ACHIEVING BETTER BUILDING PERFORMANCE AND SAVINGS USING OPTIMAL CONTROL STRATEGIES

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ABSTRACT
The Continuous Commissioning (CC[SM]) process has become a very important energy conservation topic for new and existing commercial buildings. This process can yield substantial operating savings, improved indoor air quality, and enhanced occupant comfort. It also provides solutions to reoccurring building maintenance problems. One tool that can be implemented during commissioning work is a near-optimal global set point method in an Energy Management Control System (EMCS) Direct Digital Controller (DDC). This algorithm is based on mathematical models for the chillers, boilers, chilled and hot water pumps, and air handler fans that relate the power of these components as a function of the chilled water and hot water differential temperature. The algorithm will minimize the total plant power consumption. These optimal control strategies make the CC process more effective. The Texas A&M University Systems State Headquarters is an office building, with a total floor area of approximately 123,960 ft^2. An integrated commissioning of the HVAC systems was performed for this building. This paper describes the commissioning activities and demonstrates how newly developed optimized control strategies improved the building comfort conditions and reduced utility costs during and after the commissioning period.

INTRODUCTION
The general purpose of Continuous Commissioning is to optimize a building's HVAC system and reduce energy consumption, while simultaneously not compromising occupant comfort (Claridge, etc. 2000a; Claridge 2000b; Deng, etc. 1998; Turner, etc. 2001). Continuous Commissioning achieves this by modifying existing EMCS based on optimal operation schedules and also by repairs of faulty HVAC components and equipment (Chen, etc. 2002). One of the newest and most effective methods of improving EMCS is by the implementation of near-optimal global set point control methods. Using global set point optimization greatly minimizes the total power consumption of the chillers, boilers, chilled water pumps, condenser water pump, hot water pump, and air handler fans while keeping building occupants satisfied and comfortable (Braun, etc. 1989a; Braun, etc. 1989b). This can be achieved by selecting the proper set points for chilled water supply, hot water supply, condenser water flow rate, variable speed pump differential pressure, and air handler fan static pressure. These systems can be set to respond appropriately to changing weather and building conditions, minimizing the building's operating cost. Proper tuning of these controls can result in an increase in comfort, reduction of energy, and an increase of component life (Cascia, 2000; ASHRAE 2003).

This paper presents the investigation and programming efforts at Texas A&M University System State Headquarters. In addition to regular commissioning rescheduling of the building's HVAC equipment, optimal control strategies were also implemented. The amount of global set point control strategies used is most often determined by the type of equipment used in the building. Motors, pumps, and fans with variable speed drives are essential for this type of energy saving strategy.

Figure 1: Front of State Headquarters

FACILITY INFORMATION
The State Headquarters, also known as the John B. Connally building, is headquarters of the Texas

A&M University System. It is located behind the Hilton Hotel and to the north of the main campus in College Station, Texas. This 123,960 square-foot building is comprised of a seven (7) stories and includes a detached plant building. The building serves as a business complex with numerous offices and conference rooms.

There are seventeen (17) single-duct, variable air volume (SDVAV) air handling units (AHU) with variable frequency drive (VFD), and two (2) VAV 100% outside air units. Each main SDVAV AHU has a pre-heat coil, a cooling coil, and one supply air fan. There are also 9 fan coil units (FCU) in the electrical rooms, mechanical penthouses, and several other locations. All the terminal VAV boxes (230) use hot water reheat coils and have supply air dampers, which are
DDC controlled.

The building plant provides chilled and heating water to the building. The plant consists of two 280-ton York centrifugal chillers and one 30-ton air-cooled McQuay chiller. Only one of the 280-ton chillers is needed to meet the maximum cooling requirements of the building during occupied hours. The second 280-ton chiller is for redundancy in case one chiller experiences mechanical failure. The 30-ton air-cooled McQuay chiller (Chiller #3) is used primarily to cool the building during unoccupied hours and when the building cooling load is low. Along with the chillers there are also three (3) parallel chilled water pumps (2×20 hp and 1x1.5 hp) and two (2) parallel heating water pumps (2×5 hp). The chilled water pumps operate at different times. The only time the smaller (1.5 hp) pump operates is when chiller 3 is running. The large pumps only operate when their associated chiller is on as well. All the pumps within the headquarters are constant speed control. A schematic for the chilled water system is provided in Figure 2.

There are two cooling towers, each with 840 GPM as condenser water flow. The towers each have a 15 hp fan that is controlled by a VFD device. Figure 3 shows the condenser water schematic. The towers are dependant on what chillers are running, and can run simultaneously, individually, or off. When chiller 1 is in operation tower 1 will also be in operation. The same is true for tower #2 in relation to chiller #2. Operation of chiller #3 alone requires no tower.

Also within the plant there are two parallel boilers. Each of the boilers is gas fired with an input capacity of 2000 MBH and an output capacity of 1600 MBH. A schematic for the hot water system is provided in Figure 4.

