Commissioning of A Large Office Building in Texas – A Case Study

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ABSTRACT

This case study involves commissioning of a large office building in the hot and humid climate of south Texas. The commissioning involved the installation of a VFD (Variable Frequency Drive) on a chilled water pump, improved EMCS (Energy Management Control System) programming and operation, and the installation of automatic chiller isolation valves, in addition to calibration and repair of building VAV (Variable Air Volume) boxes. In the case study building, four air-cooled chillers and two chilled water pumps were installed on the roof of a six-story, 141,514 ft^2 office building with very limited EMCS control. Some of the built-in chiller features such as staging and flow switch protection were unreliable due to age. Serious problems existed with humidity control, operation efficiency, and equipment protection in the building.

By utilizing the existing EMCS as part of the Continuous Commissioning measures, several operational problems have been solved, and significant savings have been achieved. This paper discusses our procedures in identifying and solving moisture problems, the importance of cooling production and building load management, and the effectiveness and convenience of EMCS control.

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 emerged from a program of implementing operation and maintenance improvements following retrofits in buildings. This process identifies and implements optimal operating strategies for buildings as they are currently being used rather than implementing design intent.

Energy management with a properly functioning digital control system on the building HVAC (Heating, Ventilating and Air Conditioning) systems can remarkably improve an owner's O&M (operation and maintenance) cost while providing dependable and accurate control (Fiorino, 1999). Optimizing the control system's function is important in a Continuous Commissioning where an EMCS is present. Existing system renovations, such as the conversion to variable-speed pumping, usually require the use of an existing EMCS spare channels (Fair, 1996; Karalus, 1997). System operation savings can also be achieved from improved building side pumping management (Hattemer, 1996).

This paper presents our efforts to identify existing HVAC system operation problems in a case study office building, analyzing the causes, and improving the performance through Continuous Commissioning of the HVAC systems with the help of the EMCS.

II. FACILITY INFORMATION

The building discussed in this paper is a six-story, 141,514 square-foot office building located in South Central Texas. The actual space conditioned by the central HVAC system is approximately 129,721 square-feet. Four packaged DX (Direct Expansion) units provide cooling for part of the first floor. One air handling unit serves the remainder of the first floor.

The Central HVAC system is a single duct variable air volume (SDVAV) system with electric terminal reheat for exterior zones. There are a total of eleven (11) air handling units and sixty-one (61) VAV boxes. Each unit has a relief damper in the mechanical room controlled by a static duct sensor.

There are two (2) 105-ton and two (2) 120-ton air-cooled chillers on the roof with two (2) 15-hp, 570-gpm constant speed chilled water pumps.

There is also a limited EMCS system in the facility that controls the start/stop of major equipment (each Air Handling Unit, and power supply to all four chillers and two pumps).

III. INITIAL RESULTS FROM COMMISSIONING WALK-THROUGH

When we first visited the building, there was a large temperature difference noted on several floors, and areas of high humidity were noticed. Some office rooms were too hot during the peak cooling season. Further investigation found some VAV box dampers were not controlling properly due to damage or mismatch of their spring range. Some zone thermostats were out of calibration as well. Due to these problems, the cold air supplied to different zones was unbalanced and consequentially created "hot spots" in the areas where not enough cold air was supplied.

Also, the zone temperature control system (i.e., thermostat, cold air damper and its actuator, and pneumatic to electrical (P/E) switches, electric duct heater and fan for the exterior zones) was out of calibration and therefore out of control. This caused simultaneous heating and cooling.

Another reason causing the simultaneous heating and cooling energy waste was the lack of control on the chilled water system. In the case study building, there are a total of four chillers available to serve the eleven AHUs (Air Handling Units). During the peak cooling season, all four chillers need to be turned on to meet the cooling load. For the transition periods (Spring and Autumn) and low cooling load periods (Winter), cooling loads from the building are low, and it is not necessary for all four chillers to be on. Because there was no EMCS control on the chillers' operation (i.e., all four chillers are controlled by one power supply point), and the manufacturer's temperature reset sequence of the chiller compressors was not dependable due to age, the chillers were not being staged efficiently. The extra cooling produced had to be compensated by reheat at the terminal electric duct heaters.

