Table of Contents

Continuous Commissioning® of A Medical Research Facility

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ABSTRACT

This paper presents a case study for Continuous Commissioning® (CC®)[1] of a 520,000 square foot medical research facility. All of the primary energy using systems in the building were investigated to determine their existing condition and operation. Using these findings, the needed CC® measures were developed. Some of the CC® measures include repairing the heat exchangers, valves, and dampers that are not working. Also, reset schedules for air handling unit supply temperature and static pressure were created. Chilled and hot water loop ΔP setpoints were fine-tuned. Economizer operation and air-to-air heat exchanger operation were also optimized. The airflow stations in many of the terminal boxes were found to be in need of cleaning and addition of filters. From January 2004 through March 2006 the CC® engineers implemented the CC® measures with the assistance of facility staff. Cumulative CC® savings from April 2004 to July 2006 was over $1,900,000 and the building experiencd significant comfort improvements.

INTRODUCTION

The case study building is a 520,000 square foot facility that houses medical research. A CC® assessment of the building operation was performed in 2003. During the CC® assessment process, it was noted that although the building was well run, many opportunities existed to improve the building operation. It was determined that a significant amount of energy savings could be achieved by making adjustments to the operation of the system. The CC® process subsequently began in January of 2004 and was substantially completed in March of 2006. All of the primary energy using systems in the building were investigated to determine their current condition and operation. Using these findings, the needed CC® measures were developed and implemented. This paper discusses the issues identified and the measures implemented.

[1] The terms Continuous Commissioning and CC are registered trade marks of the Energy Systems Laboratory, Texas Engineering Experiment Station, Texas A&M University System.

HVAC SYSTEM INFORMATION

Ten single-duct variable air volume (VAV) air handling units (AHUs) provide conditioned air to the building. Table 1 lists the maximum airflow, number of supply fans and sizes of motors for all the AHUs.

AHU	# of Fans	Fan Size (hp/fan)	Maximum Airflow (cfm)
1	4	100	144,000
2	4	75	106,000
3	4	75	108,000
4	4	60	84,000
5	4	60	85,000
6	2	60	46,000
7	2	50	36,000
8	2	60	44,000
9	2	60	48,000
10	2	60	78,600

Table 1. AHU fan sizes and airflows.

The nine AHUs that serve areas with labs operate the same but are of different sizes. They all are single duct systems with multiple supply and exhaust fans that are equipped with variable frequency drives (VFDs). Due to possible contaminates from the lab areas, only outside air is used in the AHUs. Figure 1 is a schematic typical of AHUs 1-9. Outside air enters through air to air heat exchangers. Incoming outside air can go directly into the AHU through a bypass or go across the heat exchanger. A set of dampers with pneumatic actuators controls how much air goes to the bypass and heat exchangers. In the heat exchanger, energy is transferred between the outside air and the leaving exhaust air. After passing through the fans, the air goes through hot water heating coils, a steam humidifier, and chilled water cooling coils. All valves and dampers on the AHUs are pneumatic.

