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A Twelve-Year, $10 Million Energy Initiative Marching on: the Texas A&M University Campus Energy Systems CC®

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ABSTRACT: The $58.5 million in measured savings for the twelve-year, $10 million continuous commissioning®[1] (CC®) program at the Texas A&M University (TAMU) makes the decision to continue easy. In today's energy environment and with the volatilities and uncertainties of the utilities market, successfully managing a dynamic energy management initiative is an instrumental and challenging priority on any campus. The TAMU project closely involves continuous commissioning of one hundred and fifty (150) major campus buildings, four (4) central utility plants [including one (1) Combined Heat and Power (CHP) plant] and their distribution infrastructure. All levels of energy consumption metering, data management, savings determination, retrofit projects, and M&V (Measurement and Verification) functions are integrated. This paper presents our philosophy, the work scope, structure, approaches, and accomplishments of this on-going initiative. It also discusses lessons learned and strategies refined. TAMU's one-of-a-kind BAC (Building Automatic Controls) network will also be covered for its role and value in the CC.

Keywords: Continuous Commissioning (CC), Energy Management and Conservation

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[1] Continuous Commissioning and CC are registered trademarks of the Texas Engineering Experiment Station (TEES), the Texas A&M University System, College Station, Texas.

1. INTRODUCTION

1.1 Commissioning

The "normal" building commissioning practice that ensures the building operates according to the design intent using a process such as that described by ASHRAE Guideline 1 [1]. In this preliminary guideline, commissioning is proposed into five phases:

1) Program and Predesign Commissioning Phase
2) Design Commissioning Phase
3) Construction Commissioning Phase
4) Acceptance Commissioning Phase
5) Post-Acceptance Commissioning

An Operations and Maintenance Training Program is suggested between the "Acceptance Commissioning Phase" and "Post-Acceptance Commissioning", because it is the best time to conduct such a training program. The fifth step "Post-Acceptance Commissionig" is also called "On-going Commissioning", which more focuses on the day-to-day system operation, performance and maintenance, and most of the time, is accomplished by facility in-house management staff.

The first four steps stay together more as a group, which is generally defined as the concept of "Commissioning". Commissioning targets at creating a better understanding of design intent, setting performance goals ahead, and ensure the performance of the system through verification tests at the Acceptance Commissioning Phase (ASHRAE, 1996) [1].

1.2 Continuous Commissioning

Continuous Commissioning® (CC®) began as part of the Texas LoanSTAR program at the Energy Systems Laboratory (ESL) at Texas A&M University [2, 13, 16]. Continuous Commissioning evolved from a program of implementing operation and maintenance (O&M) 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. Treating Continuous Commissioning as a separate discipline helped with the development of the technology and the focus on improving comfort and obtaining high energy savings.

The 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 systems and central utilities plants. For any middle to large size campus with central thermal systems, CC faces more challenges, since it has to "deal with" all the major components - all the buildings, distribution loops and central plants; but it also presents "bigger" opportunities, since it targets the performance of the entire system: this is the only way to achieve the best long-term program results [7].

As a note, this concept was planned to be a different approach than the "normal" building commissioning practice that ensures the building operates according to the design intent using a process such as that described by ASHRAE Guideline 1. Normal building commissioning is increasingly practiced by owners of large buildings because they find it to be a cost effective way to bring buildings on line quickly and with far fewer problems and callbacks after occupancy [5, 14]. It is still far from the norm, as Haasl and Wilkinson [12] reported that only 7% of the state facility administrators responding to their survey reported that many or most of their facilities received some form of commissioning. Gregerson [11] investigated existing building commissioning in 1997 and reported average savings of 11.8% for 13 buildings which had undergone conventional commissioning. The average savings noted for 21 buildings which had undergone CC was 23.8%. Buildings that have had retrofits and buildings that have not had recent upgrades to the HVAC equipment comprise two significantly different categories. From previous publications, the average savings due to the CC process in buildings that had already been retrofit were about 20% beyond the retrofit savings [2, 3].

2. FACILITY INFORMATION

Texas A&M University has one of the largest student bodies in the United States, with over 44,500 students. The main campus covers over 1 square mile, packed with buildings. The newer West Campus covers a larger area but has fewer buildings.

