# Linking Energy and Maintenance Management to Improve Knowledge Transfer within Building Operation and Management

Lewis, A.
University of Reading
(email: a.lewis@student.reading.ac.uk)
Elmualim, A.
University of Reading
(email: a.a.elmualim@reading.ac.uk)
Riley, D.
The Pennsylvania State University
(email: driley@engr.psu.edu)

## Abstract

Smart, sustainable buildings often utilize sophisticated mechanical and building controls systems to provide energy efficient strategies to meet comfort conditioning requirements and sustainability organizational expectations. To ensure mechanical and building control systems operate as designed and align with best practices, an integrated operations and maintenance approach must be understood and applied. The integrated approach must recognize and apply the interdependencies between energy and maintenance management. To study the interdependencies between energy and maintenance of mechanical equipment and building control systems, three case studies were conducted. The case studies consisted of a community college district, a university laboratory building and a medical center renovation. Using the findings from the case studies, a framework to link energy and maintenance management decision making for mechanical systems, building automation systems (BAS) and computerized maintenance management systems (CMMS) is being developed. The framework will provide a question-driven structure to help stakeholders manage and transfer knowledge between four technical thrusts and the human factor. The end goals of the framework are:

- Help promote best practice sharing across the industry
- Provide a method for knowledge transfer
- Promote the understanding and use of smart and intelligent building technologies

**Keywords:** case studies, energy efficiency, facility management, maintenance, mechanical systems

# 1. Introduction

Maintenance management and energy consumption are two key focus points of facility managers. Building automation systems (BAS) and computerized maintenance management systems (CMMS) 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 control systems, for every building control system that is operated successfully, there are hundreds that are underutilized and incapable of achieving basic energy savings (Rios 2005). Brambley, Haves 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 a study of 60 commercial buildings by Piette and Nordman (1996): 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 the literature about maintenance management, although maintenance management literature, especially academic maintenance research, is uncommon. For example, although CMMS can provide many benefits for maintenance management, 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). Ring (2008) finds that it is not uncommon for commercial buildings to suffer from insufficient proactive maintenance, erroneous maintenance work, unsound and non-institutionalized maintenance practices, unnecessary preventative maintenances, inability to track and visually find maintenance problems, blind acceptance of Original Equipment Manufacturer (OEM) recommendations, variability of preventative maintenance practices between like or similar units, and the use of ineffective preventative maintenance technology.

Although often viewed as independent challenges, an important interdependency exists between energy performance and maintenance 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. To meet aggressive energy goals, such as zero energy buildings, it is important that processes are in place to fully utilized BAS and CMMS.

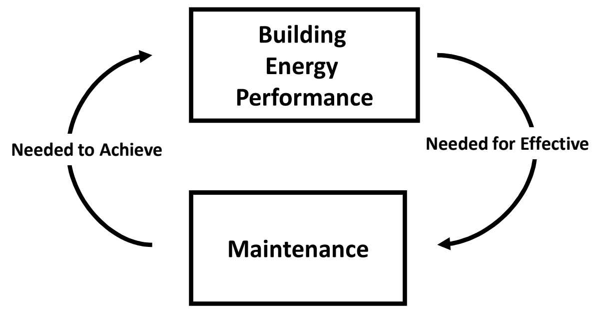

Figure 1: Link between building energy performance and maintenance

## 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 reach its energy goals. As mechanical systems are used to heat and cool the building over the building life, 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. Despite a general understanding of this topic, many buildings do not have effective maintenance programs in place. Ring (2008) has found that it is not uncommon for commercial buildings to suffer from insufficient proactive maintenance, erroneous maintenance work, unsound and non-institutionalized maintenance practices, inability to track and visually find maintenance problems, and variability of preventative maintenance practices between like or similar systems. Although many commercial buildings have computerized maintenance management systems (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).

Building automation systems (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 at different speeds, trend and manage operations and performance data, and maintain comfortable conditions within buildings. Rios (2005) has found that for every BAS that is operated successfully, there are hundreds that are underutilized and incapable of achieving basic energy savings. A study of 60 commercial buildings by Piette and Nordman (1996) found that more than half of the buildings studied had temperature control problems, 40 percent had mechanical system problems and about 33 percent had improperly operating sensors. 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 a current lack of structured methods inhibits facility managers from effectively managing buildings and reaching their maintenance and energy performance 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 effectively and economically to improve building operation.

## 2. Case studies

Three case studies were conducted using an action research approach. 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. 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 sees to have implication beyond the immediate research case, being able to provide solutions that inform other contexts (Saunders, Lewis et al. 2007).

The role of the researcher in action research is to be resource person, taking a facilitator or consultant role, opposed to an expert. Finally, when using an action research approach, the researcher must start where the people are, not where someone else thinks they are (Stringer 2007).