On the other hand, since there was no isolation valve on each chiller's chilled water side, when one chiller was turned off, the chilled water was still bypassed through the other chillers, and the building supply chilled water was a mixture of the cold water (e.g., 46°F) from the chillers in operation and the relatively warm return water (e.g., 58°F) from chiller(s) which were not on. As a result, the building supply water temperature could be high (around 50°F from the above case), which potentially created humidity problems inside the building.

In addition, because of the lack of EMCS control on the chiller operation, and the fact that the chillers' own compressor operation control and flow switch were unreliable due to age, the chillers were not able to be turned off to stop freezing some of their compressors during low load conditions. When the chilled water system was turned on manually or automatically during the nighttime or weekend, there was a mismatch of the chiller cooling production and the building cooling load. Therefore, a large amount of electric reheat was wasted at the terminal VAV boxes. In some cases, 33°F chilled water supply temperatures were also observed.

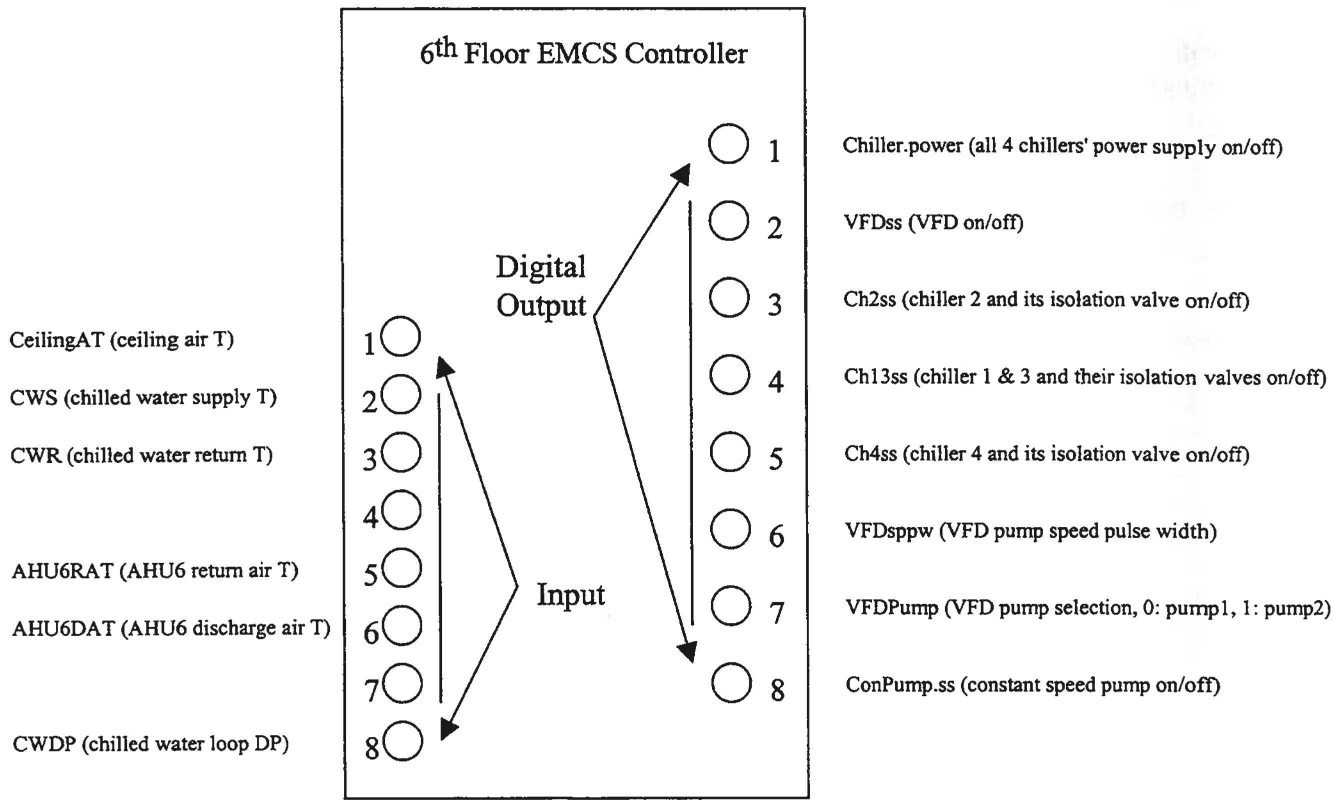
IV. CONTINUOUS COMMISSIONING MEASURES

A. VAV Boxes:

Major Continuous Commissioning measures involve the inspection, calibration, and repair of the VAV boxes. There are 61 boxes in the building. Thirty-eight (38) of them are coupled-controlled, fan powered boxes with electric reheat. The twenty-three (23) remaining boxes are interior zone boxes without reheat. Calibration and inspection of the boxes uncovered main air dampers that could not fully open. The P/E (pneumatic to electric) switches were found to be overlapping heating and cooling. These were reset to turn "off" with a dead band between heating and cooling. Gravity dampers on the fan unit were found stuck in an open position thereby releasing supply air into the plenum and lowering cool air flow to the end of the duct. The stuck dampers were released and checked for proper operation. Some damaged fan motors P/E switches were also found.

