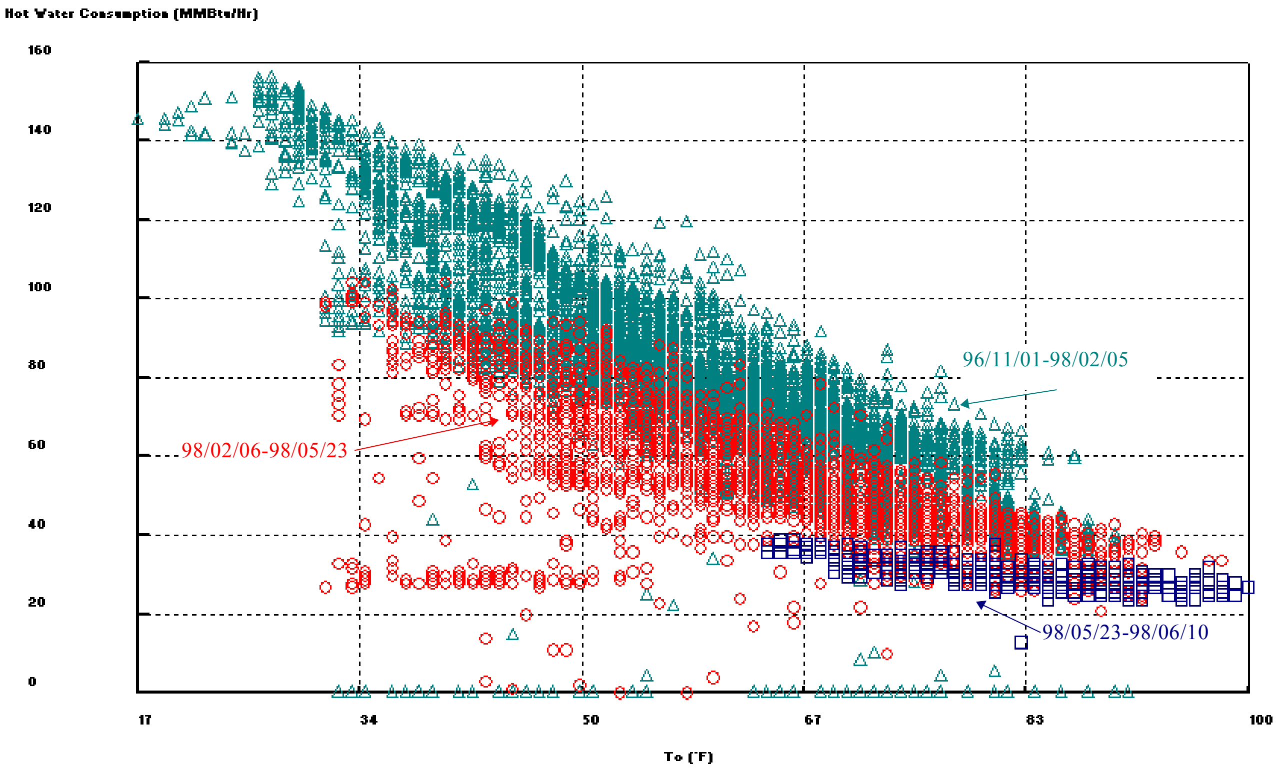


Figure 2. TAMU Main Campus Heating Hot Water Consumption Scattered Plot (11/01/97-06/10/98)

Table 2. Some Pump Deadhead Incidents

| Case | Pump Size | Period | Pipe Material | Reason | Normal Water T | Results |
|---|---|---|---|---|---|---|
| 1 | 5 hp | 20 hrs | Steel | Manual valve(s) shut | Chilled water, 44 °F | 170 °F measured close to pump |
| 2 | 5 hp | N/A | Clear Plastic | Manual valve shut | City Water, Room T | Clear plastic pipe "melted" |
| 3 | 7.5 hp | 58 hrs | PVC/ Steel | Return control valve shut | Chilled water, 40 °F | Caused upstream (about 50 ft away) PVC pipe failure? |

to either insufficient operation communication or control programming negligence. For example, not to interlock pump start/stop and control valve open/close can potentially causes pump deadhead. Table 2 presents several incidents when pump deadhead happened and the consequences.

Control components: they include automatic control valves for chillers, buildings and AHU's; balancing valves, building/chiller isolation valves, check valves, and VFD's (steam turbines for steam turbine pumps). Maintenance and fine-tuning of the control loop of these components are critical for their performance.

