Energy Efficiency Improvement of an Institutional Facility through Retro-Commissioning (RCx) – A Case Study

Lonny Simonian, P.E. and Thomas Korman, Ph.D., P.E.
California Polytechnic State University
San Luis Obispo, CA

Audrey L. Schultz
The University of Salford
Salford, Greater Manchester, UK

Arturo Ayala-Navarro
California Polytechnic State University
San Luis Obispo, CA

It is common practice for commercial buildings built prior to 1990 to undergo retrofits that attempt to increase their energy efficiency. Research findings suggest that prior to conducting retrofits, it is essential to first understand the functionality of a facility's building systems. Heating, Ventilation, and Air Conditioning (HVAC) systems are areas of investigation where modifications are frequently proposed in order to improve energy efficiency and occupant comfort; however, the literature implies that it is also common for older buildings to have poor documentation describing their original operational sequences. This paper examines the link between retro-commissioning and a case study investigating the HVAC systems in an institutional office building occupied predominantly by research scientists and support staff from which a Sequence of Operations (SOO) document was developed. The completion of the project and SOO documentation set the foundation for the retro-commissioning process to follow. The investigative process resulted in correcting redundancies and errors in the control systems and the development of a retro-commissioning directive aimed at highlighting areas of possible refinement in the overall control system for future use in operating and maintaining HVAC and Facility Monitoring and Control (FMCS) building systems.

Key Words: Heating, Ventilation, and Air Conditioning (HVAC); Sequence of Operations (SOO); Facilities Monitoring and Control System (FMCS); Building Commissioning (BCx); Retro-commissioning (RCx)

Introduction

As the necessity for building systems to become more energy efficient develops, retrofitting and Retro-Commissioning (RCx) of older buildings are becoming increasingly common practices. According to the Green California Government web site (2010) "Retro-commissioning (RCx) is a systematic, documented process that identifies low-cost operational and maintenance improvements in existing buildings and brings the buildings up to the design intentions of its current usage." Retro-commissioning processes involve the collection of operational data and the performance of functional testing of building systems to identify and correct flaws in operations and optimize performance to meet the owner's requirements. Depending on the project scope, recommendations are made and implemented to improve energy efficiency, thermal comfort, air quality, or other building services. Energy efficiency programs that offer RCx services identify and implement low-cost tune-up and optimization measures that typically reduce a building's energy use by 5 to 15%. (Jump *et al* 2007).

A building's Heating, Ventilation, and Air Conditioning (HVAC) system presents many opportunities to improve energy efficiency and increase occupant comfort. Unfortunately, many older buildings have poor documentation describing the original design intent or operational sequence of their HVAC systems. The energy required to operate and maintain buildings has become expensive, greater regulations have been put into place concerning the release of hydrocarbon emissions into the atmosphere, and Leadership in Energy and Environmental Design (LEED) certified buildings have become highly desirable. Many commercial buildings, built during an era in which energy was inexpensive and a low carbon footprint ideology had yet to gain full acceptance, are beginning to undergo retro-commissioning programs in order to increase their energy efficiency and optimize system performance.

Prior to conducting a building retrofit program, it is essential to have a keen understanding of a building's overall operational systems. In order to achieve this goal a thorough investigation of existing building systems and documentation needs to take place. According to the Whole Building Design Guide, a program of the National Institute of Building Sciences (2010), the purpose of commissioning documentation is to record the standards of performance for building systems, and to verify that what is designed and constructed meets those standards. If there are no prior Building Commissioning (BCx) documents, as in the case study on the proceeding pages, then a Sequence of Operations (SOO) is needed in order to better understand the total building operation systems and move forward through the retro-commissioning stages. The SOO directive developed as a result of this case study becomes the roadmap for a successful retro-commissioning and energy efficiency program for future use.

Literature Review

Retro-commissioning is a systematic process for investigating, analyzing, and optimizing the performance of building systems by improving their operation and maintenance to ensure their continued performance over time. This process helps make the building systems perform interactively to meet the owner's current facility requirements. Owners are increasingly recognizing building commissioning as an effective means of ensuring quality and maximizing energy performance. The demand for commissioning new construction projects has increased substantially over a short period of time with the growing demand for LEED certified buildings (Ellis, R. 2010). Therefore, commissioning is arguably the single most cost-effective strategy for reducing energy, costs, and greenhouse gas emissions in buildings today. Although commissioning has earned increased recognition in recent years, it remains an enigmatic practice whose visibility severely lags its potential. The application of commissioning new buildings ensures that they deliver or exceed the performance and energy savings promised by their design and intended operation. When applied to existing buildings, commissioning identifies deficiencies and the almost inevitable "drift" from intended performance over time, and carries out interventions to put the building back on course (Mills 2011).