The interior zone VAV terminal boxes were not able to open fully in some cases. It was also found that the spring range of many of the damper actuators was not the prescribed 3-11 psi. All actuators were checked to find the true range. This procedure also identified the proper setpoint of the thermostats.

By recalibration of the VAV boxes and zone thermostats, an improved box operation schedule was applied, which is documented in detail in the "Optimized Control Sequences" section. As a result, building comfort has been greatly improved, and fewer complaints have been reported.



Note: chiller on / off and its isolation valve open / shut are controlled by the same output point. A relay has been installed to each chiller, so that when the "on" signal is sent to a chiller and its isolation valve, the valve will be opened instantly, but the chiller will be turned on after one minute through a time delay.

Figure 1. 6th Floor EMCS Controller Diagram after CC

B. AHUs

By measuring the static pressures at each AHU before the relief damper and all static pressure controllers, the pressure drop and velocity changes were calculated to help determine if enough air was reaching the last diffuser in the trunk line (several control air flow restrictors were replaced to make the controllers operate properly). The static pressure was increased for some ducts after air flow to different zones was balanced and supply air dampers of individual rooms were adjusted. Increasing air flow to some hot zones required adjustments to the zone manual air directional vane. These changes were done incrementally in order not to upset the entire system. As a result of these air balance efforts, we have been able to lower the duct static pressure setpoint to 0.25" water column from the original 0.3" to 1.0" water column for different AHUs. With the control of the duct static pressure controllers, the extra supply air is dumped into the mechanical rooms, thereby lowering the mixed air temperature and saving cooling energy. Also, by resheaving the motor to a smaller size we have reduced the fan air volume to save fan power.

