Linking energy and maintenance management for sustainability through three American case studies

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Abstract

Purpose – The purpose of this paper is to present the findings and lessons learned from three case studies conducted for facilities located in California, North America. The findings aim to focus on energy and maintenance management practices and the interdependent link between energy and maintenance.

Design/methodology/approach – The research is based on a positivist epistemological philosophical approach informed by action research. The research cycle was completed for each case study. A case study report was provided to each facility management team to foster collaboration with the researcher and to document case study process and results.

Findings – Composite findings of the case studies include: there is an interdependent link between energy and maintenance management; reactive maintenance and energy management methods are commonly used; and more proactively operated and managed buildings require the interdependent link between energy maintenance management to be better understood.

Research limitations/implications – The three case studies were located in California. Although the case study results can be generalized, determination of how to generalize and apply the results to commercial buildings outside of the USA is beyond the scope of this paper.

Practical implications – Detailed discussion of the needs of the three facility management teams are discussed by identifying a current challenge, developing a solution and documenting lessons learned using the research cycle.

Originality/value – The paper seeks to demonstrate the interdependencies of energy and maintenance management, two topics which are often researched interdependently. Additionally, the paper provides insight about maintenance management, a topic often cited as being under researched.

Keywords Action research, Automation, Case studies, Energy management, Maintenance, Mechanical systems, United States of America

Paper type Case study

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1. Introduction

The premise of this paper is to investigate the link between energy and maintenance management to enhance the capabilities of facility managers to deliver on sustainability. Commonly, maintenance management and energy consumption are two key focus points of facility managers. Building automation systems (BAS) and computerized maintenance management systems (CMMS) are two tools that can be used to help manage maintenance and energy information. Although BAS and CMMS have many benefits, these systems are complex and fully utilizing such systems can be challenging. It has been documented that although a large amount has been written on the value of energy management and building automation systems, for every BAS that is operated successfully, there are hundreds that are underutilized and incapable of achieving basic energy savings (Rios, 2005). Brambley *et al.* (2005) find that a lack of systematic information exists to address the causes, find solutions and determine the financial payback of possible solutions. These statements are quantitatively supported by a study of 60 commercial buildings conducted by Piette and Nordman (1996). Piette and Nordman (1996) found that more than half of the 60 buildings studied had temperature control problems, 40 percent had heating, ventilating and air conditioning (HVAC) equipment problems and about 33 percent had improperly operating sensors.

Similar findings exist within maintenance management literature. Liddiard *et al.* (2007) suggested that maintenance management systems "may not be as useful as they should be" and that there is room for the quality of the data populated into these systems to be improved. In practice, industry experts find that successful implementation of CMMS is a continued challenge (Sapp, 2008). In fact, about 50 percent of CMMS implementations are not successful (Berger, 2009). The challenge of successful CMMS implementations could be impacted by the mentality that building maintenance has been historically based on a reactive "put out the fires" mentality (Price, 2006).

Although often viewed as independent challenges, an important interdependency, with impacts on sustainability, exists between energy and maintenance management of building mechanical systems. As shown in Figure 1, proper maintenance is necessary to achieve optimal energy performance, while energy performance data is needed for effective maintenance management. When the tensions between energy performance and maintenance practices are balanced, buildings operate efficiently. Efficient operation of buildings will result in decreased energy and maintenance costs and reduced environmental emissions. Understanding the link between maintenance management and energy performance is also important to meet sustainability goals.

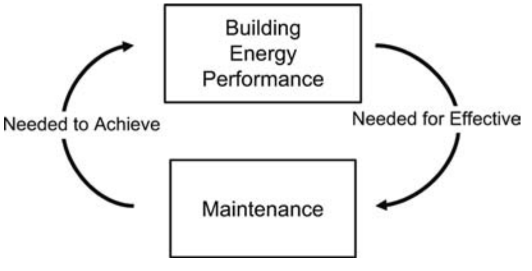

Figure 1.
Link between building energy performance and maintenance

To meet aggressive energy goals, such as zero energy buildings, it is important that processes are in place to more fully utilized BAS and CMMS.