There have been many success stories from retro-commissioning. One notable example includes Office Building 2 (OB2) on the Washington State Capital Campus. OB2 is a 1970's multi-story office building designed with two long building sections oriented north/south with a service level and four upper floors. A core section common to all floors connects the north/south wings. Various modernizations over the years have been completed, including the addition of security doors between the core area and the office wings. OB2 was selected for retro-commissioning because of a history of building static pressure control problems and poor temperature control. The primary goal was to identify and correct the pressure control problems and then address energy consumption and temperature control issues. The major findings were that the supply and return fans short cycled which caused the building's pressure to surge positive and negative; the VAV boxes were going in and out of occupied mode at the same time creating rapid air flow changes; the fan shifting was not well coordinated nor optimized for energy performance; the building static pressure sensor was not located in the right place; 73% of the 216 VAV terminal units failed one or more functional tests; the building control code was compromised; and the VFD's for the supply fans were failing. Through retro-commissioning the problems that were identified were corrected; the building systems now operate efficiently. The building pressurization problems have been resolved, the majority of the VAV boxes have been repaired, and the control system problems have been rectified (GSA Washington State)

Method

Building Commissioning is a method of risk reduction for new construction and major renovation projects to ensure that building systems meet their design intent, operate and interact optimally, and meet owner expectations. This systematic process typically includes building HVAC, controls, lighting, hot water, security, fire, and life safety systems. Total building commissioning often includes additional essential buildings systems such as the building's exterior wall, plumbing, acoustical, and roofing systems. Commissioning (Cx) these additional systems can reduce moisture penetration, infiltration and noise problems, and contribute to the building's energy efficiency and occupant productivity. Successful Cx results in optimal energy efficiency, indoor environmental quality, reduced change orders during construction, extended life of overall building systems and reduced operation and maintenance costs; often paying for itself before the completion of building construction. To be most effective, building commissioning should begin in the planning phase, continue throughout design, construction, start-up, post-occupancy, training and warranty period, and then proceed throughout the building's entire life cycle. Energy efficiency industry references include ASHRAE Guideline 14/3 which provides a framework that overlaps RCx standards and ASHRAE 0-2005.

Existing building commissioning (retro-commissioning) is performed on older buildings, restoring them to optimal performance. Retro-commissioning is a systematic, documented process that identifies low-cost operational and maintenance improvements in existing buildings and validates a building to the design intentions of its current usage. RCx focuses on high energy-use equipment HVAC and mechanical systems, electrical power and lighting systems, and related control systems to optimize existing system performance rather than relying on major equipment replacement. According to the California Commissioning Guide: Exiting Buildings (2006) "RCx typically … results in improved indoor air quality, comfort, controls, energy and resource efficiency." RCx includes an audit of the entire building including a study of past utility bills and interviews with facility personnel. Diagnostic monitoring and functional tests of building systems are executed and analyzed. Building systems are tested and monitored to fine-tune improvements; this process helps find and repair any existing operational inefficiencies. The process concludes with the identification of system operational issues, suggested improvements, and development of a final report, including a re-commissioning plan for future operations and maintenance.

It is a good idea to compile a Sequence of Operations document before starting any retro-commissioning program. A Sequence of Operations is the organizing narration of the operations of mechanical systems within a building and documents functions that will determine the ability of a building to perform in an energy-efficient manner. The importance of describing the functions of a facility's environmental systems with detailed, comprehensive control strategies cannot be overemphasized. Topics that affect energy efficiency that should be addressed by the Sequence of Operations include: systems and equipment control; system initiation; modes of operation, cooling, heating and ventilation; occupied and unoccupied periods; set points for temperature, pressure, humidity; set-back routines; optimal starts; time limited control of equipment; override sequences; alarm point ranges; and control versus monitoring point descriptions.