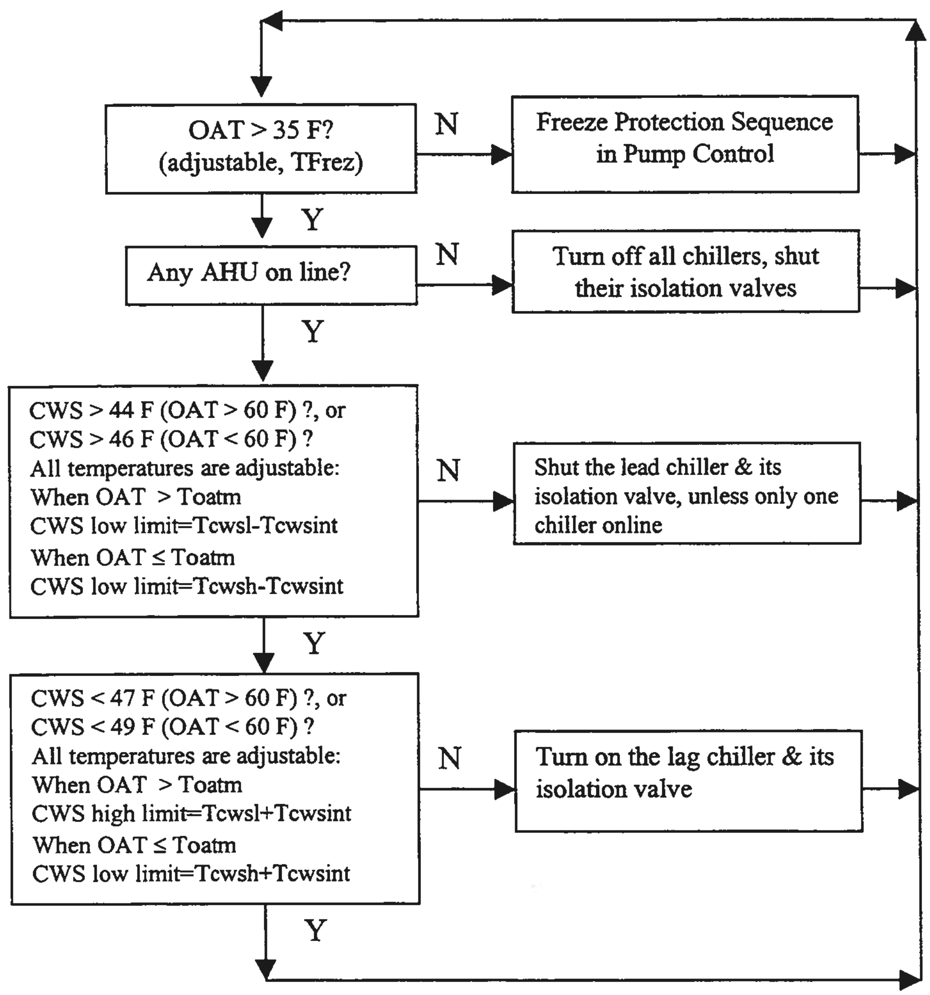


Figure 2. New Chiller Control Flow Chart

C. Chilled Water System

Optimization of the chilled water system includes installation of a VFD to the chilled water pumps, an isolation valve to each chiller and establishment of a EMCS control system (including hardware installation and software programming) on the chilled water system operation. With these Continuous Commissioning efforts, we have achieved:

1. Software freeze protection for the chilled water system based on the outside air temperature.

2. Effective freezing protection for the chiller compressors to avoid compressor damage due to the mismatch of the chiller cooling production and the building loads based on the chilled water supply temperature.