Bypasses are important control components, too, including AHU bypasses (with 2-way or 3-way control valves), building bypasses, primary-secondary system decouplers, and sometime, one building can serve as the other building's bypass. A well-designed building bypass could allow water back-flow when under high enough negative loop DP and must be shut under such circumstances. Sometime, building bypass is installed in a "hard-to-find" location out of the pump room, extra efforts must be spent to verify its operation to ensure pump system effective operation.

Case study:

1. For the Psychology Building of TAMU, building bypass is installed in some sealed ceiling space out of the mechanical rooms. With the assumption that such an open bypass doesn't exist, the building had been uncomfortable due to warm mixed chilled water supply.

2. Due to the physical location of the TAMU West I decoupler, one branch of the chilled water supply from the central plant would reach around 50 °F during low-load winter conditions, causing comfort problems.

Sometime, letting water back-flowing through buildings with insufficient pump power, especially for the heating hot water, can help the small troubled buildings with some heating supply for temporary solution instead of almost no heating due to little positive flow. The impact of this local back-flow on the central loops will be insignificant, with following conditions assumed and rules applied:

1. The buildings next to the small troubled building must be much larger buildings with enough pump power.
2. The small building doesn't have a check valve along the lines.
3. The pump(s) of the small building need to be turned off.
4. Manual balancing may be needed to achieve the right amount of flow.
5. The heating hot water supply temperature is high enough.

This method can not be used for buildings of similar sizes. When back-flow happens under such circumstances, it causes problems: as building pumps fail and one building serves as a "bypass", a short-circuit will be formed and locally circulated water eventually reaches the ambient temperature. No real cooling or heating supply will be available to the affected buildings in this case.

Case study: this kind of back-flow cases happen from time to time. It has been observed for similar-size buildings, water was trapped in a short-circuit and driven circulating locally. Such problems were also identified on some domestic hot water loops once.

<u>Control inputs</u>: they are readings from pressure, temperature and flow sensors. These sensors are not always available, and sometimes need to be installed based on requests. "Hot tabs" have been used for "wet" installations. Meanwhile, important sensors need to be verified and calibrated routinely to ensure accuracy. It was observed ambient temperature sensor readings from different buildings on the TAMU Campus could easily reach a 20 °F difference. One or two universal well-maintained weather stations will be a good solution.

<u>CC measures</u>: the goal is to develop optimized operation with more open valves and less pump operation.

1. Turn off unnecessary building pumps for buildings located close to the central plants. Verify check valve performance if a building bypass presents, and shut the bypass with manual valves if the check valve fails.

2. Develop optimized building DP reset schedule based on the ambient temperature. With the ambient temperature, the reset schedule is simple and stable. We found the return water temperature and the building flow rate are not as good to be used for this function.

3. Fully use common header to share pumps.

4. When VFD is present for pumps, shut building and AHU (Air Handler Unit) bypasses, and operate VFD according to the optimized building DP reset schedule. Operate the VFD and building control valve in time series: run VFD only when building control valve is fully open.

5. When no VFD presents, either building bypass or some AHU bypasses need to be opened to maintain stable operation and avoid pump deadhead. Use building control valve to regulate effective flow rate.

Case study:

1. When cold calls came from Butler Building of TAMU, we started a heating hot water loop balancing and DP optimization in the surrounding buildings, and improved available loop DP for this building.

Meanwhile, investigation was also carried out inside the building on its pump system and AHU heating hot water loops. Building automatic control valve was fixed, pump was tested and a larger pump was ordered. Lower floor AHU bypasses were shut and water loops were balanced. By performing CC internally and externally of this building, existing problems were identified thoroughly and completely, and solved.

2. TAMU West Campus central chilled/hot water loop balancing and optimization (Deng, 2000a).

3. TAMU Main Campus central chilled/hot water loop balancing and optimization.

## *3. OPERATION ASSISTANCE*

Energy consumption metering and operation monitoring: energy consumption metering provides data to evaluate building and central plant energy systems' performance, load magnitude and profile, and energy conservation potential. After a baseline is established, consumption data can be used to calculate savings achieved from energy conservation measures (ECM's) for savings verification. Both central plant and major buildings should be metered for major energy consumption. It is important to meter both chilled/hot water flow rate and energy consumption values, since just recording one of them can result in confusing data. For example, based on the chilled water consumption data for the Reed Arena of TAMU during 1999, it is hard to identify significant problems; but with the help of the corresponding chilled water flow rates, it becomes very easy to find out that this building was operated with only 3 to 4 °F chilled water DT for quite some time. Significant pump power was wasted due to unnecessary pump operation, and, large amounts of chilled water with low DT passing through it caused a distribution problem for some loops and a chiller loading problem for the central plant.