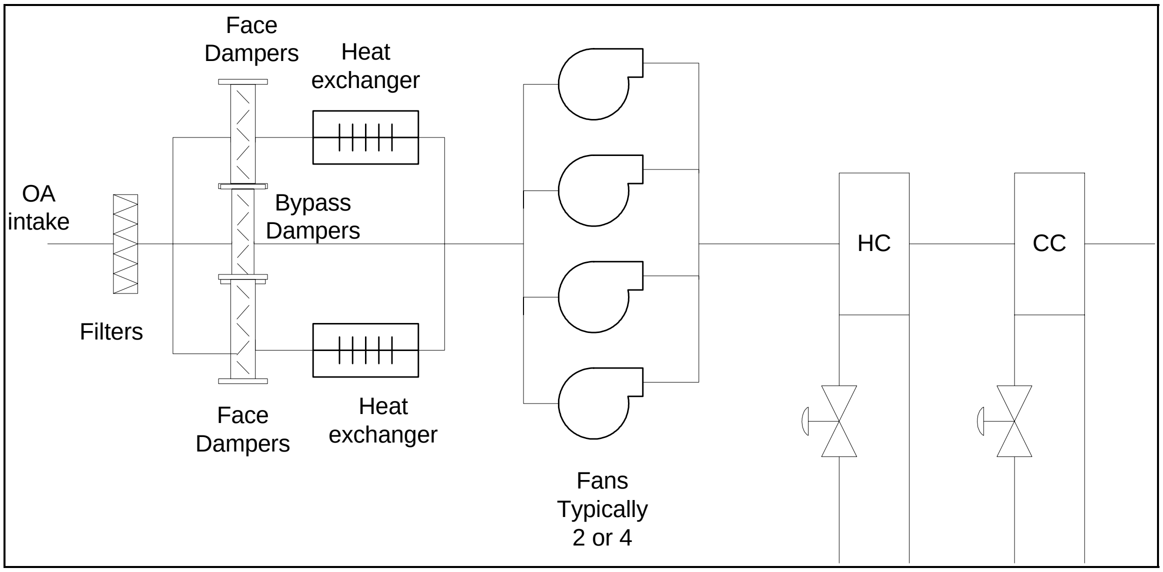

Figure 1. Schematic of a typical AHU

AHU 10 only serves office and meeting areas so it is able to use return air. It is also single duct with VFDs on both the supply and return fans. Instead of a heat exchanger, this unit has economizer dampers that control the amount of return and outside air taken into the AHU. Figure 2 is a schematic of AHU 10.

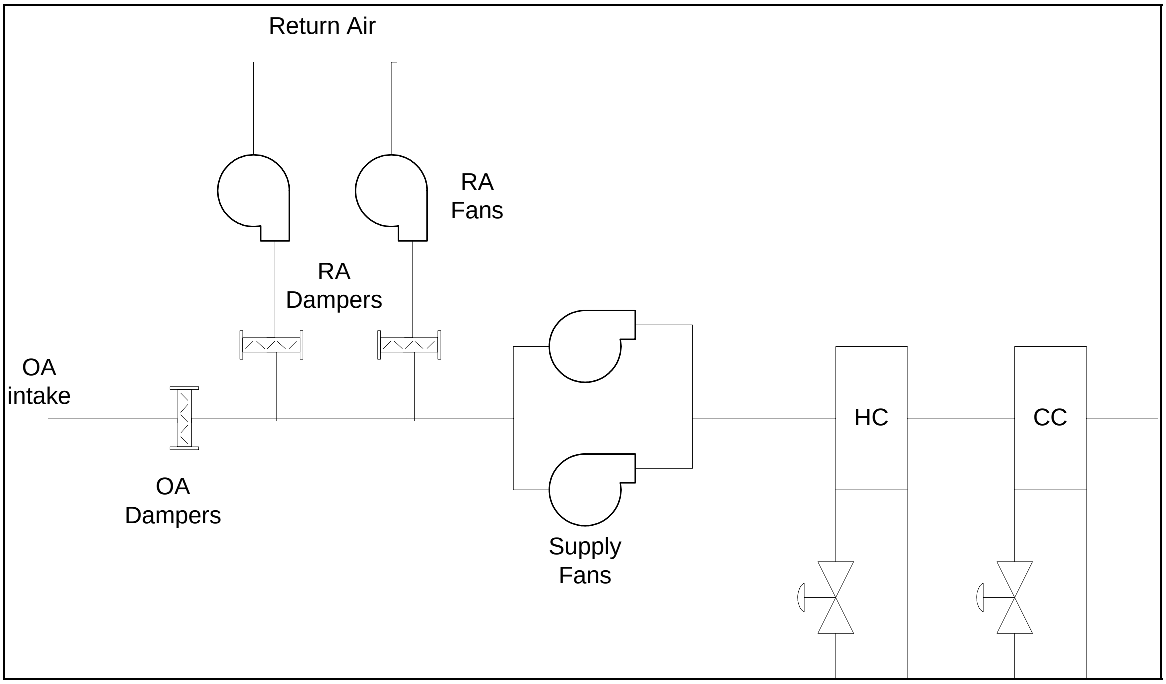

Figure 2. Schematic of AHU 10.

Airflow to the conditioned space is controlled by terminal boxes for AHUs 1-5 and 10. Each box has a damper with electric motor and an airflow sensor. Some boxes have hot water reheating coils that are controlled by an electronic valve. AHUs 6-9 do not have control dampers. Terminal boxes have heating and cooling coils to control temperature. Their airflow is controlled by manual dampers in the ducts.

These dampers were balanced to get the correct airflow to the space when the building was constructed. A testing and balancing firm was contracted to rebalance these dampers while the CC process was being conducted.

Most of the first floor and part of the ground floor is used for office and meeting space. Laboratories and offices are found throughout the rest of the building. The building occupants mostly work from 8:00 am to 5:00 pm but the labs must remain conditioned 24 hours a day because of the experiments being conducted.

Three 1200-ton chillers supply cooling for the building. Four 75 hp constant speed pumps circulate the water through the building and to the AHUs. The chillers are cooled by three cooling towers with two fans each. Each fan can run at two speeds, high and low. Water is supplied to the towers with four 100 hp pumps. A schematic of the chilled water system is given in Figure 3.