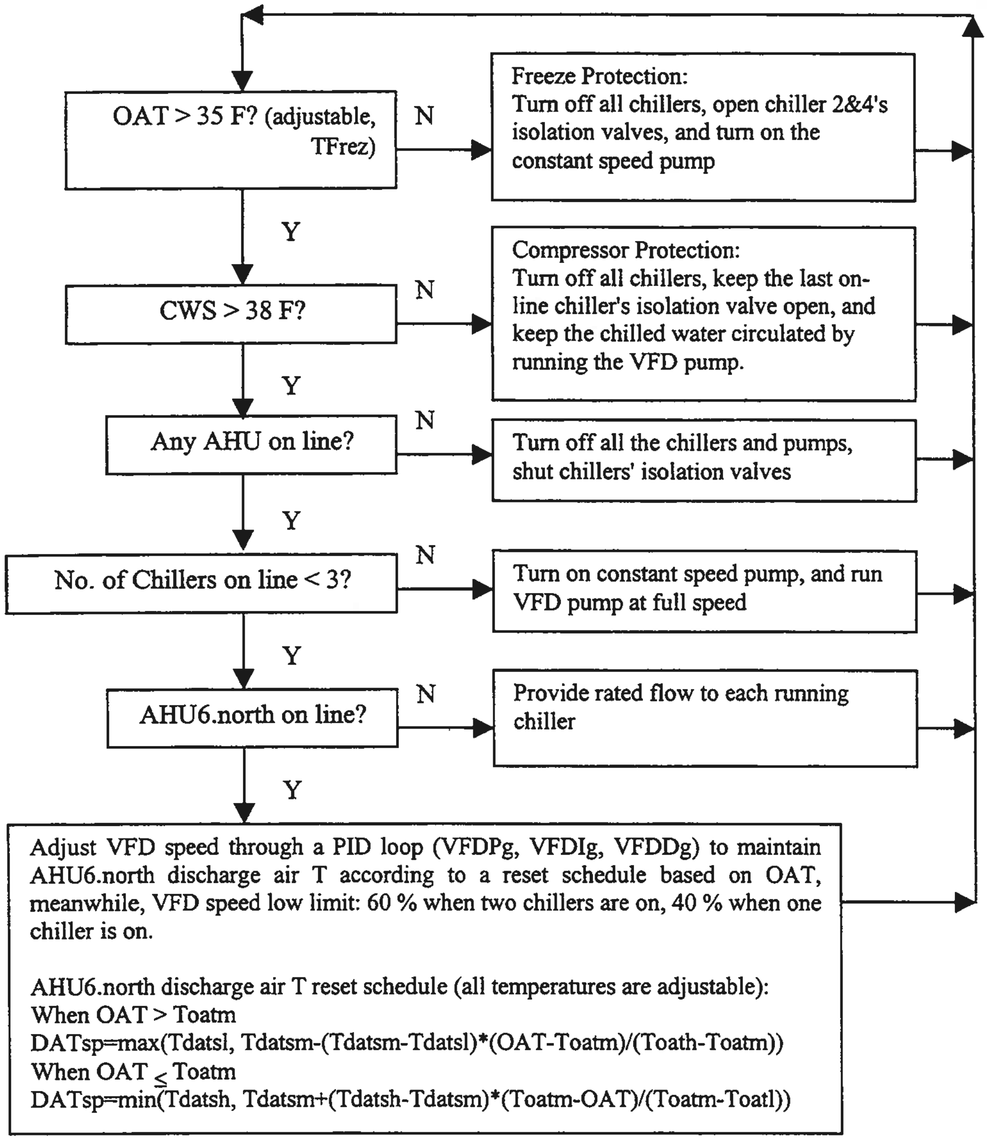


Figure 3. New Pump Control Flow Chart

3. Separate control on each chiller, which can be turned on/off from the control system.

4. Better control of the chilled water temperature because when a chiller is turned off, the supply chilled water is prevented from mixing with the relatively warm return chilled water, thus ensuring an adequate chilled water supply temperature.

5. An optimized pumping schedule with VFD control to save pumping energy.

6. An optimized AHU discharge air temperature reset schedule to avoid simultaneous cooling and heating to save energy.

V. OPTIMIZED CONTROL SEQUENCES

A. VAV BOXES

Each AHU supports about 4 to 6 zones, and each zone has a reverse acting thermostat.

a. The boxes for the interior zones have no duct electric heater, and they modulate the supply air dampers to maintain room temperature. Setpoint for the occupied periods is 74°F.

b. The boxes for the exterior zones have a duct electric heater, and the zone thermostat setpoints are reset by the control main air pressure, 73°F at 18 psi during occupied periods and 78°F at 24 psi during unoccupied periods.

In this case, maximum cooling is provided to the room(s) by fully opening the supply air damper (at 0 psi control air to the damper controller). As cooling loads decrease, the damper will be modulated to partially open positions to supply less cooling air (between 0 to 8 psi control air from the zone thermostat). At the minimum damper position (for 8 psi or higher control air), minimum cooling is provided by the minimum amount of supply air. When heating is required, the supply air damper will stay on the minimum position, and the duct electric heater fan will be turned on first by a P/E switch (for 8.5 psi or higher control air from the thermostat) to circulate some return air back to the room(s). Second, if this will not warm up the room(s) quickly, the duct electric heater will be turned on by a second P/E switch (for 10 psi or higher control air) to provide electric heating until the thermostat setpoint is satisfied.

AHU supply air damper controller and the two P/E switches that control the fan box and the electric heating have been calibrated for precise control and for elimination of simultaneous cooling and heating.

B. AHUs

AHUs are automatically turned on by the existing control system during the normal occupied periods (weekday from 6:00 a.m. to 6:00 p.m.). They can also be turned on manually during nighttime and weekends, and will stay on until manually turned off.

Chilled water loops have been balanced for the 11 AHUs (1 on the 1st floor, and 2 on each floor for the other 5 floors), so that the 6th floor AHU discharge air temperature is within 1.5°F of all the other AHUs. This discharge air temperature will be controlled by adjusting the chilled water pump VFD speed through a PID (Proportional-Integral-Derivative) control loop according to a reset schedule (from 52°F for hot summer to 60°F for winter based on outside air temperature). During nighttime or weekends, if AHUs on the other floors are manually turned on without turning on the 6th floor AHUs, pump(s) will provide the rated flow to each chiller that is running.