2.1 Main Campus

The Main Campus has more than 110 buildings with over 12 million ft^2 conditioned floor area. Almost all these buildings receive chilled water and heating hot water from the two central plants: the Central Utility Plant (CUP) and the Satellite Utility Plant 3 (SUP3), which have a total installed cooling capacity of 31,200 tons, and heating capacity of 330 MMBtu/hr. With a cooling capacity of 26,500 tons, the Central Utility Plant sends out chilled water through four loops. All these loops are interconnected through supply and return common headers in the Central Utility Plant and by pipe connections at different points on the campus. The SUP3 is a complementary plant with a capacity of 4,700 tons, connected to the south loop about 2/3 of the way from the Central Utility Plant. The Central Utility Plant also produces heating hot water and sends it out through two loops.

2.2 West Campus

The West Campus has more than 30 buildings on the central chilled water and heating hot water loops with a total of about 5 million ft^2 of conditioned floor area. All these buildings receive chilled water from two central plants: the West I Plant and the West II Plant, which together have a total installed cooling capacity of 20,000 tons, and a total heating capacity of 73 MMBtu/hr.

2.3 Cogeneration System

The Central Utility Plant on the Main Campus is a cogeneration plant, and with its four satellite plants, the cogeneration system produces electricity, steam, chilled water, heating hot water, and domestic hot water for the whole campus. The maximum generation capacity is 36.5 MW including 15 MW from a combustion gas turbine (CTG 6), 17.5 MW from two steam turbines, and 4 MW from a back-pressure steam turbine. Commercial power is purchased for the demand (with a peak of 70 MW in 2008 and a projected 75 MW in 2009 due to newly installation of chillers and campus growth) beyond the generation capacity.

A heat recovery boiler of CTG 6 has a capacity of 175,000 lb/hr. Condensing steam turbines 4 and 5 consume approximately 188,000 lb/hr of 600-psig steam under full load conditions. The 20-psig low-pressure steam extracted from these two steam turbines is sent to heat exchangers to produce campus heating hot water and domestic hot water. Back-pressure steam turbine 3 receives 600-psig steam, too, and its 150-psig exhaust is used by a steam turbine-driven pump, but also sent out to the campus after reduced to 90-psig. If all equipment is in good condition, the operation has good overall energy efficiency.

3. CAMPUS CONTINUOUS COMMISSIONING HISTORY

With over 150 large buildings and 18.5 million ft^2 of conditioned facilities, utilities represent a major cost to the university. The opportunity for the campus to benefit from CC seemed obvious once the CC process had been developed in the LoanSTAR program. In early 1994, a presentation was given to the Vice-Chancellor for Finance of the Texas A&M system, advocating implementation of the CC process for all campus buildings at Texas A&M. This presentation was next given to the President of Texas A&M and he made the decision to implement CC [4].

The Continuous Commissioning program was then made an integral part of the campus energy management program and managed through the campus Energy Office within the Department of the Physical Plant. The project was funded from the campus utility budget on the premise that savings from the program would exceed the implementation cost within the two-year university budget cycle. The Energy Systems Laboratory (ESL) project team was set up to plan and implement the CC project.

Energy monitoring equipment was installed at a cost of $750,000 in 78 campus buildings jointly selected by the Physical Plant and ESL team members. The equipment was installed over a six month period beginning during the autumn of 1995 to record hourly values of electricity consumption (kWh), chilled water consumption (Btu) and heating water consumption (Btu). This part of the project went as planned and encountered only the normal problems which arise in a large metering effort.

