Title
Trends in Energy Management Technologies - Part 5: Effectiveness of Energy Management Systems: What the Experts Say and Case Studies Reveal

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Trends in Energy Management Technology – Part 5

Effectiveness of Energy Management Systems: What the Experts Say and Case Studies Reveal

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Introduction and Background

Introduction

It is common to hear these contradictory statements:

- A high proportion of (larger) federal buildings have some type of building management system (BMS) that is used to operate the building and manage energy use. [1]
- Virtually all building practitioners feel it is necessary for a building to have one of these systems.
- It is widely believed that BMSs are not as effective as they could be, especially in terms of saving energy, indicating some deficiency in the product offerings.

These are only three of a number of statements we have collected from anecdotal information that raise questions about the effectiveness of installed BCS/EMCS systems.

In the previous articles in this series we focused on the state of practice of building control systems (BCS) and the underlying technology including assessments of newer offerings that can be classified as energy management, control, and information systems (EMCIS). The purpose of this article, which is the last in this series, is to address the issue of BCS effectiveness in Federal buildings by evaluating the authenticity of statements like those above.

Through a variety of techniques outlined below, we gather information from federal facility managers and knowledgeable industry experts to assess these perceptions. We believe that the conclusions reached in this study will convey to facility managers (and indeed all practitioners involved) that maximizing the potential of BMS technology requires adopting a comprehensive view of the entire environment within which the deployment of these systems exists. It is not just an issue of technological capabilities; design, installation, commissioning, operations, the building management structure and the interactions between all of these must be considered as well. Aligning all of these elements into a well-integrated team supportive of the overall goals is essential to achieving a highly effective system.

Background

A BMS is used to manage operations (i.e., physical operation/command and control, maintenance of mechanical and electrical systems, and management of occupant complaints, etc.) and energy, as well as to control HVAC and other facility functions. Recent trends in BMS offerings appears to emphasize the building management functions of these systems more than energy; energy management more and more is relegated to energy information systems (EIS). [Motegi et al. 2002] Current systems do, however, retain their direct digital control (DDC) functions as well as some ability to integrate with other functions such as facility access and lighting control. In this article we shift our focus from technical issues to understanding how existing BMS's are actually used, if their actual use is consistent with their capabilities, what types of problems, complaints,

[1] Here and throughout the report, we use BMS in a somewhat generalized way to represent a broad range of systems of various classifications such as BCS, BAS, FAS, EMCS, EMS.

and frustrations operators encounter when using these systems; i.e., how effective these systems are when actually installed in a building.

Organization of the Report

The remainder of the report is organized into five sections. The first section is a description of our approach and study methodology. The second contains an empirical, broadly stated, definition of effectiveness. The third section contains a summary of the results derived from the study and discusses the findings from expert interviews and case studies. The forth section provides an analysis and discussion of the results, and the fifth section a summary and conclusions.

Study Description and Approach

This study was accomplished using a combination of the following methods for organizing, collecting, and evaluating information:

Identify accepted beliefs

Create a list of the most salient accepted beliefs or claims about effectiveness of BMS technology for systems installed in Federal buildings.

Assess situation

Review demographics of BMS deployment in Federal facilities using CBECS and DOE/BTS data. Review past research and experience to identify primary factors that set the context of the study.

Define effectiveness criteria

Determine criteria for evaluating effectiveness.

Collect information

Conduct literature reviews (see references) and interview knowledgeable industry experts (nine industry experts were interviewed) to obtain anecdotal, experienced-based perspectives on existing systems. To determine potential for improvement, conduct interviews with researchers and developers working on new approaches to overcoming outstanding issues. Review results from previous work where GSA building occupants were surveyed.

Conduct case studies

Conduct "mini" case studies by questioning operations personnel at selected Federal building sites. Since a broad based survey was beyond the scope of this project, the cases studies are used to inform the perspective developed from the expert interviews. Five sites in GSA Region 9 were contacted based on building size (all greater than 100,000 GSF), age, use/activity, characteristics of the BMS (e.g., a mix of vendors was sought), and willingness of personnel to cooperate.