BUILDING ENERGY ANALYSIS

Base Year Energy Consumption

The metered electricity and gas for fiscal year 2002 (August, 2001 through August 2002) was used as baseline year energy consumption. The total annual electric electricity consumption and cost is about 2,879,280 kWh and $162,980.33 respectively. Figure 4 shows the whole building electric consumption for fiscal year 2002. The month consumption range is from 203,760 to 291,360 kWh. The average monthly value is 239,940 kWh (or 1.94 kWh per month and per square feet).

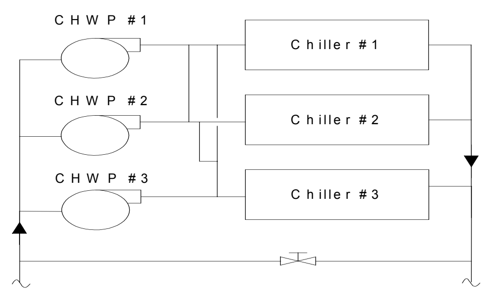

Figure 2: Chilled Water Schematic

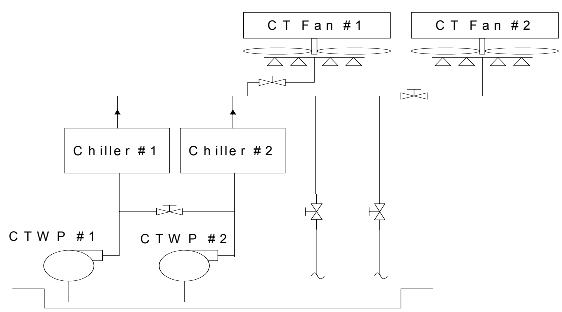

Figure 3: Condenser Water Schematic

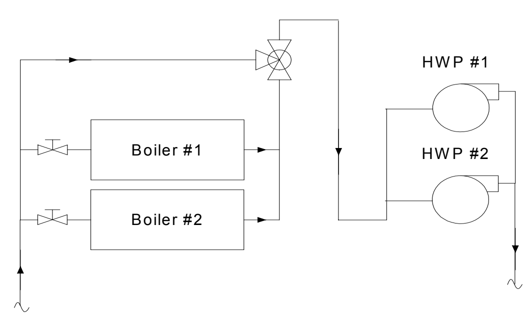

Figure 4: Heating Water Schematic

The annual gas consumption is about 4,096 MMBtu. Figure 5 shows the whole building gas consumption for the fiscal year 2002. The month consumption range is from 239 to 477 MMBtu. The average monthly value is 341 MMBtu (or 3.8 Btu per hour and per square feet).

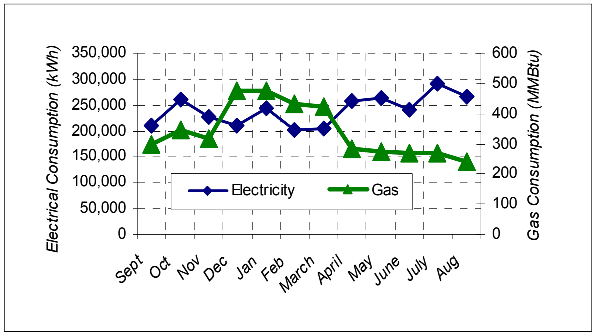

Figure 5: Annual building electricity and gas consumption for the 2002 fiscal year.

Demand Charge

Bill data analysis and information from the City of College Station Electric Utility show that the building is classified as a "Large Commercial" building because it has a demand between 300 kW –1500 kW. Under the classification of "Large Commercial" the demand charge is $8.44 /kW.

Consumption charge is based on building classification and does not work on a tier or rate schedule. There are no seasonal rate changes and no on-peak hours for demand and consumption charges. The monthly demand value was based on the maximum number of all the 15-minute interval data for each month. The annual demand patter shows that the demand was higher (712 kW) in summer and lower (472kW) in the winter. The average value was found to be 567 kW.

Energy Use Profile

The measured hourly data was used to develop typical day profiles (i.e. weekly, weekend, daily, and seasonal profiles). These day profiles are basic for identifying energy usage, energy use pattern, and potential savings. The most important purpose of the identification process is to optimize the building and chiller plant's energy consumption.

Figure 6 below shows the average energy consumption pattern for both weekdays and weekends. There is an obvious increase in energy demand between the hours of 8am and 5pm that correspond to the normal working office hours for the building personnel. Office energy consumption is determined by the summation of all office equipment (including all of the AHUs).

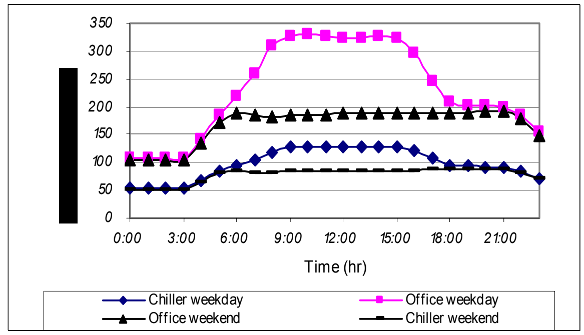

Figure 6: The average energy use for State Headquarters' office building and chiller on a day during the weekday and weekend (Sept 2001 through Aug 2002).