The first buildings to have CC applied were selected from those metered as likely candidates for significant savings based on observed consumption patterns – particularly high levels of simultaneous heating and cooling. This phase of the Continuous Commissioning began during the spring of 1996 after about nine months of baseline data spanning winter weather and hot humid weather were available for the initial buildings commissioned. By the end of 1996, 11 buildings had been commissioned – comfort problems had been addressed and basic systems optimization had been carried out. Savings realized in these 11 buildings were approximately $100,000 per month. A decision was made in 1997 to begin work on the power plant and optimize the distribution loops and major equipment within the power plant in parallel with the building commissioning. Meanwhile, building Continuous Commissioning was carried on in another 9 buildings. By the end of 1997, two and one-half million (2,500,000) gross ft^2 of building space had been commissioned. This included 20 buildings, ranging in size from 80,000 to 368,000 ft^2. The pace slowed somewhat to 14 buildings over the next two years. This occurred since the Physical Plant team decided that complete identification and repair of faulty components and equipment in each building was preferable to faster initial commissioning followed by the need for additional effort to complete the process after the major savings had been achieved. By the end of 1999, cumulative chilled water, hot water and electricity savings achieved from Continuous Commissioning on the TAMU campus (including buildings, distribution loops and central plants) have exceeded $10 million [4].

4. NOW

4.1 Overall Results

In the past decade, the TAMU campus grew rapidly, from 17.7 million ft^2 (1998) to 21.5 million ft^2 (2008), a 21.5% growth in gross area. Figure 1 shows the campus overall Energy Utilization Index (EUI, $mBtu/ft^2/yr$) with the campus growth in gross square feet. EUI dropped from Fiscal Year 1998's 398 $mBtu/ft^2/yr$ to 2007's 260 $mBtu/ft^2/yr$, a 35% reduction. This decade corresponds to the 12 years' CC efforts on the campus. There are other factors influencing the magnitude of the EUI's, but the continuous reduction definitely presents the significant energy savings achieved by CC. Since EUI is the energy utilization index, it doesn't reflect the dramatically increased natural gas and electricity rates close to the year end of 2000 and in recent years.

As of the end of Fiscal Year 2008, the CC process has been applied to more than 80 campus buildings (over 8.3 million ft^2) on the Texas A&M campus resulting in substantial improvements to the operation of the buildings. Dedicated CC teams carry out, on a daily basis, operational optimization measures on the central chilled and hot water distribution loops, the central utility plants and the campus buildings. So far, cumulative measured chilled water, hot water, and electricity savings achieved from Continuous Commissioning on the Texas A&M campus have exceeded $58.5 million. Total CC costs through August, 2008 is approximately $10 million for the past ten (12) years. For the base year of the project (from May 1995 to May 1996), major efforts were made on installing building level thermal and electric meters, establishing an hourly database, and collecting energy consumption baselines. In this period of preparation, the net cash flow was negative, but it turned positive in early 1997. By the end of Fiscal Year 2008, the net cash flow of the project is a positive $38 million.

4.2 Overall Organization

After several years' adjustment and evolvement, a relatively stable but effective structure of CC has been applied on the campus. The CC teams have also grown mature and experienced. Meanwhile, the project is still a dynamic process. Overseen by two Mechanical Engineering Department professors, there are one program director, one associate program manager, one project engineer, one technical advisor, three building CC engineers, one data quality engineer, three technicians, and eight graduate assistants from the ESL performing CC on campus on a full-time basis. Sometimes graduate students or undergraduate students volunteer to get involved in CC to help on field measurements, information collection, and documentation preparation, meanwhile, the knowledge and information gained from such activities helps them in their curricular projects and academic research. Internship is also offered by the program from time to time to graduate students.

Currently, the general building CC procedure is: the ESL program director works with the University Energy Manager to develop a CC plan for the next several years; the University Physical Plant Maintenance team works on the building first to collect equipment information, check and fix mechanical/electrical parts; the CC team performs CC (in this step, the CC engineer leads the project, has full access to the EMCS system, and responds to building comfort complaints); the Maintenance (mechanical/electrical) and Controls teams follow up to fix/replace/install/modify items identified by the CC team; then the CC team wraps up the unfinished measures. After CC is performed on a particular building, the CC team will be available to provide consulting to the Maintenance staff or directly work on trouble-shootings. CC savings will be calculated by the ESL data analysis group and the building energy performance will be monitored with hourly metering. Based on the metered data, the CC team may be drawn back to a commissioned building to carry out an investigation of unexplainable significant energy consumption changes. If a significant energy increase persists, CC may be performed a second or third time.

All teams and contractors are coordinated by the University Energy Office, which is the owner representative, and meet weekly to report progress, exchange ideas, and discuss problems.