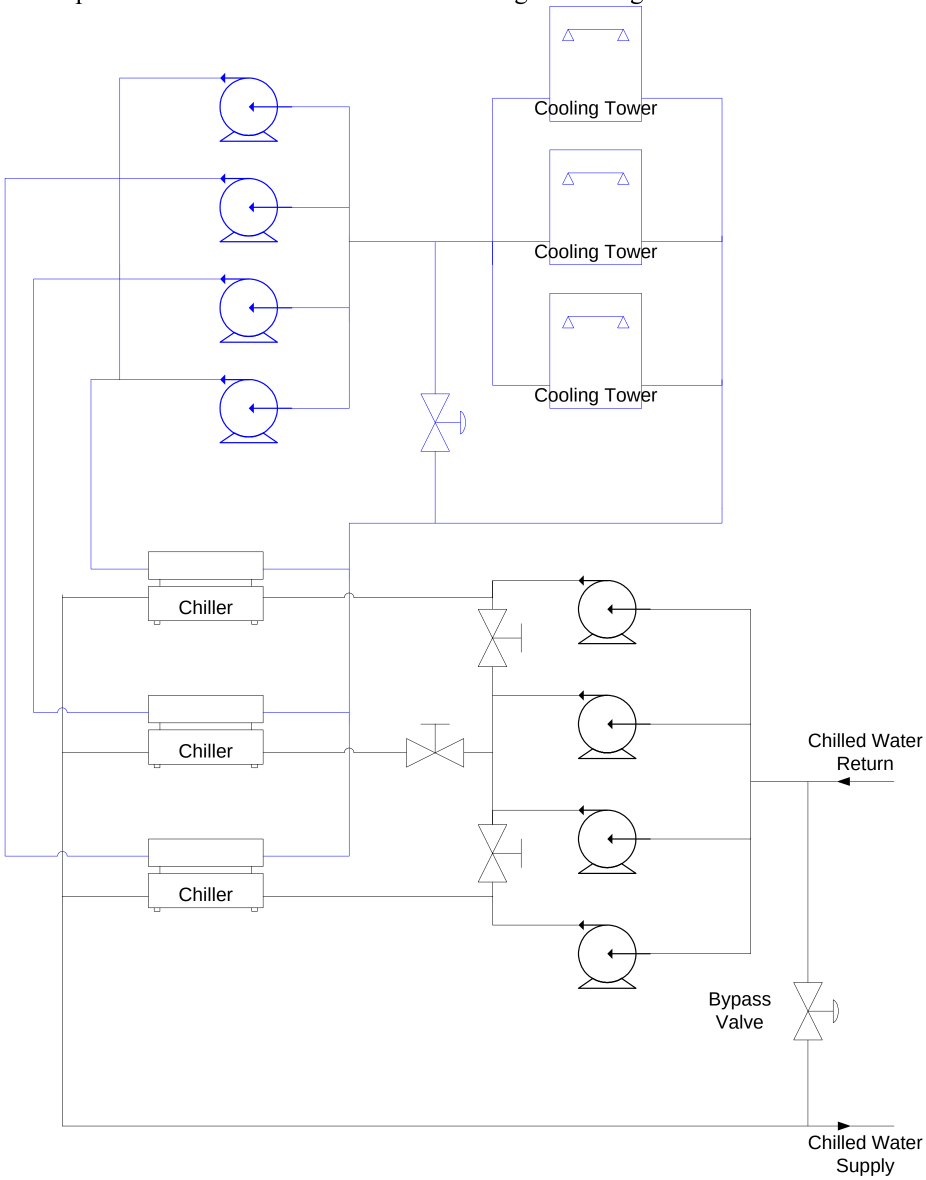

Figure 3. Schematic of Chilled Water System

Heating for the building is provided by three steam boilers. The boilers usually run on natural gas but can be switched to fuel oil when needed. Steam from the boilers is used to heat water in the heating system and the reheat system. Three steam to water heat exchangers serve the heating water system, with one of them serving as a backup. The heating water is circulated through the heat exchangers and AHUs by three 30 hp constant speed pumps. Steam from the boilers also serves a heat exchanger for the reheat water system. The reheat water is supplied by one steam to water heat exchanger and two 150 hp variable speed pumps. Figure 4 is a schematic of the heating water system.