When several interconnected chilled or hot water loops are metered, the flow meters need to be installed consistently either on supply side or return side. A data logger is desired for metered data to be stored and later processed smoothly. When it is impossible to install meters for each individual building, branches of central chilled/hot loops can be metered instead.

Major plant and building pressures, temperatures, flow rates, VFD speeds, control valve positions and equipment on/off, etc. need to be monitored. Direct Digital Control (DDC) Energy Management Control System (EMCS) serves this function the best. These days, EMCS is widely installed on building HVAC systems and central plants, but not very often on central distribution loops. In fact, installing EMCS on central distribution loops is relatively a straightforward process: install pressure, temperature and flow sensors at pre-selected critical locations, and collect and present the data.

With metered and monitored data, through engineering analysis and calculation, central distribution loops' performance can be quantified as "energy loss factor", and loss distribution can also be studied.

Maintenance and calibration needs to be carried out routinely to ensure data quality. Portable ultrasonic meters are often used for flow meter calibration.

Commercial software simulation: commercial water distribution loop simulation software and energy plant operation simulation/optimization software is available and can be used to provide operation assistance. The challenge to fully apply the software is to develop sound input models accurately representing all the major components of the central water loop or energy plant, which depends on well-designed-and-maintained metering and monitoring. After that, they can be used to simulate/predict operations under assumptions to assist decision-making, such as the impacts of adding a new building to the central loops or shutting down a major plant supply and return branch.

Performance index: loop or building DT's are used by us as an index for central chilled/hot water loop and building performance, besides energy consumption and water flow analyses. Low loop DT means extra water flow and more pump power consumption, and it also results in partial loading of chillers and boilers at the design flow rates and poor operation efficiencies. Figures 3 & 4 present some DT's calculated from measured hourly data on the TAMU Campus, showing the impacts of central chilled/hot water system CC.