1.1 The link between energy and maintenance management

Without proper maintenance, even the most efficiently designed building with high reaching energy efficiency goals will not achieve its energy goals. As mechanical systems are used to heat and cool a building, system performance degrades and sensors and meters drift out of calibration. If the systems are not maintained, they begin to consume more energy due to equipment wear and the data collected by the meters and sensors will become of little value as sensors and meters drift out of calibration (Better Bricks, 2010). Despite a general understanding of this topic, many buildings do not have effective maintenance programs in place. Although many commercial buildings have CMMS to assist with maintenance management decisions, data collection and record keeping, many industry experts find that CMMS are underutilized and not effectively used (Sapp, 2008).

BAS are also often underutilized and not effectively used (Piette and Nordman, 1996). A BAS is the "heart" of a building mechanical system, providing computerized logic to command system components on/off, cycle equipment at different speeds, trend and manage operations and performance data, and maintain comfortable conditions within buildings. BAS have extensive capabilities to collect, trend and report energy performance data. Unfortunately, BAS typically operate at extremely elementary levels of control (Hartman, 2000).

The challenge of underutilization of both CMMS and BAS strengthens the need to further understand the interdependencies between energy performance and maintenance. It is clear that there is a lack of structured methods which inhibits facility managers from proactively managing buildings and reaching their maintenance, energy performance and sustainability goals. This increases building energy consumption and operation costs. When facility managers have an increased understanding of the relationship between energy performance and maintenance, they will be able to better utilized BAS and CMMS to effectively and economically to improve building operation.

2. Methodology

Epistemologically, this paper uses a positivist approach to complete three case studies in North America. A positivist approach is used to form a question and seek an answer to the question for each case study. To seek answers to the questions, an action research method of inquiry was used. Action research is an inquiry-based process, grounded in qualitative techniques, to gather information about professional practice and the practitioner's thoughts about the practice (Stringer, 2007). It provides a systematic method to find effective methods to problems practitioners encounter in their daily professional lives by focusing on specific or localized situations. It requires a collaborative approach of inquiry and building relationships between the researcher and the practitioner. The goal of action research is to make a difference for the practitioner and the practitioner's clients (Stringer, 2007), often with a goal of resolving organizational issues. Action research also seeks to have implication beyond the immediate research case, being able to provide solutions that inform other contexts (Saunders *et al.*, 2007).

To complete the case studies, the concepts of action research were used to complete the research cycle. As stated by Booth *et al.* (1995), the research cycle consists of four phases. First, a practical problem is identified. This problem motivates the research question. The research question is then used to define the research problem. The answer or answers to the research problem helps to solve the practical problem (Booth *et al.*, 1995). This research cycle is used to frame the three case studies.

3. Case studies

Three case studies were conducted using action research inquiry. As stated by Stringer (2007), the role of the researcher is a resource person, taking the role of both a facilitator and consultant. Each case study started by having each of the three facility management teams identify a current challenge faced by the team. The three case studies consisted of a community college district, a laboratory building on a college campus and a medical facility BAS upgrade, all located in California, USA. These three facilities were selected because:

(1) They are three of the best customers of the fourth largest mechanical contractor in the USA, which has 400 customers.

(2) The facilities represented green (environmentally conscious), forward thinking facilities management groups, as demonstrated by having a strong commitment to the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED®) program and are committed to improving building management practices.

(3) The State of California has taken a more aggressive approach to energy management policy than many other states, such as Title 24, California's Energy Efficiency Standards for Residential and Nonresidential Buildings. Title 24 is more stringent that the more commonly used energy standard in the USA, ASHRAE 90.1 Energy Standard for Buildings Except Low-r ise Residential Buildings (Flamm, 2001). As a result, California building owners have sought out more advanced energy management practices.

3.1 Case study no. 1, district level study: Los Angeles Community College District

The Los Angeles Community College District (LACCD) is the largest community college district in the USA. It encompasses 884 square miles (2,290 square kilometers) within metropolitan Los Angeles and serves over 115,000 students. The LACCD Facilities Planning and Development team, of about 175 maintenance technicians and about 45 facilities administrators, manages over five million square feet (0.5 million square meters) of classrooms spread across nine community college campuses (see Figure 2), including several completed LEED® projects. LACCD is currently

Figure 2.
Los Angeles Community College District: Campus Buildings

completing $5.7 billion (US dollars) of renovation and construction projects, many which include renewable energy optimization, demand-side management and central plant construction.