It can be seen that some AHUs were operating during the weekend. There is also some evidence of other equipment running such as computers, refrigerators and other office type appliances. The average energy use per day during the weekend for the chiller part shows that it was running at 48% of its capacity. During the weekend the amount of energy used by the chiller decreased. This is due to a decrease in the building-cooling load. It can also be determined that during the weekend chiller #3 is the primary chiller.

The building energy use profiles (daily and seasonal energy use) show that electricity and gas consumption (Figure 5) vary with day (day mode, night, and weekend mode) and different seasons. The building energy use is affected by outside air temperature and the building's schedule.

This analysis indicates that the best determinate of office building and chiller energy use, is the building schedule and office temperature that is maintained within the space. Thermostat control (day and night settings for cooling and heating within the terminal electronic controller) is also important.

Demand Distribution

A detailed breakdown of energy use for the building would require assessing HVAC load distributions. This is outside the scope of this project, so brief and simplified analysis was performed.

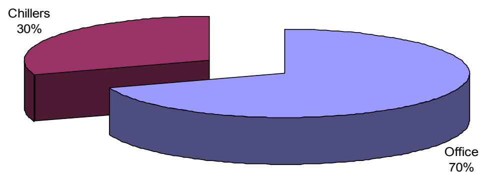

Figure 7: Demand distributions for chillers and office building

From the demand distribution of Figures 7~8, chiller energy consumption to the whole building is about 30% based on measured data, and chiller energy use to operating HAVC equipment consumption is 42.5% based on design data. The chiller energy use is the largest component. The ratio order for independent energy use to all the HVAC equipment is chiller, AHUs, terminal VAV boxes, fan coil units, chilled water pump, condenser water pump, tower fan and exhaust fans. Each equipment with higher energy consumption will in turn exhibit a higher amount of the utility bill for the building.

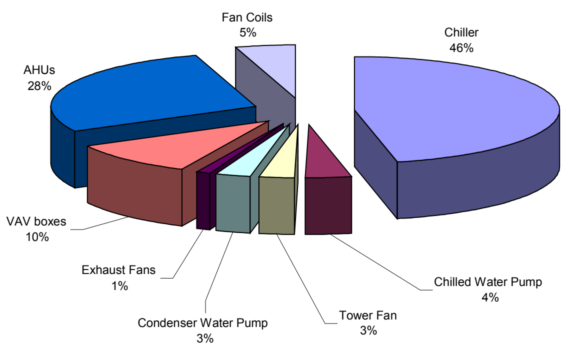

Figure 8: Energy use distribution for different HVAC equipment

COMMISSIONING ACTIVITIES

Pre-CC Chiller Plant Control

The chiller plant is made up of three water chillers. Two of the chillers (chiller #1and #2) have a 280 ton capacity and are the main chillers for the building. There is also a third 30 ton chiller used during low demand periods. Chillers #1 and #2 have their own chilled water pump, condenser water pump, and cooling tower. Chiller #3 only runs if the tonnage on either chiller #1 and #2 becomes less than or equal to 20 tons for a certain length of time and there are three or less AHUs operating in the building. The building must also be in unoccupied mode. The chilled water supply temperature is adjustable and was manually set to 42°F. The condenser water supply temperature was also manually set. The difference between actual condenser temperature and the setpoint temperature is used to control the cooling tower fan and the cooling tower dump valve. A manually set control program sets the discharge static pressure for the AHUs to 1” H_2O. The discharge AHU discharge temperature is set by a linear relationship between the highest room temperature controlled by that unit and the desired AHU discharge air temperature setpoint. Detailed information is presented in Table #2.

Problem Identified

It was found that all chillers and boilers were manual or local control. Some equipment characteristics (such as fan speed and valve position) were set to operate at a constant value all of the time, even though they could be remotely controlled. Normally, the local controller cannot operate HVAC equipment at a high efficiency and save energy as well as DDC controlled HVAC equipment. The chillers and boilers need to be updated to DDC control. Table 2 lists the identification and recommendations.

It was also found that chilled water temperature set points were based on local programs. The set point settings were not based on actual building cooling load and the chiller plant’s optimization. Optimizing chilled water temperature is necessary for the building. The optimization requires the use of a mathematical model representing power versus chilled water differential temperature for each chiller, chilled water pump, and AHUs in the building (Braun, etc. 1989a; Braun, etc. 1989b; Braun, etc. 1990; Cascia, 2000).

All the pumps currently operate at constant speed all the time. These water pumps serve the existing chilled water system, condenser water system and hot water system. The water systems will not work properly without the capacity for automatic modulation of water flow or DP in response to varying load conditions. AVFD will significantly reduce the consumption and cost of utilities for State Headquarters. A VFD was recommended, but the building proctor did not agree with VFD installation due to budget constraints.

The condenser water supply temperature setpoint and the AHU discharge static pressure setpoint were also set to a fixed value. Most of the AHU discharge temperature setpoints did not respond to the actual load well. Field survey found that any changes in the duct static pressure setpoints for several AHUs did not affect the VFD speed.

The chiller capacity was based on the seasonal distribution of extreme temperature and humidity (1, 2.5, and 5% frequency of occurrence during summer). The building load varies with the weather temperature data the actual building load is much lower than the chiller's capacity most of the year. The measured data showed that existing chiller's efficiency was lower than 50% most of the time.