Analyze data and evaluate accepted beliefs

Using the various sources of data identified above, evaluate the authenticity of the accepted beliefs identified in the first task above.

What is Effectiveness?

It is difficult if not impossible to come up with a simple, quantifiable definition of effectiveness. The best we can do is look at the combination of various interrelated factors that together provide a perspective about how well these systems perform needed facility functions. It is not only the technical capabilities that matter, but also the organizational issues that affect how the system was designed, installed, and operated. Based on our experience and research for our previous papers, we developed the following definitions to help organize and categorize the primary factors that allow us to gain a perspective about BMS effectiveness. Throughout these discussions, it is assumed that all BMSs have the capability to perform basic DDC functions for HVAC control.

Technical effectiveness

How capable is the system in terms of:

- Communications, networking and control
- User interface
- Data monitoring
- Functionality/features tailored to facility needs i.e., ability to transform monitored *data* into *information* in a form that is useful to operations and management
- Support for integration and interoperability

Operational effectiveness

The degree to which the BMS is effective in supporting facility operations and maintenance (O&M):

1. Occupants:
    - Support maintaining and improving occupant satisfaction and productivity
    - Supports complaint/trouble call diagnosis and resolution
2. Facility maintenance and repair (M&R) and operational efficiency:
    - Provides information for building operations personnel
    - Is amenable to improving operations via changes in sequences and control algorithms
    - Provides relevant information for building/property managers
    - Supports scheduling and alarming functions
    - Allows for remote access
    - Provides relevant information for planning and building management
3. Energy performance:
    - Tracks equipment performance
    - Tracks energy use and/or savings
    - Facilitates changes to improve energy performance

Organizational effectiveness

Those institutional and industry factors that influence the ability to achieve high levels of operational effectiveness using a BMS:

1. Design and deployment:
   - Designed and specified according to owners intent[2]
   - Procured, installed, and commissioned successfully
2. Building/property management:
   - Management philosophy, priorities, and expectations
   - Management technical knowledge
   - Support for operator training
   - Budgets/financial constraints
3. Industry issues:
   - Relationships between vendors, engineers, contractors, and building management and operations personnel

Study Results

Accepted beliefs

Based on our experience and discussions with numerous building design and operations personnel, we prepared the following list that summarizes our perception of generally accepted beliefs about the overall state of practice of BMS implementations. Our goal is to investigate these and determine, to the extent possible using the methods outlined above, the veracity of these assertions and to provide insight into underlying issues.

- Almost all larger Federal buildings use a BMS; these systems are considered key to operating a building well.
- Keeping the occupant's satisfied and systems operational is the primary focus of operations staff. These systems are considered effective in this regard.
- The energy saving potential of BMSs is not fully realized.
- The implementation/deployment process for BMSs is very difficult and fraught with problems.
- In practice, there is a mismatch between the capabilities and sophistication of BMS technology and the ability to exploit them due to lack of skills and training..
- Vendors tend to hype the potential compared to what is actually delivered.
- Despite many claims and much hype, true interoperability has not been achieved.

Situation assessment

Demographics

According to the 1999 CBECS [EIA 2002] report there are 63,000 Federal non-residential buildings in the US. GSA, the largest civilian properties owner, owns and manages 8400 of these properties, 1600 of which are government owned [GSA 2005]. On a square foot basis, about 40% of these buildings have a BMS installed. In Table 1 BMS use in Federal and commercial buildings is compared. For this comparison, contrary to Table 1 of the first article in this series [Webster 2002], the Federal buildings totals were subtracted from CBECS data for all commercial (plus other non-federal governmental)

[2] Assumes one of the owner's intents is energy efficiency.

buildings. Furthermore, the CBECS commercial data was recomputed to be consistent with the basis of the 1993 Federal Buildings Supplemental Survey (FBSS) [EIA 1997] and divided into small (10-50k GSF) and large (>50k GSF) categories.[3] The CBECS Federal buildings data shown in Table 1 was derived from the distributions of building and BMSs in the FBSS. The table indicates that except for the number of large buildings, BMS use in the private sector is somewhat greater than in Federal buildings.