The practical problem identified by the LACCD executive facility management team was that standard practices for neither energy nor maintenance management currently existed within the district. It was hypothesized that a lack of standardization attributed to decreased productivity and insufficient maintenance funds. The renovation and construction projects across the district were a large motivator to increase productivity by transitioning from reactive to proactive energy and maintenance management practices.

3.1.1 Research question and data collection. The research question for the LACCD case study was: "How should current energy and maintenance management practices be identified and quantified?" To answer this question, semi-structured phone interviews were conducted with eight facility directors, one lead HVAC technician, the director of facilities planning and development, the executive director of facilities and an engineering management consultant. Each telephone interview lasted about one hour and included standard series of open-ended questions asked of all interviewees.

The researcher documented the results of the interviews in a case study report. The report contained a summary of maintenance practices used, the frequency of each maintenance practice used, methods used to collect and analyze energy data, current challenges faced by the facility directors and recommendations to align strategic facility management goals with current practices.

3.1.2 Results, the research answer. The results of the case study found:

- Reactive maintenance practices were the most commonly used maintenance approach across the district.
- The use of preventive and predictive maintenance techniques was minimal.
- Most commonly collected maintenance records were work order requests submitted by faculty and staff.
- Building energy performance measurements was generally limited to the review of utility bills.

The largest challenges faced by the facility directors were: lack of staffing and funding, and lack of properly commissioned building automation systems. A few quotes from interview participants are provided below:

> I only have one guy. I should do more paperwork and less labor. However, I do more labor than paperwork. Hiring freezes impact the ability to hire.

> Staff and budget – we are completely short of both. I cannot maintain systems like I would like or how we should.

> We track energy costs, but do not have anything to compare against. The level of data is too high to be useful.

3.1.3 Feedback and completing the research loop. After sharing the case study results with the facility management team and in accordance with the research cycle, LACCD engaged the researcher as a consultant to work with the team to determine the criteria for a district-wide CMMS. Starting the planning process for a district-wide CMMS demonstrates that the research cycle was completed, as the results of the research answer were applied to help solve a new practical problem.

3.1.4 Lessons learned. The following lessons were learned during the case study and the CMMS selection criteria determination:

- Transitioning from a reactive maintenance program to a proactive maintenance program is a complex process that requires changes in both technologies and process used. The time required for educating and seeking buy-in from stakeholders who will use the new technologies and processes can take several years. Process changes often take more time and stakeholder engagement than the technology implementation.
- The understanding of the value of documenting maintenance information, such as parts used and labor hours to complete a maintenance activity varies greatly between the facility director and the facility executive. Facility directors generally concluded that documentation takes too much time and reduces the time technicians can be in the field performing maintenance. Whereas, the facility executive concluded that documentation is critical to the efficiency maintenance management.

3.2 Case study no. 2, single building study: University of San Francisco, Mission Bay Campus Rock Hall

Rock Hall, a highly instrumented laboratory building at the Mission Bay campus of the University of California: San Francisco (UCSF), USA, was selected for the single building case study (see Figure 3). The 176,000 square foot (16,400 square meters) building was completed in November 2003. A retro-commissioning project for the building was completed in 2005. The building is managed by the UCSF Facilities Management Group. The group manages about three million square feet (279,000 square meters) of laboratory, office and classrooms.

At the time of the case study, the Facilities Management Group was pursuing Leadership in Energy and Environmental Design for Existing Buildings (LEED-EB®)

Figure 3.
University of San Francisco, Mission Bay Rock Hall Building

Version 2.0 Silver certification, a program developed and administered by the United States Green Building Council (USGBC). As part of the LEED-EB efforts, Credits EA 5.1 and 5.2: Performance Measurement Enhanced Metering was sought. To earn these credits requires quarterly metering reports to be submitted to the USGBC. To assist in this process, the facility management team wanted to automate the process to collect, manage and analyze energy performance data using the BAS. As a result, the practical problem identified for the case study was manual calculation of quarterly building energy performance is very cumbersome and time consuming.

3.2.1 Research question and data collection. Given the challenges with the manual energy performance calculations, the research question was: How can the process be automated? As a result of this research question, the goal of the case study was to determine the requirements for a partially-automated building performance scorecard. The scorecard developed during the case study was intended to be used by the energy engineers, operators and facility managers on a quarterly basis to proactively evaluate and benchmark building energy performance. The facility management group also sought to use the findings from this study as a pilot project that could be applied to other university buildings.