There are three building CC teams, one central plant CC team, and one distribution loop CC team, and one auxiliary enterprise energy management service team. One data quality engineer works most of the time at the Energy Office, providing help on special tasks such as auxiliary building billing metering through the EMCS and data analysis. All teams share man power dynamically with daily morning meetings. Inside the ESL, there is also a metering group, a database group, a data analysis group and a computer group to support and interact with the CC teams.

Due to the accumulated knowledge of the campus buildings and their HVAC systems, the CC teams have become the major resource to provide engineering service to the Energy Office and the area maintenance shops on various tasks. Trouble-shootings occur not only on the commissioned buildings, but also on any campus building. These problems are often assigned to a CC engineer and her/his team after the area maintenance staff and the Energy Office manager feel help is needed. In fact, during peak heating and cooling seasons, all the CC teams may be pulled out from their routine activities to balance and optimize the whole campus level system performance under an emergency mode. Because of the success of the campus energy management team, the Energy Manager and the ESL Program Director have been attending and becoming key players of the design planning and review meetings for campus new buildings and utilities infrastructure/equipment projects. Their inputs, recommendations, and requirements on the HVAC system (sensors, flow meters, piping, field measurement ports, etc.) and its control sequences greatly benefit the design and results in a smoother and more efficient operation and maintenance of the building after it is built, and similar contributions achieved to the utility projects.