Given this approach, it is very appropriate that the research started with a question from a practitioner. A mechanical system contractor and service provider asked, "Why is it that when our firm goes into the field to perform maintenance on a BAS installed one year ago, it is being used as a time clock?" In other words, why is the BAS no longer functioning as it was after it was commissioned one year earlier?

Building on this question, the researcher was given the opportunity to work with three of the contractor's clients to conduct three case studies. The three case studies included a community college district, a laboratory building on a college campus and a medical facility BAS upgrade, all located in California, United States. These three facilities were selected because:

- They are three of the best customers of the fourth largest mechanical contractor in the United States, which has 400 customers.

- The facilities represented green, forward thinking facilities management groups, as demonstrated by having a strong commitment to LEED® and are committed improving building management practices.

- The State of California also has taken a more aggressive approach to energy management policy than many other states (such as Title 24). As a result, California building owners have sought out more advanced energy management practices.

## 2.1 2.1 Case study #1, District Level Study: Los Angeles Community College District

The Los Angeles Community College District (LACCD) is the largest community college district in the United States. It encompasses 884 square miles (2290 square kilometres) 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 5 million square feet (0.5 million square meters) of classrooms spread across 9 community college campuses, including several completed Leadership in Energy and Environmental Design (LEED®) projects. LACCD is currently completing $5.7 billion (US dollars) of renovation and construction projects, many which include renewable energy optimization, demand-side management and central plant construction.


Figure 2: Los Angeles Community College District: Campus Buildings

### 2.1.1 Case study goal

The goal of the LACCD case study was to document current maintenance and building energy management practices and current challenges across the 9 campuses. The results of the case study were documented in a case study report completed August 2008. 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.

### 2.1.2 Data collection

To collect the data, phone interviews were conducted with 8 facility directors, 1 lead HVAC technician, the Director of Facilities Planning and Development, the Executive Director of Facilities and an engineering management consultant. Each phone interview lasted about 1 hour and included standard series of open ended questions asked of all interviewees.

### 2.1.3 Results and feedback

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 collect 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.

After sharing the case study results with the facility management team, LACCD hired the researcher to work with the team to determine the criteria for a sophisticated computerized maintenance management system. The work done after completion of the case study demonstrated that LACCD is committed to transitioning from reactive to proactive maintenance and energy management practices.

### 2.1.4 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 are 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.

## 2.2 Case study #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), United States, was selected for the single building case study. 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 3 million square feet of laboratory, office and classrooms.

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

### 2.2.1 Case study goal

At the time of the case study, the Facilities Management Group was pursuing certification for certification for Leadership in Energy and Environmental Design for Existing Buildings (LEED-EB®). The goal of the case study was to determine the requirements for a semi-automated building performance score card. The score card was to support LEED-EB Energy and Atmosphere credits EA5.1 and EA5.2: Performance Measurement Enhanced Metering. To earn these credits requires that quarterly metering reports be submitted to the United States Green Building Council (USGBC).

The score card was also 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 UCSF buildings.

### 2.2.2 Data collection method

To develop the score card, 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, building automation documents (points lists, BAS screens, and equipment data sheets), and the 2005 retro-commissioning report were reviewed.

### 2.2.3 Results and feedback

The end result of the case study was a report that was provided to the facility management team's building automation system technician completed in May 2009. The report included directions of how to use the score card and the data and equations and needed by the technician to program the building automation system to collect data for five energy indicators:

- Overall building energy consumption in units of BTU/SF/year (W/m2/year)

- Energy consumption per source for electricity in kW/SF (W/m2) and natural gas in BTU/SF (W/m2)

- Overall chiller load in kW/ton

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

- Peak electrical demand in kW

A 6 question questionnaire was sent to the facility management team at the end of the project to evaluate if the case study goals where achieved. The findings of the questionnaire were:

- The final score card exceeded expectations of 60 percent and met expectations by 40 percent of the facility management team

- The most valuable parts of the score card were:
    - Provided a tool to include energy efficiency within building operations metrics
    - A single standardized tool that can be customized
    - Graphs used to present data

- The inclusion of cost data would add value to the score card

### 2.2.4 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 score card was not possible as the electric and natural gas meters were not connected to the BAS. Additionally, customized reports needed to be developed in order for the score card to be developed.

## 2.3 Case study #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. The Sacramento facility was in the process of replacing an existing building automation system (BAS) from the mid 1980's with a new Siemens APOGEE® building automation system. The replacement of the control system is occurring 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.

Figure 4: Sutter Medical Central Plant

### 2.3.1 Goal

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 Sutter to move towards a proactive building energy performance program.

### 2.3.2 Data collection method

A project kick-off meeting was held with the project team. Following the project kick-off, phone and e-mail correspondence occurred to narrow the pilot study scope and collect necessary information. Project documents, including basis of design narratives and building control system product data sheets were reviewed.