To develop the scorecard, an in-person project kick-off meeting was scheduled to discuss the project goals and define the project scope. To collect additional information, conference calls were scheduled as needed with the project team. In addition, building automation documents (points lists, BAS screens, and equipment data sheets) and the 2005 retro-commissioning report were reviewed.

3.2.2 Results, the research answer. The end result of the case study was a report that was provided to the facility management team's building automation system technician. The report included directions of how to use the scorecard and the data and equations needed by the technician to program the building automation system to collect data for five energy indicators:

(1) Overall building energy consumption in units of BTU/SF/year (W/m^2/year).

(2) Energy consumption per source for electricity in kW/SF (W/m^2) and natural gas in BTU/SF (W/m^2).

(3) Overall chiller load in kW/ton.

(4) Overall ventilation load for air handlers in CFM (L/s).

(5) Peak electrical demand in kW.

3.2.3 Feedback and completing the research loop. A six-question questionnaire was sent to five members of the facility management team at the end of the project to evaluate if the case study goals where achieved. All five members of the team completed the questionnaire. The results of the questionnaire found that the final scorecard exceeded expectations of 60 percent and met expectations by 40 percent of the facility management team. The most valuable parts of the scorecard were that the scorecard was a single standardized tool that could be customized by the facility management team to meet specific needs; the tool included both energy efficiency and operational metrics and used graphs to represent data. One shortcoming of the scorecard was that it did not include cost data.

The research loop was completed because the case study report was discussed with the facility management team's building automation system technician and the report recommendations were implemented by the facility management team in 2009. From correspondence with the Director of Facilities Management "a campus wide scorecard for all buildings that provides energy consumption per unit area each month was a first step in implementing the recommendations." In May 2010, software was procured to implement the other metrics recommended. The facility management team plans to have the software implemented by the end of the 2010 calendar year.

3.2.4 Lessons learned. The following lessons were learned during the case study:

- The BAS points and type of points needed by the operators are not necessarily the same points needed to track energy performance. For example, many of the points were setup as change in value for the operation of the system. However, when tracking energy performance data, collecting data at a specified time interval allows data to be normalized more accurately.
- The primary function of BAS is to control equipment, not necessarily to track energy performance. Completely automating the scorecard was not possible, as the electric and natural gas meters were not connected to the BAS. Additionally, a report generator and customized reports was needed to develop the scorecard.

3.3 Case Study no. 3, central plant BAS upgrade: Sutter Medical, Sacramento Sutter Medical Facility

Sutter Health owns and operates 26 affiliate hospitals in northern California. The case study was completed for the facility management group at the Sacramento Sutter Medical Center (see Figure 4). The Sacramento facility was in the process of replacing an existing building automation system (BAS) from the mid-1980s with a new Siemens APOGEE® building automation system during the completion of the case study. The replacement of the control system occurred in conjunction with the construction of a new women's and children's hospital and a mixed use diagnostic and clinical building for the Sutter Medical Foundation.

3.3.1 Research question and data collection. The practical problem identified by the Sutter Medical facilities team was that hospitals are very energy intensive. The research question was: "What information can be provided to a very busy project team to encourage further consideration of energy efficiency when life safety is the primary focus in a hospital environment?" A project kick-off meeting was held with the project team to further discuss the research question. Following the project kick-off, phone and e-mail correspondence occurred to narrow the pilot study scope and collect necessary

Figure 4.
Sutter Medical Central Plant

information. Project documents, including basis of design narratives and building control system product data sheets, were also reviewed.

The goal of the case study was to document and create a methodology to implement a building energy performance program for the new BAS. The case study report was developed to serve as a road map for the facility management team to move towards a proactive building energy performance program. One of the challenges with the Sutter Medical case study team was that the team was very busy and less able to engage in the case study than the other two teams in cases studies 1 and 2. Thus, the end goal of the case study was to provide a very concise case study report to the facility management team that could be used to form the foundation of an energy efficiency road map.

3.3.2 Results, the research answer. To create the road map, three one-page documents were developed to summarize the top three energy performance program needs within the case study report. The one-page documents included:

- An energy program planning pyramid.
- A sensor de-calibration detection guide.
- A critical equipment selector guide.

The energy program planning pyramid is a set of bounded steps to help the facility management team to plan, implement and refine an energy management program. Each bounded step is represented by a box within the pyramid. Using a bounded step approach, facility managers will be able to incrementally develop an energy management program, while also completing other daily responsibilities.