There is no doubt that existing building performance problems are all-encompassing. According to Mills (*et al* 2005) deficiencies such as design flaws, construction defects, malfunctioning equipment, and (most of all) deferred maintenance have a host of ramifications, ranging from equipment failure, to compromised indoor-air-quality and comfort, to unnecessarily elevated energy use or under-performance of energy-efficiency strategies. Fortunately, building commissioning (and retro-commissioning), can detect and remedy most deficiencies.

The combination of a Sequence of Operations directive document and strong retro-commissioning program can play a major and strategically important role in attaining broader national energy savings goals. As technologies and applications change and/or become more complex in the effort to capture greater energy savings, the risk of under-performance will increase and the value of the building commissioning will summarily increase. Indeed, innovation driven by the desire for increased energy efficiency may itself inadvertently create energy waste if those systems are not designed, implemented, and operated properly (Mills *et al* 2005) as found in the following case study.

Analysis

This case study focuses on a 90,000 ft^2 (8,360 m^2) institutional office building (Building 90) at Lawrence Berkeley National Laboratory (LBNL), located adjacent to the University of California, Berkeley campus. The facility is occupied predominantly by research scientists and support staff. The building has four floors plus an occupied basement. It was built in the 1960's and has undergone many renovations to its mechanical and electrical systems over the past 50 years. The building has a long history of problems with thermal comfort, ventilation, energy usage, and maintenance issues. It scored very poorly on an occupant survey with the most common complaints pertaining to thermal comfort and indoor air quality (Stein, 2008). In 2003, air conditioning units were added to the building to address these concerns, yet due to system control limitations, areas of the building were overcooled while other sections remained too hot. Using the limited number of temperature sensors originally installed in the building it was difficult to understand how the system was actually performing. This problem was compounded by the lack of a written SOO document on how the existing systems were designed and intended to operate. The combination of an inadequate amount of sensors and lack of a SOO directive led to inefficiencies, such as operating the cooling and heating systems concurrently.

The building's main HVAC system consists of three primary air handling units (AHUs) served by two 100 ton evaporative cooled condensing units, two return fans and a hot water heating system (LBNL 2008). The building contains 21 zones on the first, second, and third floors. HVAC to the basement, fourth floor, and conference rooms are supplied via separate equipment. The entire building's HVAC system is controlled using a combination of control systems as depicted below in Figure 1. The graphical representation shown in this figure was derived by analyzing all existing system components and their connections and communications flow.