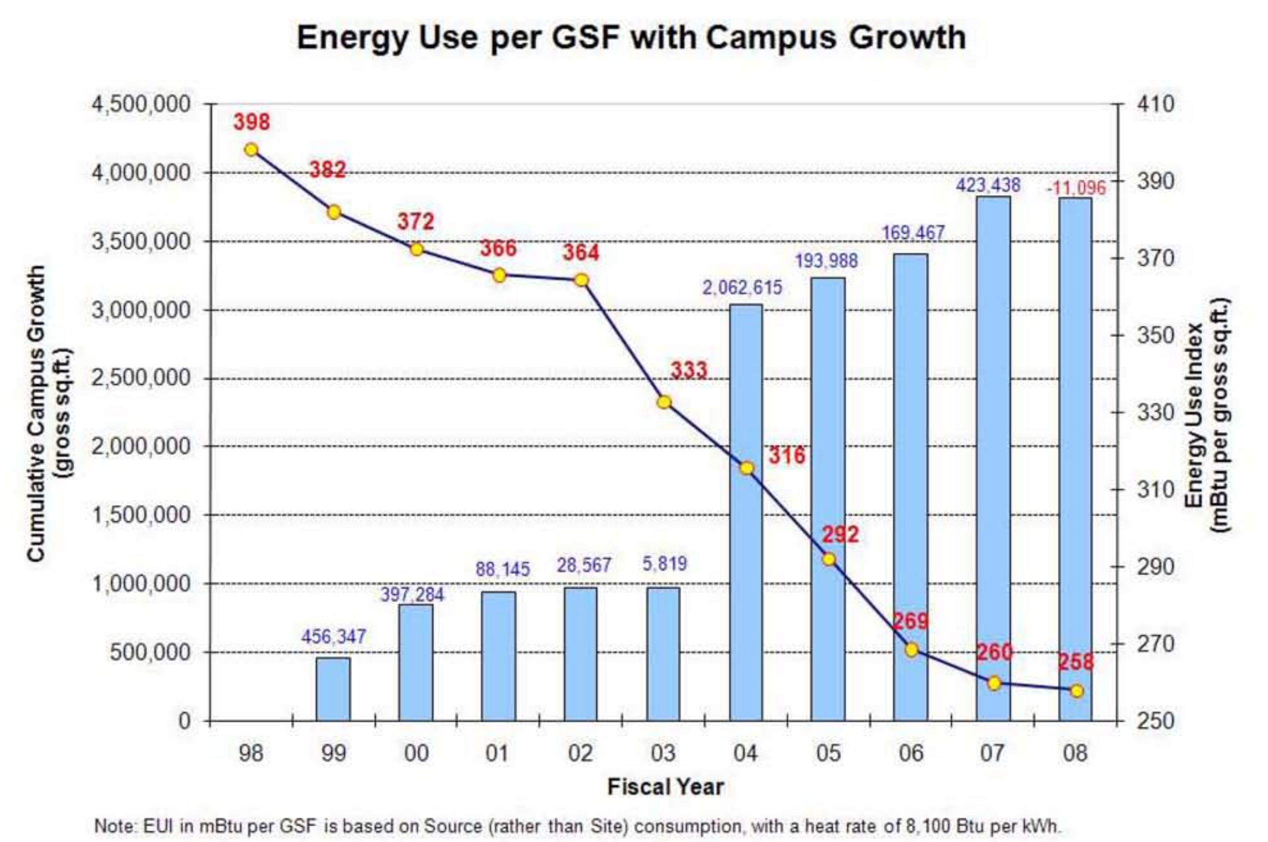

Figure 1. Energy Use vs. Campus Growth in Last Decade

4.3 Buildings

Building CC has been discussed in detail in previous papers [4]. Turner [17] reported the findings in savings persistence of ten previously commissioned buildings. Further investigation results suggest that follow-up should be initiated when consumption increases by a financially significant amount. This amount will differ from owner to owner and building to building. But it certainly must exceed the cost of the follow-up activity in a relatively short interval. Setting up a system which notifies a designated individual any time control settings are changed would also appear to have merit.

4.4 Loops

Operational Optimization: The central thermal distribution loops serve 99% of the 150 plus campus major buildings, and the performance of these loops has always been a major concern for facility O&M staff, engineers and managers. For example, low system differential temperatures (DT's) are a common problem and present a constant challenge. Effective and efficient delivery of cooling and heating energy to all the buildings is another major task. The loop pressure heads at buildings close to the end of the loops are always negative. To solve such problems requires consistent and comprehensive efforts on building controls, plant and loop operation, and central thermal system development planning [7, 9]. Some major CC measures at the building and plant level are: identify and apply optimized central plant chiller/boiler operation schedules/sequences, central plant chilled/heating 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.

Optimization with Simulation: A computer simulation model is an economic and convenient tool to perform analysis of the water loops. Simulation models of the central chilled water/heating hot water loops on the campus have been built with commercial hydraulic software. The knowledge and experience gained from loop modeling and simulation on the TAMU campus benefits other campuses as well. Recently, the loop simulation team was able to build a chilled water distribution system model in a limited period of time for the University of Texas at San Antonio. From the simulations, different loop expansion options were examined and compared, which greatly helps the administration to identify not only the most economic but also a practical way of expanding the loops for future campus growth.

4.5 Central Plants

Operational Optimization: Through CC in the central utility plants, CC engineers became familiar with the system and operation staff, and gained insights in operation [6, 7, 9]. This enabled the CC engineers' direct involvement in campus utilities planning and retrofits evaluation, such as the 15 MW combustion turbine generator overhaul [8]. More CC opportunities normally show up afterwards. The operation of a cogeneration utility plant is complicated. An Energy Optimization Program was designed to simulate and optimize the operation of the TAMU cogeneration plant. All major plant components were represented by appropriate models and then structured to establish a system model. A better understanding of the complicated interaction among the energy components was achieved through systematic simulations.

Operational Optimization under a Turbulent Utility Market: In unstable utility market environments like those seen not too long ago and expected in the near future, operating a large university cogeneration system presents opportunities as well as challenges. Will the existing "generate-as-much-as-we-can and buy-the-rest" operation scenario continue to be the best, or does the operation need to be optimized? If operational changes are recommended, what is the optimum scenario? How sensitive is the optimum scenario to natural gas prices and electricity purchase rates? The Texas A&M University combustion gas turbine is an old machine. The economics of an overhaul and upgrading costs also come into play.