The majority of the time an inappropriate building bypass valve control problem resulted in was as low a DT of 3 F between the chilled water supply and return.

The hot water and the domestic hot water boilers each had local controllers for the water temperature set point. An update from the local control to a remote DDC control for the hot water and the domestic hot water boilers is needed and was recommended.

The existing AHU schedule was on from 5:00 am to 11:30 and off during any other time. However, the building is normally only occupied between 8:00 am until 5:00 pm. Since the AHUs keep working during this time, the chiller, chilled water pump, condenser water pump and tower are also required to keep working. The building needs a better optimized schedule to reduce energy consumption cost.

The major problems identified from the field measurements were a) sump level or make-up water control from local control device, b) not reliable dump valve #2, c) failed two-way isolation valve and three-way mixing valve both for hot water boiler, and several bad motors in terminal VAV boxes, etc.

New Control Schemes (Chiller Plant Optimization) and Other CC Measures

The objectives of the CC work are to improve building comfort and reduce operational and energy costs. These objectives will be achieved through the installation and commissioning of the new EMCS and through the engineers' expertise in this field. The scope of work will include the following tasks listed below in the Table 2.

1. *Optimal Chilled Water Supply Temperature Reset*

The purpose of this strategy is to minimize the summation of chiller power, chilled water pump power, and air handler fan power by operating the chillers with optimum chilled water supply temperature set points. The total system power is first mathematically modeled as a sum of chiller power, chilled water pump power, and central air handler fan power as a function of chilled water supply/return differential temperature. At each load step the coefficients of the plant power model are re-evaluated to account for efficiency differences in equipment. DEMs (Digital Energy Monitors) are used to measure the KW draw from the chillers, the chilled water pumps, and the AHU fans. Chilled water reset points for chillers 1 & 2 were added to the Siemens panels to aid in the chilled water reset. Additionally, the building bypass valve modulates to maintain the chilled water DP set point based on chilled water valve position.

2. *Optimal AHU Discharge Air Temperature Setpoints*

Using the optimum chilled water delta T, an energy balance analysis will be conducted across the AHU cooling coils. The chilled water flow through each cooling coil and the airflow blowing across each coil will be used to determine the set points. It is imperative that these set points not violate high or low limits; if violation should occur the set points will be assigned low and high values.

3. *Optimal AHU Static Pressure Setpoints*

New static pressure reset schedules will be implemented on each AHU. The maximum operating static pressure will be found using the values found under full cooling for the box with the highest requirement. Accordingly, the static pressure the VAV box with the highest cooling demand will be used as the basis for the reset. This will be done by commanding all of the boxes for a particular AHU to full cooling, through the use of the DDC system, then identifying the positions and airflow for each box. If, when in full cooling, the boxes are open at relatively low percentages, the static pressure will be reduced at the AHU until one of the boxes is open at least 90%.

4. *Optimal Cooling Tower Air Flow*

In order to reduce the power consumed by the tower-chiller combination the optimal cooling tower air flow is calculated. The specified high and low limits for exit water temperature must also be maintained. The optimum air flow through the tower will be a percentage of the maximum total air flow through the tower. The resulting Condenser supply temperature will be the optimal condenser water supply temperature.

5. The schedules for the AHUs , FCUs, and exhaust fans (based on the day, night , and weekend schedules for the building) were developed for reducing total energy cost. The new schedules (for the AHUs , FCUs, and exhaust fans) are designed to

maintain a positive DP constantly, therefore not violating the air balance.

6. An economizer cycle and a CO_2 sensor were both recommended for the outside airflow control. The two outside AHU fan speeds will be based on the building's CO_2 level.

7. The set points for each terminal VAV boxes were reset. The new set points were adjusted as follows:

- The net minimum and maximum airflow that is required for all of the offices' load conditions.
- The day and night temperature set points were increased.
- Override time and switch dead band's adjustment, etc.

8. The measured data indicated that chiller #2 was operating at 120 tons or less 97.6% of the time. This indicated that the chiller was running very inefficiently since it is a 280 ton chiller.
Chiller #3 was intended to serve the building during off-peak and unoccupied hours. While doing commissioning investigations, it was determined that the 30-ton-air-cooled McQuay chiller was undersized for its intended application and was often offline because of mechanical problems. As a result, one of the 280-tons chillers would be called upon to provide cooling for the building under low load conditions. Because of the low load level, low load alarms would be tripped since serious damage could be done to the chillers.

As a result of this investigation, the purchase of a 120-ton chiller that will operate during "off-peak" seasons and during building unoccupied times was proposed. Besides replacing chiller #3, this chiller will operate more efficiently since it was designed to operate at 120-tons. This will greatly minimize energy consumption and expand chillers' #1 and #2 lifetimes.

SAVINGS ANALYSIS

Baseline Model

A statistical model was developed to examine how annual office building energy consumption and chiller energy use varied with physical parameters. Influence on the demand was expected. Based on energy consumption and weather data of FY 2001-2002, two three-parameter regression models and one four-parameter model (electricity and gas) were developed by using an E-model program (Energy Systems Laboratory, 1993). These baseline models and post-CC weather data were used to project post-CC energy consumption. Table 1 shows the monthly baseline models for electricity and gas energy consumption.