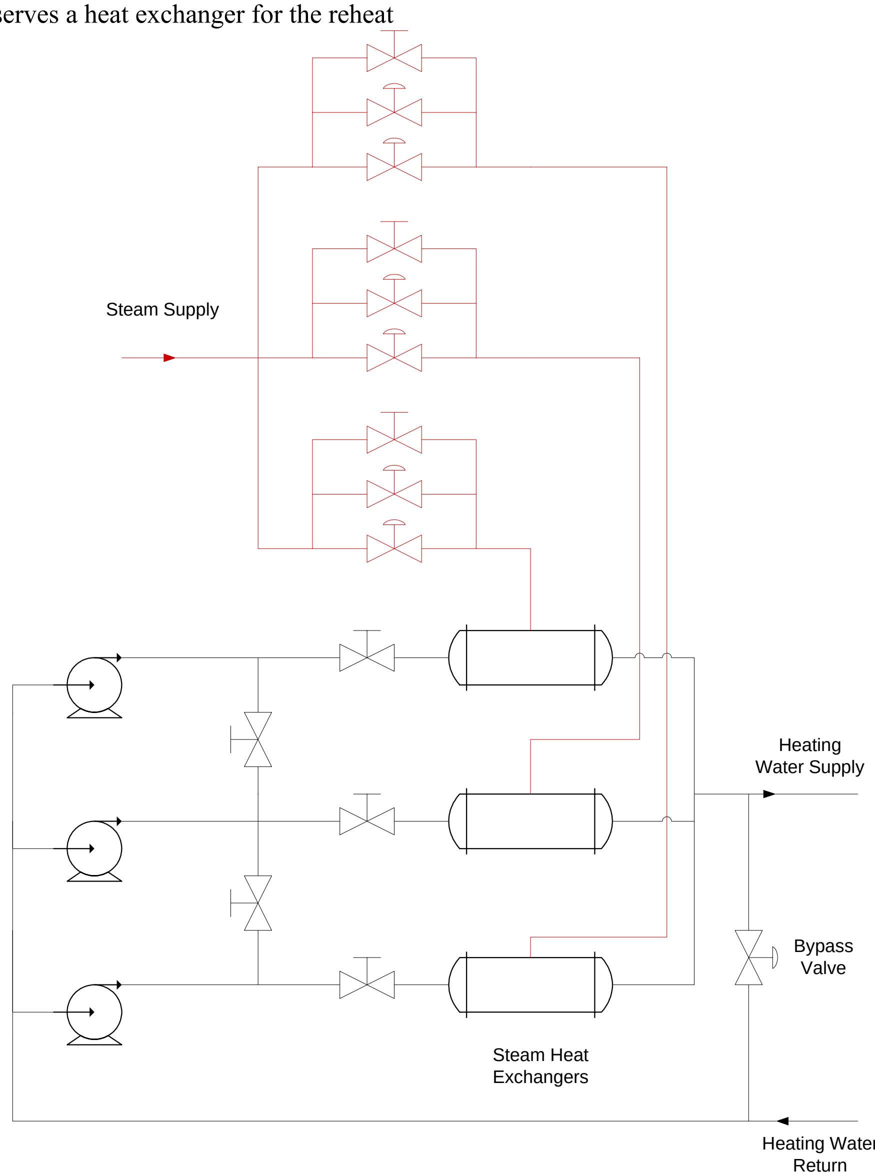

Figure 4. Schematic of the Heating Water System.

The building has an Energy Management Control System (EMCS) that monitor and control all the components of the building HVAC system.

PRE CC® OPERATING CONDITION

AHUs 1-9 use the same control sequence. The discharge air temperature sensor modulates the preheat valve and the cooling valve in sequence to maintain its adjustable setpoint. Each unit has up to four duct static pressure sensors. The supply fan VFDs modulate to maintain the lowest pressure reading at the setpoint. A temperature sensor at the discharge of the air-to-air heat exchanger modulates its face and bypass dampers to maintain setpoint. The heat exchangers have separate setpoints for winter and summer operation. AHU 10 controls its supply temperature and pressure the same way as the other AHUs. If the outside air enthalpy is higher than the return air enthalpy, the outside dampers are commanded to minimum and the return dampers are opened. If the return air enthalpy is higher than outside air enthalpy, the return dampers are closed and the outside dampers are opened.

Outside air for AHUs 1-9 enters through air to air heat exchangers. Incoming outside air can go directly into the AHU through a bypass or go across the heat exchanger. A set of dampers with pneumatic actuators controls how much air goes to the bypass and heat exchangers. In the heat exchanger, energy is transferred between the outside air and the leaving exhaust air. By keeping the air streams separate, there is no possibility of exhaust air contaminating the incoming air.

Each terminal box has a minimum and maximum airflow setpoint that was determined in the original design of the building. The airflow setpoint is raised or lowered to maintain the temperature in the room. The damper is then adjusted to maintain the airflow setpoint. For boxes that have reheat, the heating valve is opened when the airflow is at minimum and the room temperature is still below setpoint. The room temperature setpoint cannot be changed at the thermostat, it must be changed at the front end computer.

The three chillers were on a lead/lag sequence that stages them on and off as needed. However, there was always at least one chiller running even in the winter. When a chiller is commanded on, the corresponding chilled water and condenser water pumps are turned on. A bypass valve on the chilled water system is modulated to maintain the system differential pressure setpoint. Condenser water flows to all three cooling towers no matter how many chillers are running. The fans are staged to turn on and change speed to maintain the condenser water temperature at its setpoint. A bypass valve is opened when the water temperature is below setpoint and all fans are off.