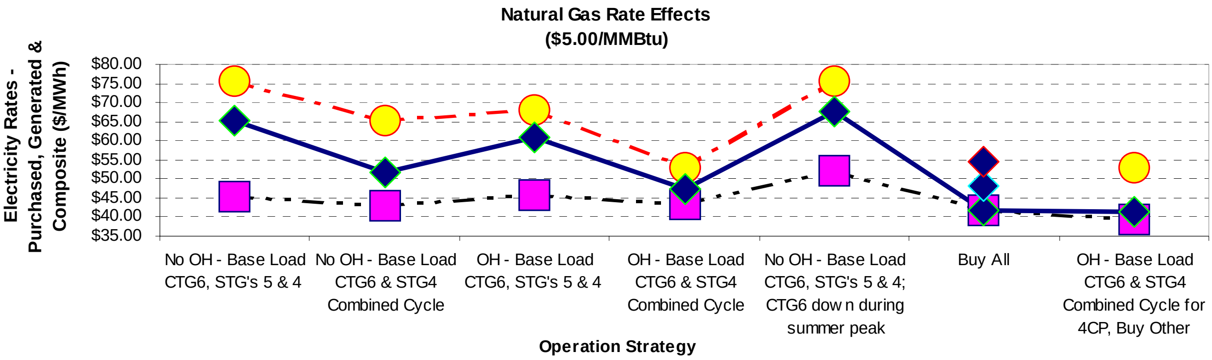

Figure 2. Buy, Make and Composite Electric Rates of Various Operating Scenarios at $ 5.00 / MMBtu Gas Price

Various operation scenarios are proposed, then evaluated and compared for different natural gas prices and purchasing electric rates (such as shown in Figure 2). The results show how to maintain flexibility in the uncertain electricity market, and to minimize the impact of electric utility deregulation. The analysis also investigates the cost impact of increased natural gas prices, and the economics of the major gas turbine upgrade. Deng and Turner [8] reported this special task CC study in a previous paper. The fact that Texas A&M's cogen system can produce up to 65% of the university's own electricity, that the plant has both electric-driven and steam-driven chillers, and that the university can purchase its additional electricity on the wholesale market presents additional opportunities and possible operating strategies.

4.6 EMCS

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 cost while providing dependable and accurate control [10]. Optimizing the control system's function is important in Continuous Commissioning where an EMCS is present.

TAMU has one of the largest energy management systems in United States and the world (over 160,000 data points). The standardized DDC (Direct Digital Control) system and network on the TAMU campus makes CC more powerful and effective. Meanwhile, CC of the EMCS is an essential step in the CC process, which verifies the control system hardware (sensors, controllers, etc.) and software (control sequence and algorithms) first. There are also special CC tasks being explored through the EMCS. For example, a procedure to generate energy (electric and thermal – chilled water, heating hot water and steam) utility bills for the auxiliary buildings on the TAMU campus is under construction. Magnetic flow meters and matched thermometers have been installed in the pilot-project buildings, and data are being collected, processed and stored through the networked EMCS. Instead of billing the customers by building square feet, bills are generated from metered consumption. Currently, reliability is the key interest of this study.

4.7 Lighting Retrofit

Lighting typically accounts for at least 25% of the electrical power consumption of any given building. Significant advancements in lighting technology allow the opportunity to reduce the lighting load, frequently by more than 35% (10% for the overall load for the building). In the case of the Engineering/Physics (EPB) complex we have reduced the electrical load 97 kW - a 36% savings in lighting (270 kW baseline) and 10% savings for the overall building (970 kW Baseline) when combined with plug loads and HVAC. This retrofit was commissioned as a pilot for the express purpose of evaluating the feasibility of a campus-wide re-lighting effort to ease the ever-increasing campus electrical burden. EPB consists of two buildings connected by a tunnel and catwalks totaling 162,000 ft^2. The complex houses laboratories, classrooms, machine shops, and many offices. The retrofit would consist of converting the old T12 lamps and ballasts to the newer T8 high-frequency lamps and ballasts and the incandescent lamps to compact fluorescent lamps. Additionally, we used the opportunity to install occupancy sensors in areas which typically were lit, unoccupied, 24 hours-per-day. The cost of the EPB Lighting retrofit is slightly misleading due to the fact that the Physics labs required highly specialized (and more expensive) materials. The final price of the project is $89,639 ($0.55 per ft^2), with an estimated payback of approximately 5 years.

Lighting standard is also improved in this retrofit process, when existing lighting is replaced with low wattage lamps and ballasts. At current high energy prices, the simple payback is only around 2 years.