### 2.3.3 Results and feedback

To create the road map, 3 one-page summary sheets were developed to summarize the 3 most needed energy performance program needs within the case study report completed in July 2009. The summary sheets included:

- An energy program planning pyramid

- A sensor de-calibration detection guide

- A critical equipment selector

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 the bounded step approach, facility managers will be able to incrementally develop an energy management program, while also completing other daily responsibilities.

The critical equipment selector is tool to help the facility management team 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.

The sensor de-calibration detection guide provides facility managers with 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 building control system actions may not be triggered as needed for proper system operation and/or the value of trend data for energy analysis is reduced.

A 7 question questionnaire was sent to the facility management team at the end of the project to evaluate if the case study goals where achieved. The findings of the questionnaire were:

- The results of the case study met expectations by 2 participants and exceeded expectations of 1 participant.

- The energy program pyramid was found to be of greatest value by all 3 participants. The energy program pyramid was found to be of greatest value because:

    - It is an easy map to understand and helps the user to focus on key areas

    - It is the basis for the remainder of the other 2 tools

- The sensor de-calibration guide was found to be of least value by 2 participants. One participant found the critical equipment selector to have the least value. Least value was assess by the regulatory nature of the health care industry requires a risk assessment whenever new equipment is installed and daily responsibilities of the participants.

### 2.3.4 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 direction from executive decision makers are needed to encourage energy efficiency.

- Hospitals are large energy consumers; however, the criticality of operation increases the complexity of energy efficiency.

- The culture and structure of an organization and project teams greatly influences how new ideas are embraced.

## 3. Framework concept development

The case study findings and support from literature allowed the researcher to conclude that facility managers need tools to help plan and implement maintenance and energy management programs. To help meet this need, a building operations decision framework is being developed. The framework will provide a systematic, structured and measurable approach that can be readily applied by facility managers for making energy and maintenance management decisions.

Within the research, a framework is defined as a structure to study, discuss and develop an approach for practitioners to understand the interdependencies between energy and maintenance. The framework will be used to apply the understanding of the interdependencies through defined, actionable steps in the form of recommendations.

The framework will:

- Be a simple, robust, question-driven decision analysis tool for maintenance and building energy management planning, implementation and continuous improvement

- Help to transfer knowledge of energy and maintenance management best practices by providing guidance about how to more fully utilize smart technologies to improve building energy efficient and reduce maintenance costs

- Help facility managers to collect repeatable, verifiable maintenance management and building energy performance data for mechanical systems

- Be tested through an efficient process using test case studies

The primary users of the framework will be practicing facility managers who manage single buildings or campuses of buildings. Consultants to facility managers and building owners, such as facility management consultants, maintenance management consultant and energy engineers will also benefit from using the framework.

## 3.1 Framework components

As the 3 case studies were completed, 4 main thrusts emerged (Figure 5):

- Energy performance program planning
- Energy performance program implementation and refinement
- Maintenance program planning
- Maintenance program implementation and refinement