All the heating water heat exchangers have pneumatic control valves on the steam pipes that adjust to maintain the supply temperature at their setpoints. The temperature setpoint for the heating water is on a reset schedule based on outside air temperature and ranges between 130°F and 175°F. When the outside temperature is below 45°F, two heat exchangers are used for the heating water system. Between 45°F and 50°F only one heat exchanger is used. When the outside temperature is above 50°F, the heating water system is turned off. A pneumatic bypass valve controls the differential pressure on the heating water system. The reheat system runs at all times and does not change according to outside air temperature. The temperature setpoint for the reheat system is 105°F constant. The variable speed pumps control system differential pressure, and the bypass valve is not used.

PROBLEMS IDENTIFIED

Static pressure setpoints for most AHUs were 2.4" or above. These setpoints were providing more pressure than necessary and could be reduced. One duct branch of AHU 4 was not able to reach its setpoint. This caused the fans to run at full speed all the time and caused some airflow problems in the lab areas.

By observing the temperatures in different parts of the AHUs, it was found that hot water valves in AHUs 5, 6, and 8 were not closing completely. The leaking hot water valves were making it necessary to use some chilled water during the winter. At least one chiller was running at all times.

The AHUs that use 100% outside air (AHUs 1-9) have air-to-air heat exchangers on them to recover some of the energy from the exhaust air. Entering outside air will either be routed directly into the AHU or through the heat exchanger depending on what is needed to maintain the temperature setpoint. Pneumatic actuators move the dampers open and closed to direct the airflow. When we first inspected these dampers, none of them were working. They were stuck in random positions and could not move. Figure 5 shows that the face dampers were only about 30% open when they were commanded to 100%. The dampers cannot open fully and the horizontal driving rod is warped from the strain put on it. The heat exchangers are an important part of the AHU system and when they do not work it increases the load on the cooling and heating system. In the summer of 2002, the building lost control of space conditions even though all three chillers were operating at full load.

Figure 5. Heat Exchanger Dampers in Original Condition (Fully Open).

AHU 10 has outside and return dampers instead of a heat exchanger. We found the outside dampers were stuck open and some of the linkages were broken.

An investigation into the terminal boxes revealed that many of the boxes were reading much lower than the actual flow. The problem was determined to be a buildup of dirt and dust that restricted airflow to the sensor. The incorrect readings were causing the boxes to allow more airflow than needed and in some cases to remain at 100% flow all the time. Extra airflow increases energy use by making the supply fans run faster and requiring more reheat water use. Also, the low pressure in one of the branches of AHU 4 was determined to be caused by most of the box dampers being open 100%.

A lead/lag sequence was used to determine when the load conditions required turning a new chiller on or off. The sequence allowed the operator to choose either chiller 1 or 3 as the lead chiller. Chiller 2 was always the first lag chiller to be turned on. This sequence caused chillers 1 and 3 to be run more than chiller 2.

The setpoint for the reheat water system was 105°F, which is too low during cold weather. It was discovered that the original design for the building called for the reheat system to use heat recovery from the chiller. Using a heat recovery system, the water can only be heated to 105°F. Since heat recovery was not used, the temperature could be raised. However, when the temperature in the reheat system was increased, it caused water to be released from the pressure relief valve. The system has an expansion tank that should be able to allow the water to heat up without causing the pressure relief valve to release. The expansion tank was investigated and found to have a leak, preventing it from regulating the system pressure.

CC® MEASURES IMPLEMENTED

<u>Air Handling Units</u>

All the AHUs have air temperature sensors for the discharge, heat exchanger discharge, preheat discharge, and outside. AHU 10 also has a return air temperature sensor and humidity sensors for return and outside air. All these sensor readings were compared to readings taken by ESL. If they were incorrect, an offset was given in the programming or it was replaced. Static pressure sensors are used to control the speed of the supply fans for all the units. Each AHU can have up to four static pressure sensors depending on the number of branches in the ducts. All the static pressure sensors were verified and adjusted as necessary by changing the zero and span.

When first inspected, the outside air dampers on AHU 10 were stuck. The dampers were repaired and adjusted so that they open fully and close to a minimum position. In addition to the existing enthalpy control, the economizer cycle was given an upper limit so it will not turn on when outside air is above 70°F.

The static pressure setpoints for some of the AHUs were higher than necessary. Lowering the static pressure reduces the speed of the supply fan, thus reducing electrical consumption. To determine the optimal setting, pressure measurements were taken at the boxes at the end of the ductwork. The setpoint was reduced until it was slightly above the amount need to operate the box. This process was done in the summer when the demand for air is the highest. As the outside air temperature decreases, the demand for air is reduced and the static pressure can be lowered further. Reset schedules were created for the static pressure setpoint based on the outside air temperature.

Reset schedules were also given for the discharge temperature setpoints based on outside air temperature.