The AHUs are operated with constant speed fans. Duct static pressure setpoint has been adjusted to 0.25" water, which is able to provide sufficient amounts of air to each room while maintaining high system efficiency. Relief dampers in the mechanical rooms are modulated to maintain the setpoint.

C. CHILLED WATER PUMPS

a. Freezing protection: when the outside air temperature is below 35°F, all the chillers will be shut down and all the chiller isolation valves will be opened. Both pumps will be turned on (VFD pump runs at full speed) to circulate the water.

b. Compressor protection: by collecting and analyzing the chilled water system operation data under the original control scenario, we found that when AHUs for some floor(s) are turned on during nighttime and weekend periods (i.e., when most of the building is unoccupied), the cooling load inside the building is much less than the cooling production by the chillers. This is a serious cooling mismatch. Under such conditions, the chilled water supply and return temperatures were observed as low as 33.53°F when 4 AHUs were on and all 4 chillers and 2 chilled water pumps were on. This low-load condition will damage the chiller compressors.

Through existing building control points and programming protective and efficient control schemes, we have eliminated the above mismatch, and the chilled water supply temperature will never be less than 38°F if the new control system is maintained. We have programmed it in such a way that the chiller cooling production will always match the cooling load from the building, no matter if AHUs are turned on automatically during the regular working periods or manually during the nighttime/weekend periods. Whenever the minimum cooling production by one chiller is still much more than the cooling load from the building, the last running chiller will be turned off automatically to protect the compressors. Meanwhile, the chilled water pump will keep running to circulate the cold water to maintain the room comfort.

c. Occupied Periods: during normal occupied periods (all the AHUs are automatically turned on by the existing control system), when two or fewer chillers are running, the constant speed pump will not be turned on, and the VFD pump speed will be adjusted through a PID control loop to maintain the 6th floor AHU discharge air temperature setpoint. When three or more chillers are running, the constant speed pump will be turned on, and the VFD pump will run at full speed.

If during nighttime or weekends, some AHUs are turned on, the pump(s) will provide the rated water flow to each chiller that is running.

d. Unoccupied Periods: both pumps will be turned off.

D. CHILLERS

a. Freeze Protection: No chiller will be run when the outside air temperature is below 35°F, and chiller 2 & 4's isolation valves will be open.

b. Compressor protection: We have programmed the controls system in such a way that the chiller cooling production will always match the cooling load from the building, no matter if the AHUs are turned on automatically during the regular working periods or manually during the nighttime/weekend periods. Whenever the minimum cooling production by one chiller is still much more than the cooling load from the building, the last running chiller will be turned off automatically to protect the compressors; however, the chilled water pump will keep running to circulate the cold water to maintain room comfort conditions.

c. Occupied Period: Chiller(s) will be turned on or shut off to maintain chilled water supply temperature in the range of 44°F to 47°F when the outside air temperature is higher than 60°F, and 46°F to 49°F otherwise. When the chilled water supply temperature is lower than the low limit, the lead chiller will be turned off, and its isolation valve will be shut. When the chilled water supply temperature is higher than the high limit, the lag chiller will be turned on. There will be a minimum 12-minute interval between every action. At any time during an occupied period, at least one chiller will be on line, and its isolation valve will be open.

d. Unoccupied Periods: No chiller will be on, all of the chiller isolation valves will be shut.

As the 6th floor controller diagram shows, chiller 2 and its isolation valve are controlled by the control point "ch2ss" for on/off. Chiller 4 and its isolation valve are controlled by "ch4ss". Chiller 1 & 3 and their isolation valves are controlled together by one point — "ch13ss". By programming with different combinations of these three points, one, two, three or four chillers will be turned on according to the above chiller sequence, i.e. when chiller 1 & 3 are turned on through the control point "ch13ss", one on-line chiller will be turned off to make sure that the on-line chiller number will only increase by one each time. A similar approach is applied when chillers 1 & 3 are turned off, so that each time the on-line chiller number will only decrease by one.