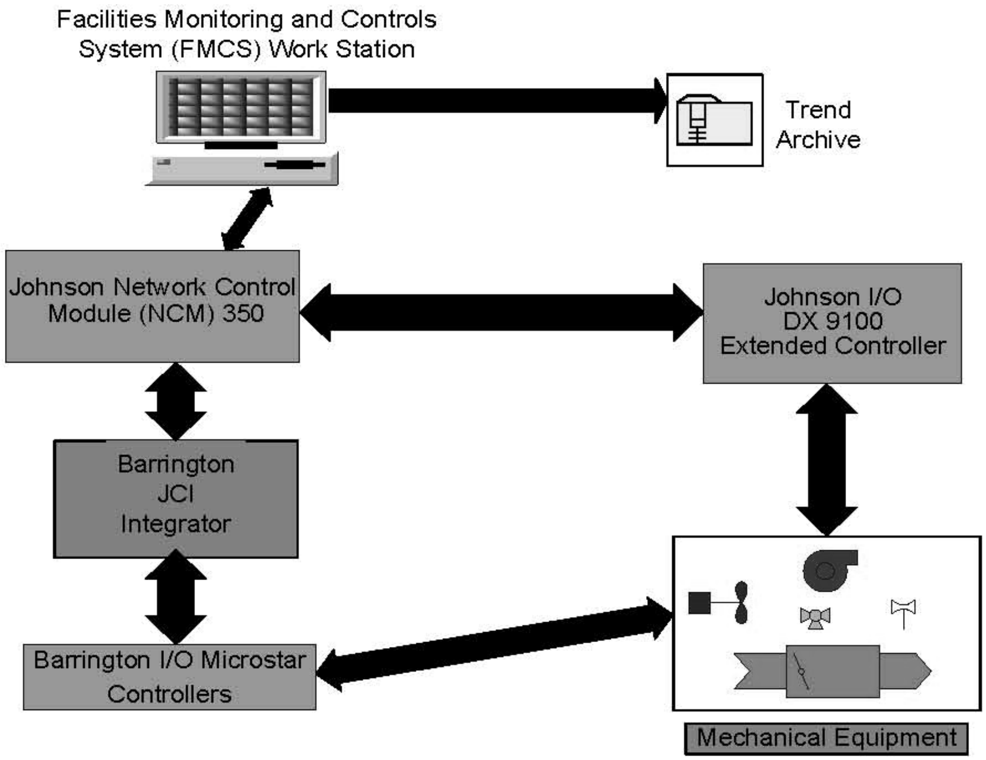

Figure 1 : HVAC control system components and communication interconnections

Currently, building 90's control system is composed of several Barrington Microstar controllers, a Johnson Controls Incorporated (JCI) integrator, and JCI NCM 350 and JCI DX 9100 extended controllers. The two controllers currently in use transmit programmed logic using different software. The logic written to the Microstar-NCM 350 I/O integrated control system uses JCI's Metasys Network software while the DX 9100 extended controller transmits logic using JCI's GX9100 software.

Barrington Microstar and Lanstar controllers were originally used within LBNL buildings; over time the systems became obsolete, security became an issue, and the Barrington point capacity dwindled below that of other control systems available. Ultimately, LBNL chose to migrate to JCI as their primary control systems distributor. There were many reasons for this decision, including increased point capacity and better security capabilities. Another reason was that a control systems upgrade would allow LBNL to adhere to the newly standardized communication protocol, Building Automation and Control Networks (BACnet). However, the main reason was that JCI was the only manufacturer offering an integrator that allowed the old Barrington hardware to communicate with the new Johnson NCM during prior systems renovation.

The ultimate requirement for LBNL was to optimize occupant satisfaction while reducing energy usage. This goal has proven to be difficult to achieve. The building's energy usage is respectable and is only five points shy of earning Energy Star status; however, its occupant satisfaction is less impressive. In spite of the recent cooling package upgrade to the air-handling units, building occupants still rank thermal comfort as poor (LBNL 2009). There have been several projects conducted within the building with similar project requirements: to develop a strong understanding of the functions within the building, including potential areas of improvement, and propose solutions for occupant comfort. Unfortunately, like many other half-century old buildings, the existing building systems documentation is less than extensive, and the exact operation of the building's HVAC system is not well understood. There is no SOO document describing the control strategies currently implemented. Therefore, deriving an HVAC Sequence of Operations document was a key step to lay the foundation for future work.

Results

An as-constructed SOO document was developed based upon an analysis of the existing systems. This involved several steps. First, physical investigations were performed validating the system's mechanical components, including reviewing and becoming familiar with existing mechanical drawings, zone diagrams, and engineering reports; and conducting interviews with senior engineers. Second, an understanding of the interfacing of the multiple control systems was acquired through meetings with facilities personnel and control engineers. However, most of the project's effort occurred in the final step: due to the lack of documentation, the majority of the SOO was derived by directly analyzing the programming codes.

Each individual subsystem was sequenced independently; then subsystems were compared to real time status of components using the FMCS workstation. Figure 2 illustrates the division of subsystems and their corresponding controllers.