The sensor de-calibration detection guide provides guidance to develop a sensor calibration and re-calibration plan, as well as tips to consider during plan development. It is important to re-calibrate sensors because they drift outside of tolerance over time. As a result, the BAS actions may not be triggered as needed for proper system operation and/or the value of trend data for energy analysis is reduced.

The critical equipment selector guide outlines a tool that could be used to help facility management teams quantitatively determine the tradeoffs between energy efficiency and equipment criticality. Determining the criticality of equipment is especially important in a hospital, as hospitals often operate 24 hours per day, have stringent air quality and ventilation requirements and have significant potential for energy and cost savings. However, mission critical needs of a hospital must not be sacrificed to reduce energy consumption or utility bills.

3.3.3 Feedback and completing the research loop. A seven-question questionnaire was sent to the five members of the facility management team at the end of the project to evaluate if the case study goals where achieved. Three members of the team completed the questionnaire. The results of the questionnaire found that the results of the case study met expectations by two participants and exceeded expectations of one participant. Of the three one-page summary documents, the energy program pyramid was found to be of greatest value by all three participants. The energy program pyramid was found to be of greatest value because it was an easy map to understand and helped the user to focus on key areas and is the basis for the remainder of the other two tools. Two quotes from the survey about the value of the energy program pyramid include:

> It is an easy map to understand and quickly focuses your attention on key areas.

> As we build out the campus, we can begin to monitor and program our systems to get a better cost saving structure with our utilities.

The sensor de-calibration guide was found to be of least value by two participants. One participant found the critical equipment selector to have the least value. Least value was defined based on the regulatory nature of the health care industry, a risk assessment is needed whenever new equipment is installed and the daily responsibilities of the participants.

Although the researcher provided the completed case study report to the facility management team, it is uncertain if the research loop was complete. The researcher was unable to determine if the recommendations of the case study report were implemented.

3.3.4 Lessons learned. The following lessons were learned during the case study:

- Cost and energy savings alone are not significant enough to motivate change within a large organization. Day-to-day responsibilities and process changes require direction from executive decision makers and buy-in across the entire organization to encourage energy efficiency.
- Hospitals are large energy consumers; however, the criticality of operation increases the complexity of energy efficient operation.
- The culture and structure of an organization and project teams greatly influences how new ideas are embraced.

4. Composite findings

From a positivist epistemological philosophical approach informed by action research, the findings of the case studies can be generalized. Two main themes emerged from the three case studies. First, maintenance and energy management practices are generally reactive. The primary reactive energy management practice revealed during the case studies was the use of utility bills to make energy management decisions. Using energy bills for decision making is reactive because the bills provide one historical energy consumption data point for the whole building or multiple building level. When only historical whole building energy consumption data is available, it is difficult to determine sources of energy waste. Reactive maintenance management practices were demonstrated through multiple discussions of "fire fighting," responding to one maintenance management emergency to the next with little or no time for planning. Additionally, the need for re-commissioning or retro-commissioning of heating, ventilating and air conditioning systems and BAS was a common theme across the three case studies. This may suggest that proactive maintenance and/or continuous commissioning could reduce this need.

The second theme that emerged was that cost and energy savings alone are not sufficient motivators for organizational change to move from reactive to proactive maintenance. Organizational change requires a transitional period. During the transitional period by-in from team members at all levels of the organization must be sought, training must be provided and new business processes must be planned and implemented in order to advance the sustainable management of facilities. Transitioning from a reactive to proactive energy and/or maintenance management approach requires synthesized knowledge of technology, processes and people. Stated in the context of sustainability, to move from reactive to proactive energy and/or maintenance management processes requires a structured balance of people, economic and environmental decision criteria.

5. Conclusion

Three case studies were completed using an action research method of inquiry. The composite results of the pilot case studies demonstrate that there is an interdependent link between energy and maintenance management. However, current energy and maintenance management practices of the three case studies discussed within this paper demonstrate that this interdependent link is not widely embraced in practice. If the link were widely embraced, energy and maintenance management practices would be more proactive.

The results of the case studies allowed the researcher to conclude that tools are needed to assist facility managers to plan and implement energy and maintenance management programs. As a result of this finding, a Framework to Improve Building Operating Decisions is being developed. More information about the framework can be found at the web site, www.improvebuildingperformance.com

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