Heating valves for AHUs 5, 6, and 8 were not working properly and allowed water to leak through. This leakage caused a need for chilled water all year long. The valves were repaired which allowed the chillers be turned off in cold weather.

Some residents living near the facility have been complaining about noise coming from the building. Studies have been conducted but they could not determine the cause of the noise. The CC® measures implemented on the building caused a reduction in the speed of the AHU fans and the outside air taken in. These reductions have caused a decrease in the noise coming from the building. The suspected source of the noise is AHU #4. Because of the airflow problems, the fans were running at 100% speed all the time. Once the box airflow measurement accuracy problem was resolved, the AHU #4 speed was reduced, and the noise level also reduced. The neighborhood citizens group noted the reduction in sound levels and reported their satisfaction to the facility manager.

Air-to-Air Heat Exchangers

The dampers for the heat exchangers were not working when the project began. They were all stuck in various stages of open and closed. The building maintenance personnel attempted to make them operational as originally intended. Some of the actuators were replaced or the pneumatic controls were adjusted. The dampers were lubricated and realigned in an attempt to make them move in the correct sequence. The operation of the dampers was much improved but they were never able to fully open and close. It was determined that a new mode of operation would be needed to get the largest possible benefit from the heat exchangers. The new method called for the dampers going to the heat exchanger to be disconnected from the driving shaft and left open permanently. With only the bypass dampers being driven, it was possible to align them so they could open and close completely. Now, the full effect of the heat exchangers can be used by closing the bypass dampers. When bypass is needed, the bypass dampers will open. Air will still go through the heat exchangers but some of the effect of the bypass will still be achieved. By fixing the face dampers fully open all the time, some energy is lost during mild seasons when the economizer (bypass dampers) should be in full operation. However, we also determined that the pressure drop through the bypass dampers was also higher than the pressure drop through the heat exchangers. Therefore, the loss of "free cooling" is just about offset by the increased fan power in full bypass mode. The poor heat exchanger design precluded any opportunity for the heat exchangers to work as designed, so the decision was to fix the dampers in the heat exchange mode.

Figure 6 is a picture of the dampers in their new configuration. The damper on the left side is a face damper. It is being held open by a bracket from the top and the driving rod has been disconnected. The damper in the middle is a bypass damper in the open position. There is no bracket holding it open and the driving rod is still connected.

Figure 6. Heat Exchanger Dampers in New Configuration.

The position of the bypass and heat exchange dampers was originally modulated to maintain a setpoint at the heat exchanger discharge. There were two setpoints for the discharge, one for summer mode and one for winter mode. A switchover setpoint was used to determine at what outside air temperature it changed between summer and winter modes. New programming was added to change the control of the dampers in the winter mode. The winter setpoint is now 1°F above the supply temperature setpoint and measured at the discharge of the unit. This allows the heat exchanger to take advantage of the new supply temperature reset schedule. The summer mode still controls to a constant setpoint of 73°F measured at the heat exchanger discharge. The switchover setpoint is 55°F.

Terminal Boxes

Many terminal box flow stations were reporting flows much lower than the actual flow. This problem was found to affect all AHUs with terminal boxes but especially AHU 4. The boxes for AHU 4 were opening their dampers much more than needed because of the improper flow reading. The boxes closest to the AHU were using very high amounts of air and that starved the far boxes of airflow. We found that blowing air through the sensors in the opposite direction of normal flow generally cleaned them out and made the sensors read correctly. The methodology used was a small "squeeze bulb" used to pressurize pneumatic thermostats. Several squeezes were usually enough to clean out the lines and/or clean out the small sensor used in the boxes. The procedure was repeated several times if it did not work the first time. This approach was not always 100% successfully, but it worked most of the time. Putting air filters in the tubing to the sensor will prevent the problem from occurring again. Several filters were tested for their effect on the flow reading. The ESL then purchased the filters and installed about 30 in the boxes. After verifying the boxes airflow was still giving correct readings after several months, a contractor was hired by the facility to blow out the sensors and put in filters for the terminal boxes.

Chilled Water System

The chilled water system was being used all year round. After the heating valves on the AHUs were repaired, there was no need for chilled water in cold weather. Running the system when it is not needed wastes electricity and it is bad for the chillers to run at low loads. A new sequence in the programming was added that turns off the chillers when the outside air temperature goes below 45°F.

Originally, only chiller 1 or 3 could be the lead chiller and 2 was always the first lag. Since in the cooler periods, only one chiller was required most of the time, chillers 1 and 3 were used much more than 2. In order to more evenly spread the load between the chillers, a new program was written that allows any of the chillers to be the lead.