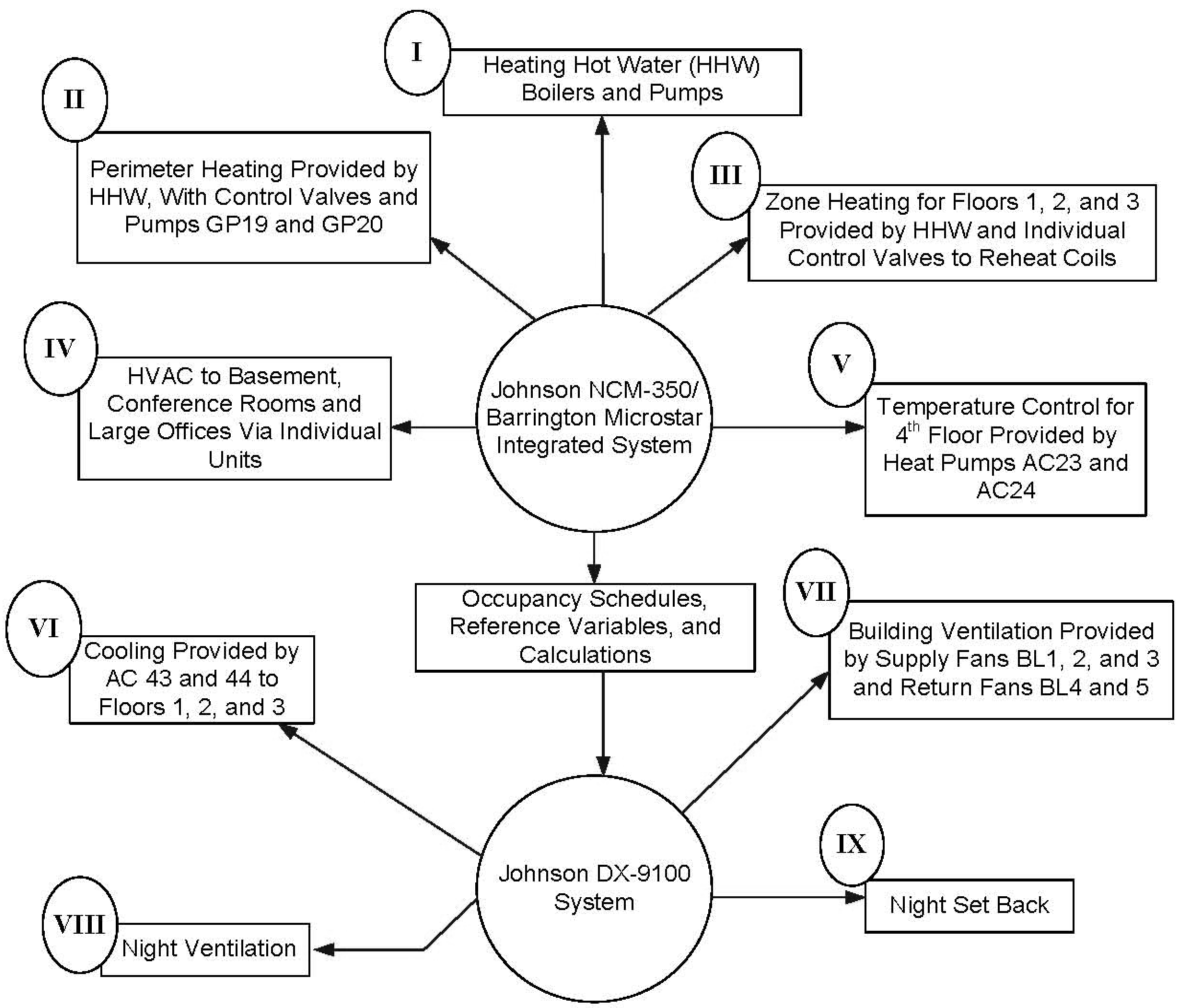

Figure 2: Graphical representation of the building's HVAC subsystems and controllers.

The process of sequencing the Heating Hot Water System (HHWS) consisted of the following steps:

1. The code controlling the HHWS was accessed through the FMCS workstation and found within the building's NCM1. The control strategies for the boilers, pumps, and perimeter heating valves were all within the HHWS module.

2. The code was deciphered, translated, and documented. Constant referencing of JCI's Graphic Programming Language Programmer's Manual was essential in the translation of the code.

3. Set-points, reset schedule limits, and occupancy schedules were recorded.

4. The FMCS was scanned for overrides. If overrides had been implemented, they were documented in the notes section of the SOO.

5. The derived subsystem's sequence was compared to current and historic data describing the status of its mechanical components. This was done using the monitoring capabilities of the FMCS, which allowed the user to note the status of valves, pumps, boilers and additional building systems.

Once the subsystem's sequence had been completed, it was reviewed for any apparent mistakes, or redundant logic. If an apparent correction opportunity was present, a controls engineer was consulted. Figure 3 illustrates the graphical monitoring feature of the FMCS.