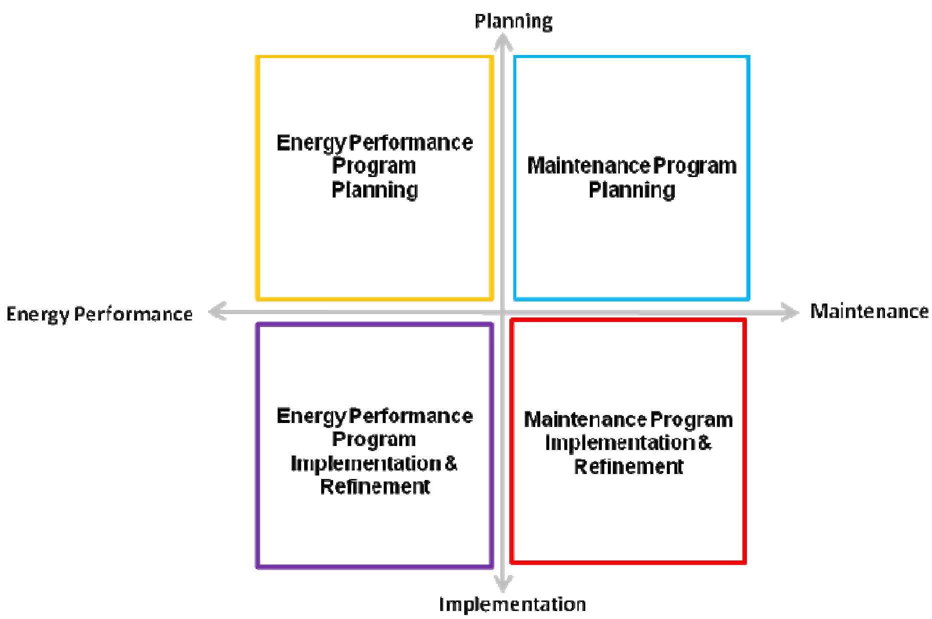


Figure 5: Framework Level 1: Four technical framework thrusts

After review of the 4 thrusts by a team of facility managers, a fifth thrust was added: the human factor. The human factor acknowledges that a planning or implementation process cannot occur without the interaction of team members and that the success of a project is limited by the abilities and motivations of the team members and their ability to interact and communicate effectively. It also acknowledges that the level of sophistication of a plan or project implementation cannot exceed the technical competence of the team who will be implementing the plan or the users of the end product.

Several tensions exist between the human factor and the 4 technical thrusts:

- Return on investment (ROI)
- Competencies and skills of the facility management team
- Strategic goals

Level 2, the *Framework Architecture*, (Figure 3) depicts the relationship between the technical thrusts and the human factor, as well as the tensions and flow between components. Planning is followed by implementation, and implementation results in a balanced operations program. A balanced program achieves equilibrium between facility goals, planning, and implementation; acknowledging limitations created by tensions.

Within this conference proceeding, the framework development is limited to Levels 1 and 2. Several other framework components have been developed or are also under development, including the *Needs Assessment*, *User Interface*, *Framework Tool Summary Sheets* and *Implementation Evaluator*. More information about the framework components not covered within this proceeding can be found at the research project website: [www.improvebuildingperformance.com](www.improvebuildingperformance.com).

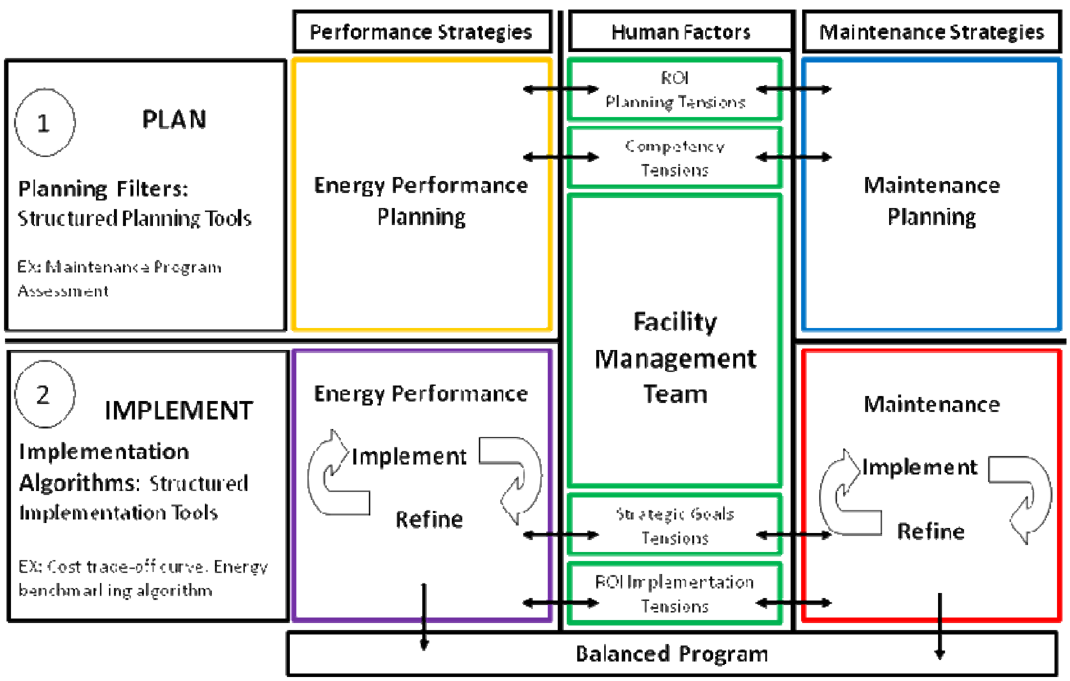


Figure 6: Framework Level 2: Framework Architecture

# 4. Further research

At the time this paper was submitted, the conclusions of Current Practices, Challenges and Needs of Maintenance and Energy Management Programs Survey to inform the framework development was recently completed. The next steps of the research are to test the Needs Assessment and to develop the coding structure for the User Interface. After the User Interface is developed, it will be tested by a pool of facility management, energy management and maintenance management practitioners.

# 5. Conclusion

Three case studies were conducted to study the interdependences between energy and maintenance management. 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 currently in development. The goals of the framework are to help promote best practice sharing across the industry, provide a method of knowledge transfer, and promote the understanding and use of smart and intelligent building technologies. More information about the framework can be found at www.improvebuildingperformance.com.

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