Switching logic was used to control the speed of the cooling tower fans and the position of the bypass valve. The fans staged to higher or lower speeds based on the temperature of the condenser water. The bypass valve would open when condenser water was below 70°F and close when it was above 70°F. All the fan and valve setpoints were constant. The controls were changed so that everything would be controlled by a single setpoint. The setpoint for the condenser water is 8°F above the outside air wet bulb temperature with a minimum of 70°F and maximum of 85°F. Outside air temperature and humidity sensors are used in an equation to calculate the outside wet bulb temperature. The fans stage higher and lower depending on the difference between the setpoint and the condenser water temperature. The valve can now modulate so it will not cause sudden temperature changes.

Heating Water System

The original setpoint for the reheat water temperature was 105°F because the design called for heat recovery from the chillers. Since heat recovery was never implemented, the setpoint can be changed. A reset schedule based on outside air temperature was given to the reheat setpoint. The new setpoint will be 100°F when outside air is 60°F and 160°F when outside air is 10°F.

Investigation of the reheat system revealed that the expansion tank bladder had a leak and could not hold any pressure. The bladder was replaced by the building maintenance and now the system can change temperature without losing any water.

The differential pressure setpoint for the reheat system had a constant value of 15 psi. That was changed to a reset schedule based on outside air temperature. The differential pressure setpoint for the heating water system was also given a reset schedule based on outside air temperature.

SAVINGS FROM CC®

Savings were determined by analyzing data from the time some major CC® work had been completed (April 2004) until July 2006. The baseline model and outside air temperatures were used to predict what the electricity and gas usage would have been without CC®. Utility data from that same time period was compared to the baseline prediction to determine the energy savings. Figures 7 and 8 show the baselines for electricity and gas respectively as a function of outside air dry-bulb temperature along with data points taken before and after CC®. The total accumulated electricity saved between April 2004 and July 2006 is 11,212,000 kWh. Total gas savings for the same time period is 741,000 therms.

When the project began, utility rates were $0.087/kWh for electricity and $0.62/therm for gas. Since that time, rates have increased and the facility is currently paying $0.1193/kWh and $1.1654/therm. Savings estimates were made using two methods, the first was to assume the rates remained the same as original, and the second was using actual rates. Using the original utility rates, the total savings in this period amounts to $1,434,000. Of that total, electricity savings amount to $975,000 and gas savings are $459,000.

The cumulative savings from CC® calculated from the actual utility costs is given in Figure 9. The total accumulated savings amounts to $1,910,000.

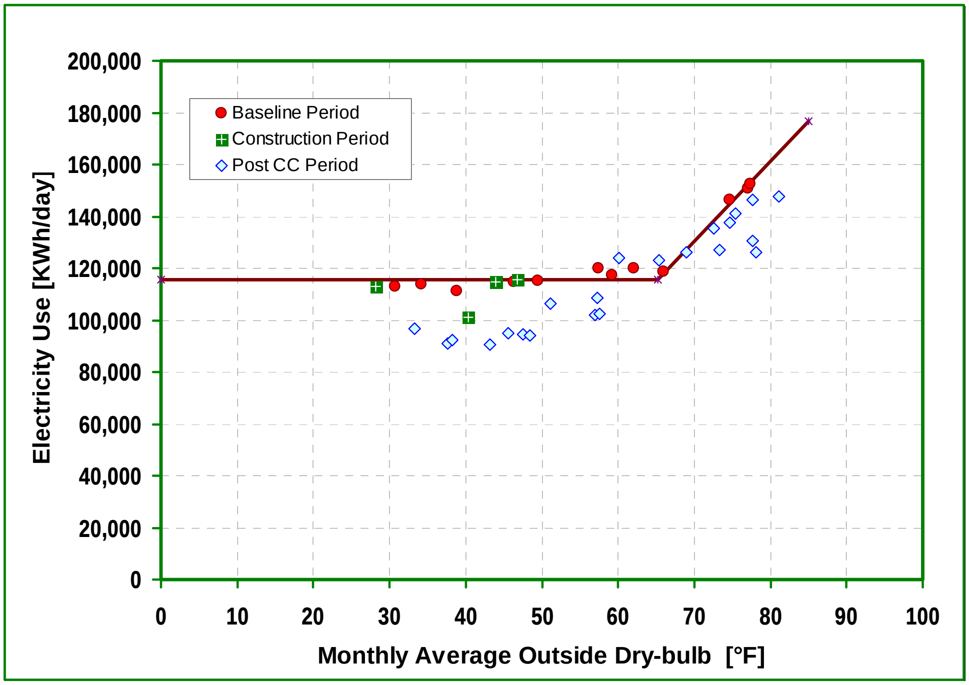

Figure 7. Pre-CC Electricity Use and Measured Electricity Use After CC.