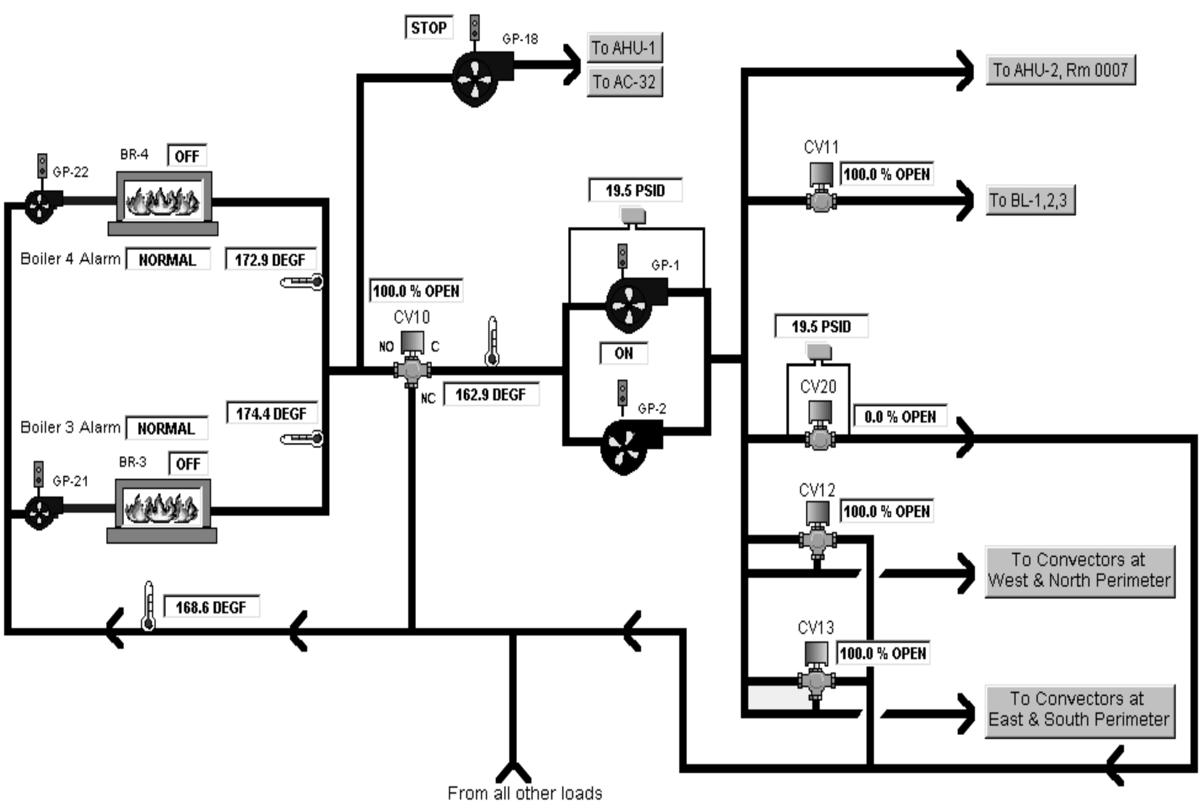

Figure 3 - Illustration of the HHWS emphasizing the monitoring capabilities of the FMCS

Discussion

The primary result of the project was the creation of a Sequence of Operations document that could be used by the building control systems engineers, interested occupants, and functional personnel to optimize building performance and energy efficiency. Secondary results included the correction of apparent mistakes and redundancies in the controls code and the development of a best practices document aimed at highlighting areas of possible refinement in the HVAC control system. One operational mistake was identified during the sequencing of HVAC HHW subsystems. It was discovered that the code being used to control the boilers were not executing properly; two boilers were being enabled when only one was actually required. This correction provided a small contribution to the long-term goal - an improvement in building energy efficiency. The composition of the SOO along with a proposed best practices document, programming modifications, and areas for further investigation will assist the building retro-commissioning process to run smoothly and be more successful.