Table 1: Monthly Baseline Models

Item	Model	Statistical Parameter
Electricity (kWh)	48537.4+1967(temp-58.8) OA temp>58.4F 218537.4 OA temp ≤ 58.8F	R^2=0.8 CV-RMSE=9.5%
Demand (kW)	521.5 +12.3(temp-71.5) OA temp>71.5F 521.5 - 0.49(temp-71.5) OA temp≤ 71.5F	R^2=0.6 CV-RMSE=11.9%
Gas	268.5 OA temp>74.2F 268.5-84 (temp-74.2) OA temp ≤74.2F	R^2=0.9 CV-RMSE=8.5%

Savings Calculation and Analysis

Electricity

An electricity baseline model was used to calculate a relationship for energy consumption after most of CC measures were completed. Figure 9 shows an electricity consumption (time-series) comparison of Pre-CC and the projected bill for Post-CC with respect to the current electricity bill. Figure 10 represents Electricity Consumption vs. Temperature for Pre-CC and projected Post-CC to current bill. Pre-CC electricity consumption was represented by using a bold bar (Figure 9) and a line with diamond symbols in Figure 10. Current bill was indicated by a light colored bar in the Figure 9 and a line with a square sign in the Figure 10. The line with triangle symbol shows projected data for Post-CC in both Figures 9~10.

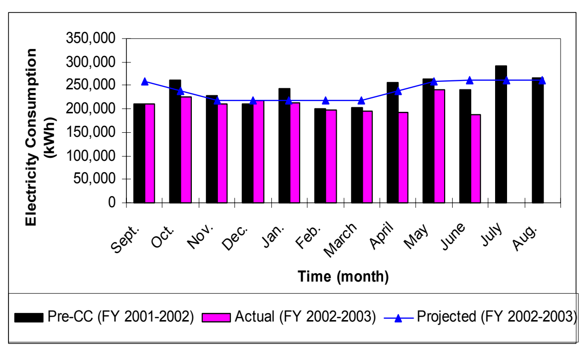

Figure 9: Electricity Consumption (Time-series) comparison of Pre-CC and projected Post-CC to current bill.

Figure 9 is a comparison for Pre-CC, projected, and current bill. Figure 10 is a comparison with electricity vs. temperature. It is obvious that Pre-CC electricity consumption was higher than the current bill, and the current bill was less than projected the

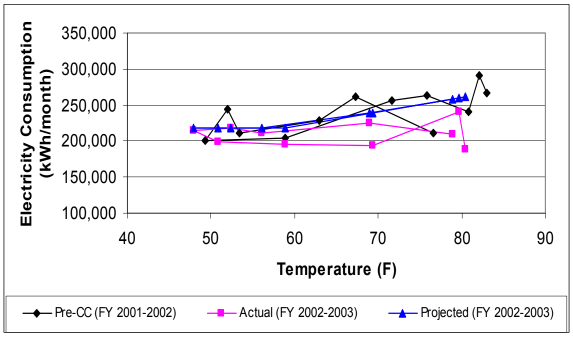

Figure 10: Electricity Consumption vs. Temperature comparison of Pre-CC and projected Post-CC to current bill

monthly data. Particularly, CC measures were carried out for chillers, AHUs, and condenser towers since January 2003. The period of September 2002 and December 2002 consisted of investigation and troubleshooting. The difference between the projected Post-CC data and the current bill is savings. Figure 10 shows the electricity savings for 2003. The current electricity bill extends to June 2003. The savings for each figure steadily goes up throughout the time period. The electrical savings alone ranges from 9% ($783 reduction) in February 2003 to 28 % ($2886 reduction) in June 2003. It is obvious that actual or current electricity and gas bills decreased with time because more CC measures have been effective within the building.

Demand Bill

Figure 11 shows the electricity demand (time-series) comparison of Pre-CC, the projected bill for Post-CC, and current electricity demand. Figure 12 is Electricity Demand vs. Temperature of Pre-CC and projected Post-CC to current bill. The representative lines, bars, and signs in Figure 11~12 are same as in Figures 9~10. The demand savings was 17 kW ($143.48) in February and 56 kW ($472.64) in June 2003.

Gas Consumption

Figure 13 shows gas consumption (time-series) of Pre-CC, the projected bill for Post-CC, and current gas bill. Figure 14 shows Gas Consumption vs. Temperature of Pre-CC and projected Post-CC to current bill. All of the representative lines, bars, and signs in Figures 13~14 are same as in Figures 9~10.