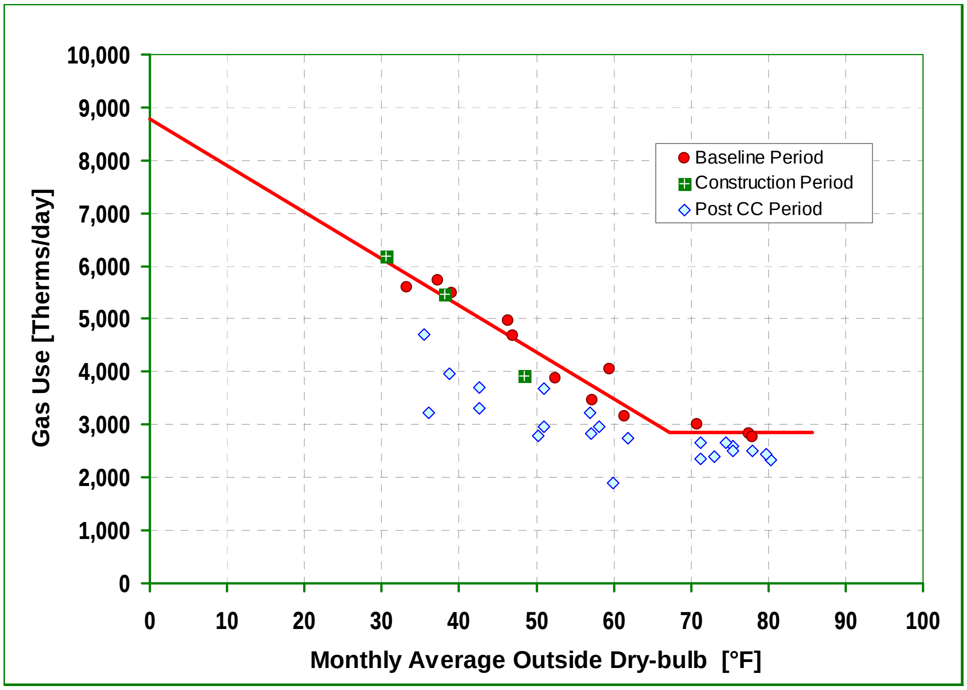

Figure 8. Pre-CC Gas Use and Measured Gas Use After CC.

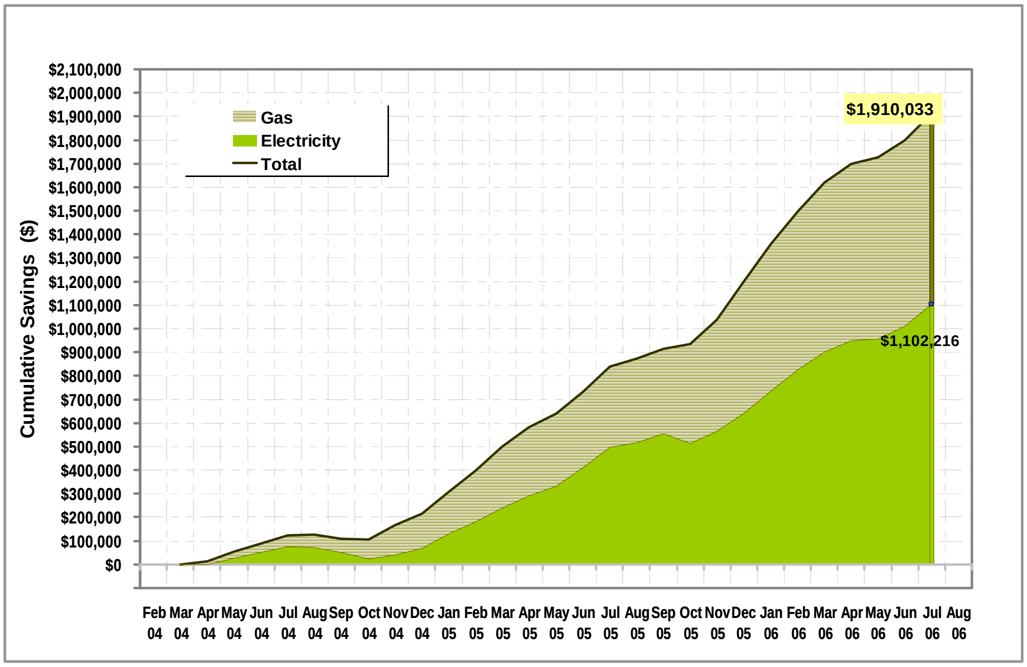

Figure 9. Cumulative Savings for the Facility Using Actual Utility Rates.

Conclusion

The Continuous Commissioning of a medical research facility has been presented above. Large reductions of energy use were achieved by correcting operation and maintenance problems and by optimizing control sequences. The energy requirements caused by high outside air usage were minimized by changing the operation of the air to air heat exchangers. Fan power was reduced by correcting the airflow readings in terminal boxes. Chiller efficiency was increased by optimizing control of the chillers and cooling towers.