VI. PRELIMINARY RESULTS

At the end of April 1999, we finished the installation of the necessary components to build control into the chilled water system under the existing controls system and applied the control program. Since that time we have been fine-tuning the AHU discharge air temperature reset schedule and other sequences. For the period from 04/21/1999 to 05/21/1999, the building electrical meter measured 168,960 kWh electricity consumption, which is 10.7% lower than the consumption (189,120 kWh) of the same period in 1998. These saving should mainly come from the newly-applied chiller and AHU operation management during nighttime and weekends, since most of the time during the daytime working period, all four chillers and two pumps were always turned on to meet the 49°F AHU discharge air temperature setpoint. (This setpoint was applied during the testing of the control program and was based on the decision of the facility maintenance staff. It has been put back to a fine-tuned reset schedule with agreement from the maintenance staff). For the peak cooling season, savings will not be significant, since all four chillers' operation is necessary most of the time. But the building comfort level (temperature and humidity control) has been greatly improved under the current control scheme. We look forward to significant savings during the transition periods and the low cooling load season, when simultaneous cooling and heating happen in a large scale under the original building HVAC system operation. Building electricity consumption bills will be collected and analyzed to determine savings and verify the performance of the improved HVAC system operation.

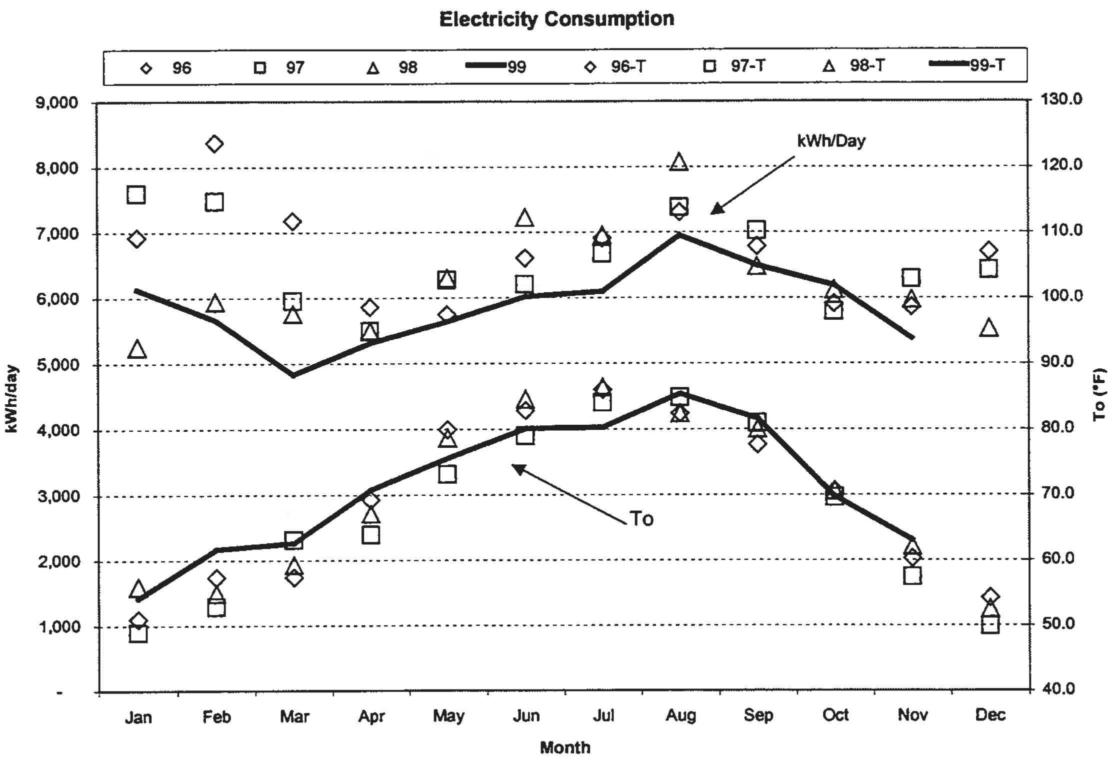


Figure 4. Monthly Average Electricity Consumption (kWh/day) and Outside Air Temperature Comparison (1999 data shown in lines for post-CC period, the others are for pre-CC periods)

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