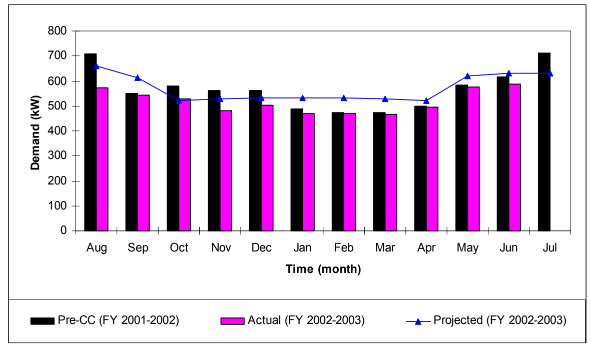

Figure 11: Electricity Demand (Time-series) comparison of Pre-CC and projected Post-CC to current demand

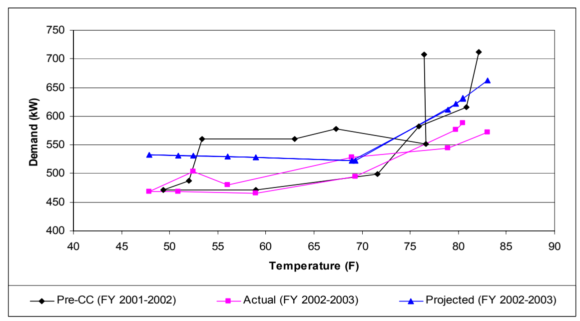

Figure 12: Electricity Demand vs. Temperature of Pre-CC and projected Post-CC to current demand

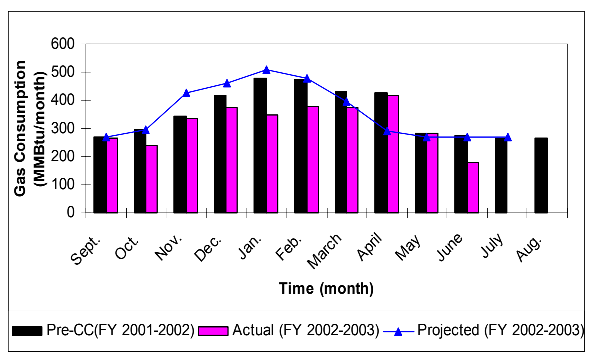

Figure 13: Gas Consumption (Time-series) of Pre-CC and projected Post-CC to current bill

Figures 13~14 show a comparison of the projected gas bill, based on gas baseline models and weather data to the current gas bill. The difference between current bill and the projected data is savings. The current gas bill extends to May 2003. The highest gas savings is in January 2003 at almost 33%.

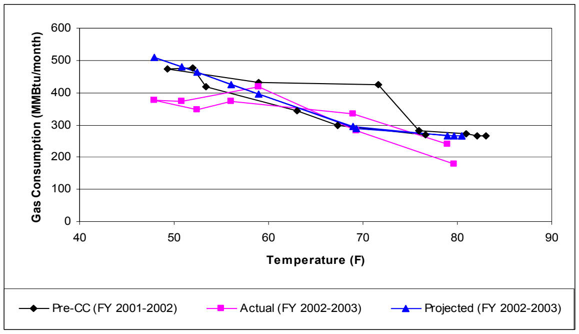

Figure 14: Gas Consumption vs. Temperature of Pre-CC and projected Post-CC to current bill

Figures 13~14 show a comparison of the projected gas bill, based on gas baseline models and weather data to the current gas bill. The difference between current bill and the projected data is savings. The current gas bill extends to May 2003. The highest gas savings is in January 2003 at almost 33%.

The current bill and projected data patterns in the above figures show that savings has been increasing because CC measures were carried out in the building step by step with time. More savings from electricity and gas is expected after all of the CC measures take effect within the building. The CC measurements for the chillers, towers, terminal VAV boxes, schedules on AHUs, and exhaust fan were carried out first in spring of 2003. The CC measures for the boilers were carried out in March 2003. These figures show that gas savings were not as prevalent early as the electric savings, due to the reason stated previously.

Briefly these CC measures are as follows:

- Some local or manual controls were updated to DDC remote control.
- Releasing some control points after modifying the building control program, which restored automatic control from local or manual control.
- Constructing an optimal operation schedule for AHUs, FCUs, exhaust fans, chillers and pumps.
- Setting optimal set points for terminal VAV boxes, boilers, AHUs, chillers and condenser tower.

CC is currently having an effect within the building except, there still needs to be further adjusting and modifying for an optimized chilled plant. Once all of the CC measures are completed throughout the building, the savings will be higher than what can be seen now.

Proposal New Chiller Installation

Figure 15 compares the daily KWh for the 280-ton chiller with the estimated daily KWh for the 120-ton chiller. By utilizing the 120-ton chiller during these times, the daily KWh consumption could have been reduced. This reduction in KWh consumption would lead to a daily savings of approximately $111. The estimated yearly savings would be $39,985. The cost and installation of the 120-ton chiller is estimated to be approximately $75,000. If the 120-ton chiller were to be utilized, the estimated payback time would be approximately 1.88 years, therefore, it is recommended that a 120-Ton chiller replace the existing 30-Ton chiller #3.