4.8 Metering and M&V

Metering was installed in 78 of the largest campus buildings in 1995 and 1996 to collect individual building energy consumption baselines, preparing for the measurement and verification (M&V) of the CC, and also following the operational management philosophy of Monitor and Management (2M) [15]. Continuous Commissioning requires on-going monitoring and analysis. At the Energy Systems Laboratory, the monitored data was collected and quality checked weekly. The analysis was performed monthly and put into a Monthly Energy Consumption Report (MECR). The MECR shows trends and savings. Based on these reports the building staff could take appropriate action to correct a degrading situation.

Right now, the University Energy Office took over this responsibility, and installed a large amount of billing quality electric and thermal metering to completely meter all the utilities to the campus buildings. Up to date, over 1,200 revenue quality meters have been installed, and 200 additional meters have been planned for installation. Data is collected through the campus EMCS and electric metering system, and stored in a SQL database. Dedicated personnel and commercial software are assigned to maintain and manage the system and generate utility bills for campus customers. An ESL data quality engineer, as mentioned earlier, full-time on-site contribute to data quality check with data analysis expertise. Automated methods have been and are being developed to achieve such functions.

4.9 Contribution to University Education Programs

As mentioned above, graduate students and undergraduate students get involved in the CC process and gain knowledge of building HVAC systems and CC measures from paid or unpaid (volunteered) jobs. In fact, the simulation and optimization tasks of the plant cogeneration system and central distribution system are carried on by trained graduate students under the supervision of engineers. Commissioned buildings are used as on-site classrooms for students from mechanical engineering courses such as “HVAC Principles” and “Commercial Building Energy Management”. Commissioned or un-commissioned buildings are simulated with DOE-2 and other programs as class projects by students. Sometime, CC-educated students are granted only reading access of the campus EMCS system and physical access to the building mechanical rooms, so they can obtain equipment/operation information, and even identify CC measures acting as “pilot” CC teams. So far, two Ph.D. dissertation and seven Master degree theses have been produced from the research work under TAMU CC, and several other are on going. Quite a few non-thesis option graduate students found their report topics from the campus CC, also. Hundreds of students have benefited from this on-campus program to their engineering education.

4.10 Some Key Factors

CC identifies and resolves operating problems, but it goes much farther and develops and implements optimized operation and control methods for each individual building, water loop, and energy plant by using detailed field measurements, engineering analyses and testing. Facility O&M staff are key players in this process. Their inputs and involvement are important for the CC engineers to develop optimized and practical energy conservation measures, schedules, and sequences. This teaming effort also provides on-site training for the O&M team, and therefore contributes to the persistence of the optimized system performance and CC savings in the on-going operation. This process is the most efficient and effective energy conservation process for the existing systems, since it doesn’t require major capital investments. As shown above, the CC process may also be used to evaluate or identify energy conservation retrofit opportunities. On-going follow-up is a key factor in CC to achieve persistence of savings. Well-organized communication and documentation is very important when pursuing the long-term overall success, as it combines information from all aspects and explains the modified operating procedures so the operators can resolve future problems in a manner consistent with the CC operational plan.

5. SUMMARY AND CONCLUSIONS

Continuous Commissioning requires a common sense approach to maintaining building mechanical and control equipment. We have yet to find any building with all of the mechanical systems working optimally. A detailed fundamental understanding of the equipment and functions of the building is used to solve long-term problems. Solutions which optimize building performance in the context of current use are implemented rather than solutions which implement design intent. The energy conservation measures are almost entirely operational changes, though minor retrofits to the mechanical systems are sometimes implemented. Monitoring is very useful for identifying problems and for maintaining operational savings once these changes have been implemented. Finally, both informal and formal training of the facility staff is essential to maintain optimal operating practices.

The CC process has been applied to buildings on the Texas A&M campus since 1996 and the process has been applied to implement substantial improvements to the operation of the campus chilled water and heating hot distribution loops and to the central plant operation. By the end of Fiscal Year 2008, cumulative chilled water, heating hot water and electricity savings achieved from Continuous Commissioning on the Texas A&M campus have exceeded $58.5 million with an expenditure of about $10 million.

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