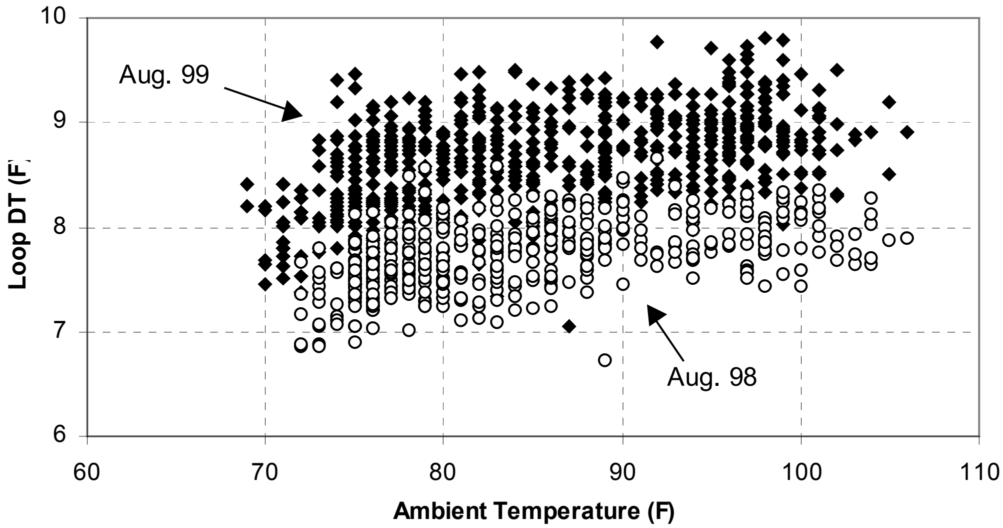


Figure 3. Main Plant Chilled Water East Loop DT's in August 1998 and 1999

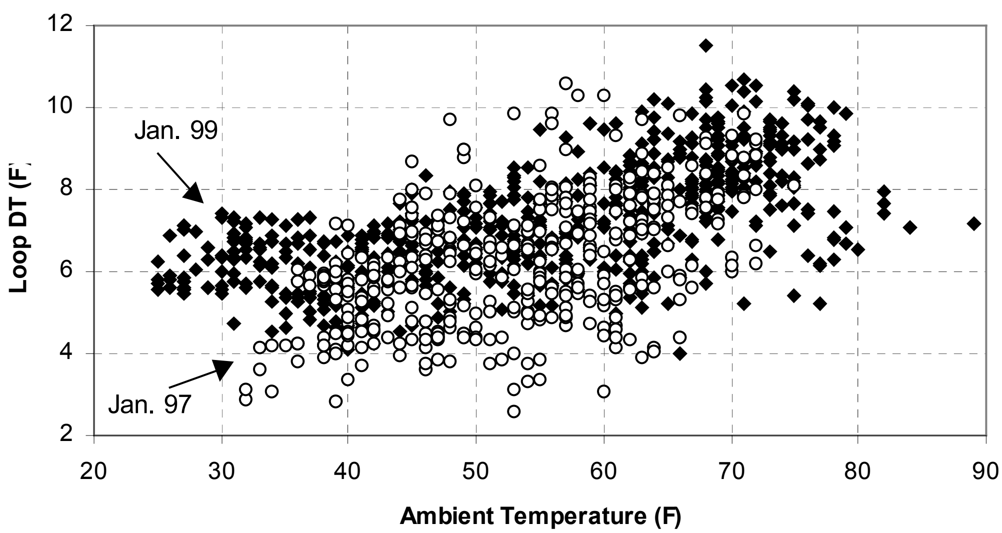


Figure 4. West Campus One Major Chilled Water Branch DT's in January 1997 and 1999

Figure 3 shows DT's of Main Campus chilled water East Loop in August 1998 and 1999 respectively. An increase of 1 - 2 °F was generally achieved from CC performed in between.

Figure 4 shows DT's of West Campus one major chilled water branch in January 1997 and 1999 respectively. An increase of 3 - 4 °F was achieved for the low load conditions under ambient temperatures around 30 °F. Meanwhile, the 1999 data are closer to each other, and the 1997 data are more scattered. The reason behind it is that the 1999 operation was following an optimized plant operation schedule, but the 1997 operation was much more "flexible", with overshoots and undershoots. Also, the 1999 data still have a lot of potential to be further improved.

*4. OPERATION MANAGEMENT*

The pursued central chilled/hot water system operation management is described below:

1. Campus distribution loop map is shown on a large-size computer screen for each individual system.
2. Map is labeled with monitored water DT's and DP's at critical buildings, critical locations of loops and central plants. Simulated DP's by commercial software or desired DP's and DT's from experience are labeled beside the measured ones.
3. Alarms are triggered for low DT and high DP areas, and a CC team will be sent to investigate in field and send request based on investigation results to different resources to improve the low DT's.
4. Flow rates are monitored and labeled for critical areas.
5. All pressure, temperature, flow rate, DT and DP information can be processed and presented in a table or report format for desired areas and in desired orders. Trending capacity is available. Individual trouble-shooting and CC history is stored for each system component.
6. Maintenance and calibration is performed routinely on sensors and control components (control valves, VFD's, etc.).
7. Similar presentation and management for in-plant energy systems, but with recommended operation from commercial software optimization simulation shown for comparison.

## IV. CONCLUSIONS

Lessons and measures learned from central chilled water and hot water system continuous commissioning$^{SM}$ have been presented above. The major measures include: identify and apply optimized central plant chiller/boiler operation schedules/sequences, central plant chilled/hot water supply temperature and DP reset schedules, identify and apply optimized building loop DP reset schedule, turn off unnecessary building pumps, correctly commission all kinds of bypasses, and use loop DT's as performance evaluation index, etc.

CC identifies O&M problems, but it is not the major goal of this process, which is to develop and implement optimized operation and control methods for each individual building, water loop, and energy plant by detailed field measurement, engineering analyses and testing. Facility O&M team is among the key players of this process. Their inputs and involvement are very valuable for CC engineers to develop optimized and practical energy conservation measures, schedules and sequences. This teaming-up also helps the O&M team to receive on-site training, and therefore ensure the persistence of the system optimized performance and CC savings in the on-going operation. It is clear from the case studies that this process improves system overall performance and leads to significant pump power and thermal energy savings. It is the efficient and effective energy conservation process for the existing systems, since it doesn't require major capital investments. Meanwhile, CC process evaluates or identifies energy conservation retrofit opportunities.

Continuity is the key factor of the CC process, which means as long as the system exists, commissioning needs to be performed continuously with expertise. System performance M&V (Metering and Verification) is essential for performance evaluation, major CC timing identification and savings calculation.

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