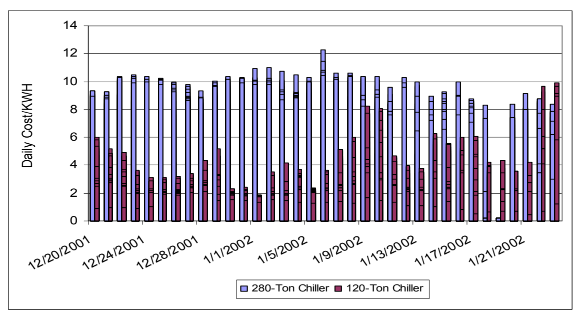

Figure 15: Cost Comparison of Existing 280-ton Chiller to Proposed 120-ton Chiller

Table 2: Energy Cost Reduction Measure (ECRM) Investigation, Analysis and Current CC Status

Item	Demand (kW/HP)	Original design sequences of operation	Pre-CC sequence of operation	CC measures and recommendation	Current CC status
Chiller #1 or #2 (centrifugal chillers)	190 kW for each chiller (280 tonnage)	Local controls. If the lead centrifugal chiller system is equal to the full capacity of that chiller, the lag system will be energized. After the minimum on time has expired, the lag chiller will be de-energized, when the load is less than 40% of the capacity of the lead chiller.	Either chilled #1 or chiller #2 is needed to carry the entire cooling load whenever the AHUs start operating; Reduce the compressor-motor kW input by adjusting the temperature control set point. The local controller controls the chilled water temperature set point.	Update the original set point from a local control to a DDC remote controller; Chilled water reset with optimal supervisory override. This should be controlled by the cooling plant optimization package (CPOP) software	DDC remote control. An optimal chilled water temperature set point is reset by CPOP. Further modification for the optimal set point reset is needed.

Table 2 cont.: Energy Cost Reduction Measure (ECRM) Investigation, Analysis and Current CC Status

Item	Demand (kW/HP)	Original design sequences of operation	Pre-CC sequence of operation	CC measures and recommendation	Current CC status
Chiller #3 (air cool centrifugal chiller)	44 kW (32 tonnage)	It was local control. When there are less than 3 air handling units operating, or supply water temperature is 50° F or less, chiller 3 will be energized.	This chiller will run only if the tonnage on either chillers (#1 or #2) becomes less than or equal to 20 tons for a certain length of time and if there are 3 or less AHUs running within the building. The building must also be in the unoccupied mode. The chiller is set to maintain a local chilled water supply temperature.	Update the local control to a DDC remote controller; Chilled water reset with optimal supervisory override should be controlled by CPOP software.	DDC remote control. An optimal chilled water temperature set point is reset by CPOP. Further modification for the optimal set point reset is needed.
Building bypass valve		A differential pressure (DP) will control the differential system bypass valve to maintain a DP set point.	Modulated to maintain a DP set point of 25 psi whenever chiller #1 or chiller #2 was on, and 15 psi whenever chiller #3 was on.	The DP set point is supposed to protect the chiller's operation and to satisfy all of the AHUs' requirements. Use CPOP to optimize the DP set point	The program for the DP optimization has been completed, but it needs to be modified further.
Chilled water and condenser water pumps	20 hp (chilled water pump) and 15 HP (condenser water pump)	If one of chillers was on, its associated pumps will be on. All of the pumps are constant speed control.	Same as the original design.	A VFD was recommended for the future tasks	There is no variable frequency drive (VFD) conversion due to budget restrictions.
Tower fans	15 HP for each	When a chiller condenser water pump is energized, the respective cooling tower fan will be on. The chiller condenser water supply sensor will control the speed of the fan to maintain 75° F condenser water supply temperature.	The condenser water supply temperature set point is set by the plant operators; If the difference between the actual condenser water temperature and the condenser water setpoint is maintained at a high level for a certain length of time, the respective cooling tower fan will come on. The speed of the cooling tower fan is modulated based on the magnitude of this difference. This difference is also used to modulate the corresponding cooling tower dump valve.	Optimum tower fan control: optima tower airflow by CPOP	Adjusting the optimal program is in process
Hot water boiler #1 or #2 (gas fired boilers)	Output/input: 1600/2000 (MMBtu/MMBtu); 190/150 (F/F);	Anytime any air-handling unit is energized or if the outside air temperature is less than 55° F, the hot water system will be energized. The lead hot water pump will start & the lead boilers' isolation valve will open on a drop to 35° F. The lag boiler and pump will be energized, and the lag isolation valve will open. Temperature sensor will control the 3-way mixing valve as required to maintain supply in accordance with the reset schedule.	Controlled locally with an operator control aquastat which is backed up with a high limit aquastat, a low water cut off relay and a high fire control. The local reset point was 180°F constantly; Two isolation valves failed to control the boilers; The three-way mixing valve for the boiler did not function properly;	Install relay in series with the operator control aquastat. Setup both setpoints and schedule for the boiler control while maintaining the safe operation logic. The setpoint will be effective in the range between ambient temperature and the operator control setpoint. Repair or replace failed components.	Updating from local control to remote DDC has not yet begun. All of the isolation valves were fixed. A new three-way mixing valve was ordered.
Hot water pump #1 and # 2	5 HP for each pump		Pump #1 failed to operate	Repair pump # 1; A VFD was recommended.	In progress
Discharge set points (Temperature and static pressure) for 17 AHUs	Total 145 HP (VFD control)	Once energized, the outside air damper will be allowed to open and the sensor will control the chilled water valve as required to maintain the set point. The space sensor requiring the most cooling will reset the discharge set point. A static sensor will control the fan speed to the maintain duct static set point.	Discharge temperature setpoints: determined by using table statements which form a linear relation between the highest room temperature served by a particular AHU and the desired AHU discharge temperature setpoint; Discharge static pressure setpoints: set 1" WG manually for all of the AHUs in the control program.	Discharge air temperature and static pressure optimization need to be based on the CPOP.	Optimization completed, but further modification is still needed.