Several additional steps were recommended for implementation in order to optimize building energy efficiency:

- Composition and implementation of a retro-commissioning plan,
- Refinement of the building Energy Plus model (used to calculate energy consumption),
- Investigative analysis using data and information gathered from the Sequence of Operations,
- Refining the Energy Information System model,
- Incorporating the results from a Miscellaneous Electric Loads investigation

Conclusion

This paper presents findings that validating an existing facility's Sequence of Operations is a required first step toward the incorporation of a retro commissioning plan, making a facility more energy efficient and optimizing the operations and maintenance of equipment and systems to run at peak performance in order to improve the built environment (McKew 2010). The problems that occur with older existing facilities - such as codes that control boilers not executing properly, issues with thermal comfort, ventilation, energy usage and overall maintenance problems can be easily avoided with a structured preventive maintenance and retro commission plan in place. This case study resulted in performance tracking of existing systems and led to corrections of redundancies and errors in a 1960's era institutional building. To enable building systems to perform at optimum levels, data collection and validation are necessary to develop a generic framework such as an ongoing SOO. The SOO procedures were tested on the LBNL case building and the amount of available data was presented. The same generic framework on system performances was implemented to review the standards related to lifetime commissioning. In that way it was possible to estimate the amount of performances defined by standards. Such procedures give possibilities that building extension is enabled and any system change during the building lifetime can be easily noted (Djuric and Novakovic 2009). This resulted in adding value to the customers and extension of the overall building systems lifecycle. The SOO directive developed will serve as a part of a future energy efficiency improvement plan that LBNL will be able to use as part of their RCx initiative, resulting in optimum building systems performance.

References

Bandurowski, Tad (2010). Silver Lining in Campus Building Renovations, *Engineered Systems vol. 27*(6)

California Commissioning Guide: Existing Buildings. (2006), *California Commissioning Collaborative*.

Djuric, N. & Novakovic, V. (2009). Correlation between standards and the lifetime commissioning, *Energy and Buildings, Elsevier BV, 42*, 510–521.

Ellis, R. (2010). Commissioning: BCx essential attributes part 3. *Engineered Systems, 27*(9).

Ellis, R. (2010). Commissioning: Commissioning certifications. *Engineered Systems, 27*(3).

Green California Government. (2007). Commissioning and Retro-Commissioning Buildings, http://www.green.ca.gov/CommissioningGuidelines/default.htm (visited 2011, December 10).

GSA Washington State (2009). Department of General Administration, Division of Engineering and Architectural Services, Facilities Engineering Section, Building Commissioning Case Study.

Jump, D., Denny & M., Abesamis, R., (2007), Tracking the Benefits of Retro-Commissioning: M&V Results from Two Buildings, *National Conference on Building Commissioning*: 2007, May 2-7.

LBNL (2008). Center for the Built Environment, 2008. CBE Occupant Satisfaction Survey LBNL Building 90, University of California, Berkeley.

LBNL. (2009). "Toward the Holy Grail of Perfect Information: Lessons Learned Implementing an Energy Information System in a Commercial Building" Building Technologies Department, Lawrence Berkeley National Laboratory.

McKew, H., (2010). A Failure to Plan is a Plan to Failure, Tomorrows Environment, *Engineered Systems, BNP Media,* 2010, February www.buildingsmartsoftware.com, 74 (visited 2010, January 27).

Mills, E. (2011). Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions in the United States, *Energy Efficiency, 4*(2), 145-173.

Mills, E., Bourassa, N., Piette, M.A, Friedman, H., Haasl, T., Powell, T., & Claridge, D. (2005), The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings, *National Conference on Building Commissioning*: 2005, May 4-6.

McCown, P. (2011). Commissioning of a LEED-EB gold certified office building. *Energy Engineering: Journal of the Association of Energy Engineering*, 108(1), 42-54.

Opfer, N. & Shields, D. (2010). Building commissioning for energy efficiency. *AACE International Transactions*, 732-740.

Pekalski, A., Dasher, C., & Stum, K. (2000). Commissioning public buildings in Oregon: Market transformation via the public sector. *Proceedings ACEEE Summer Study on Energy Efficiency in Buildings*, 4257-4266.

Stein, J. (2008). Lawrence Berkeley National Laboratory, Building 90 - HVAC Analysis, Taylor Engineering, Alameda, CA: Taylor Engineering.

WDG Project Management Committee. (2010). Whole Building Design Guide, Document Compliance and Acceptance, http:/wbdg.org/project/doc_comp.php (visited 2011, October 24).

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The work described in this report was funded by the National Science Foundation, Award No. HRD-0802628. The authors would like to acknowledge the assistance of the building monitoring team, including Dale Sartor, Girish Ghatikar, Rick Diamond, Geoffrey Bell, Steve Greenberg, Steven Lanzisera, John Fiegel, John Wunderlich, Jessica Granderson, and Dave Watson.

.

Disclaimer