Table 2 cont.: Energy Cost Reduction Measure (ECRM) Investigation, Analysis and Current CC Status

Item	Demand (kW/HP)	Original design sequences of operation	Pre-CC sequence of operation	CC measures and recommendation	Current CC status
2 Outside air AHUs	3 HP for each unit. These two Outside air AHUs provide outside airflow to entire building.	These units will be started and stopped by its respective DDC panel during occupancy time provided one of its associated air handling units is operating. A static sensor will control the fan speed to maintain the static pressure set point.	2 Outside air AHUs run at full speed.	An economizer cycle and a $C0_2$ sensor need to be installed. Outside air AHU fan speed will be based on the building's CO_2 level	Not yet completed
Schedule control for 17 AHUs	Total 145 HP (VFD control)	These units' supply fans will be started and stopped by its' respective DDC panel.	It was running from around 5:00 am – 11:59 pm during the week and weekend.	During unoccupied time, all of the AHUs are supposed to be shut down unless some one activates the override switch. Day time run: Monday: 5:30 am 8:00 pm; Tue ~Fri: 6:00 am 8:00 pm; Night time shut down: Monday: 8:00 pm ~ 5:30 am; Tue. ~ Fri: 8:00 pm ~ 6:00 am Weekend: Shut down During unoccupied time, room temperature will automatically maintain the range of 65 F to 85 F and the minimum airflow will reset to "0" cfm.	Completed
Schedule control for the following fan coil units: FC –3 FC –4 FC –5 FC –6 FC –7 FC –8	Total 4 HP (The purpose of these units is to cool the stairwell)	During occupied mode the supply fan will run continuously. Space sensor will modulate the chilled water supply in sequence with staging the electric duct heat to maintain temperature within the space.	They were running all of the time	These FCUs were on all of the time. Schedule needs to be modified based on day, night, and weekend mode. Day running mode: Monday: 5:30 am 8:00 pm; Tue ~Fri: 6:00 am 8:00 pm; Night shut down mode: Monday: 8:00 pm ~ 5:30 am; Tue. ~ Fri: 8:00 pm ~ 6:00 am Weekend: shut down	Completed
Schedule control for the following exhaust fans: EF – 5 EF – 9 EF - 10	Total 3 HP	These fans will be energized during the occupancy period. High limit thermostat will de-energize the fans if a high temperature is detected.	These exhaust fans were on all of the time. They serve the locker & toilet room	Schedule needs to be modified based on day, night, and weekend mode.	Completed
Domestic hot water system	The domestic hot water system currently consists of a 300 gallon gas fired heater and a 1/3 hp circulating pump.	Local control based on boiler set point.	At one time the pump was on a timer but that has been bypassed at this point. It appears that the water heater has been operating solely with its built in operating TSTATS.	Install relay in series with the operator control aquastat. Setup both setpoints and schedule for boiler control while maintaining the safe operation logic. The setpoint will be effective in the range between ambient temperature and the operator control setpoint.	Not yet Completed
Terminal VAV Box (230 VAV boxes)	Total 42.25 kW	During the occupied mode, the VAV box fan will run continuously and the space sensor will reset the box controller and control the re-heat control valve to maintain space temperatures. In the unoccupied mode, the cooling set point will be increased while the heating set point is decreased.	The day cooling setpoint was 70 ~ 72° F; The day heating setpoint was 70° F Switch dead band: 1 F;	Reset set points for cooling, heating, mode, switch dead band, override time, etc.	Completed
Night cooling set point for FC – 1, FC – 2 and FC – 9	These three FCs serve computer labs	Space sensor will cycle the supply fan in sequence with modulating the chilled water valve to maintain space temperature at set point.	The set point during the day for cooling was 72 F and at night the set point was 85 F.	Day and night settings are different in these computer labs.	Completed

CONCLUSIONS

Optimal setpoint technology was used at Texas A&M University's State Headquarters Building. This energy saving technique, which has been under development over the last fifteen years (Braun, etc. 1987), is a great way to minimize energy consumption while maintaining comfort. The three chillers, which were previously locally controlled, have been set up as a remote DDC control and a cooling plant optimization package (CPOP) was developed along with a new equipment operation schedule for the entire building. With energy bills reaching close to 300,000 kWh per month, this energy saving method will be sure to save in the building operating costs.

Field studies also indicated the need to replace some of the equipment, particularly in the case of chiller #3. It was determined that a new chiller needed to be purchase in the size range of chiller two and chiller three. Chiller #2 was used very inefficiently 97.6% of the time and with 30% of the energy consumption coming from this equipment alone, a small, more efficient chiller will be cost effective.

The purchase of a new chiller along with a new equipment schedule, the implementation of global optimal set point methodology, and the installment of DDC controls for the two boilers are sure to make this building more comfortable and provide better energy savings for the building.

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