Table 1: Demographics of BMS use
(Based on 1999 CBECS and 1993 FBSS criteria)

	U.S. Stock	**Federal Stock**
By Total building *inventory*	**27%**	**21%**
Small buildings*	20%	16%
Large buildings	24%	38%
By Total building *floor area*	**48%**	**39%**
Small buildings	24%	16%
Large buildings	62%	51%

*Small buildings are defined as those in the range of 10-50,000 sf.

Building services environment

In recent years, outsourcing of building management services has been a dominant trend in the Federal government. While this is not unlike what has occurred in private commercial sector and the BMS products installed are no different, the scale and unique character of the "owners" and associated service environment dictates that we focus our study on experiences with Federal facilities. This service environment is one of the keys to understanding BMS effectiveness because it sets the context in which these systems are installed and used. For the purposes of this study, we have focused on buildings owned and/or operated by the general Services Administration (GSA), the Federal Government's largest landlord. In the GSA these services are either contracted (mostly at the region level) by GSA, or in some cases, (i.e., leased buildings), by the occupying agency or private owners. The GSA buildings we studied (four of the five buildings studied) all used the former model; government owned with services contracted by GSA.

Literature review

A brief literature review identifies some of the potential benefits and issues related to deploying and upgrading BMSs. For example, it has been demonstrated] that high quality monitoring and appropriate trending capabilities can improve energy performance and reduce O&M costs. Energy savings of 20% and a reduction in trouble calls were achieved with the prototype high quality monitoring system installed in a 100k GSF San Francisco office building. [Piette et al. 1999]

[3] The FBSS study also excluded warehouses and religious buildings.

The value of commissioning buildings and BMSs was demonstrated in a large study conducted by Mills and others [Mills et al. 2004]. Sixty nine existing buildings were studied to determine measures implemented and cost and savings derived from the commissioning effort. Average energy savings of 18% were reported with paybacks of less than 5 years. Since many of the measures implemented were operations and controls related, these results indirectly indicate the potential for BMSs that are properly operating.

A study by LBNL identified energy savings of about 9% associated with EMCS retrofits in a San Francisco Federal building. [Diamond et al.1999]. As a part of that study, operators reported a high degree of satisfaction with a new more capable BMS and in fact staffing was reduced by ~50%. However, it was noted that the BMS was used primarily for operations and was used little for energy management.

A prototype central monitoring system, GemNet, was installed in GSA Region 9 in an attempt to improve energy performance and reduce cost of operations. While some success was achieved, it appears that there are still a number of technological and operational issues that need to be resolved before the value of these systems can be demonstrated (see discussion below on Potential Improvements). Among these were high maintenance and cost of the central monitoring interface, slow network response, and unavailability (due to budgetary constraints) of technically qualified staff. [Piette et al. 2002, Levi 2005]

Another view of BMS effectiveness, in terms of savings potential and operator satisfaction, is provided by GSA surveys conducted by the Center for the Built Environment (CBE). An occupant satisfaction survey was conducted in 2004 on 72 GSA buildings with a total of 14,737 respondents. This survey measures the occupant's satisfaction with various aspects of the building they work in and includes a self-reporting productivity scale. A summary of the results are shown in Figure 1. [Abbaszadeh Fard et al. 2004] Note that out of all the categories, besides acoustics, thermal comfort and air quality received the lowest mean scores.[4] This indicates there is potential for improved control, and possibly better HVAC solutions.

[4] Each category was scored on a scale of 7-point scale that ranges from -3 (very dissatisfied, to +3 very satisfied)

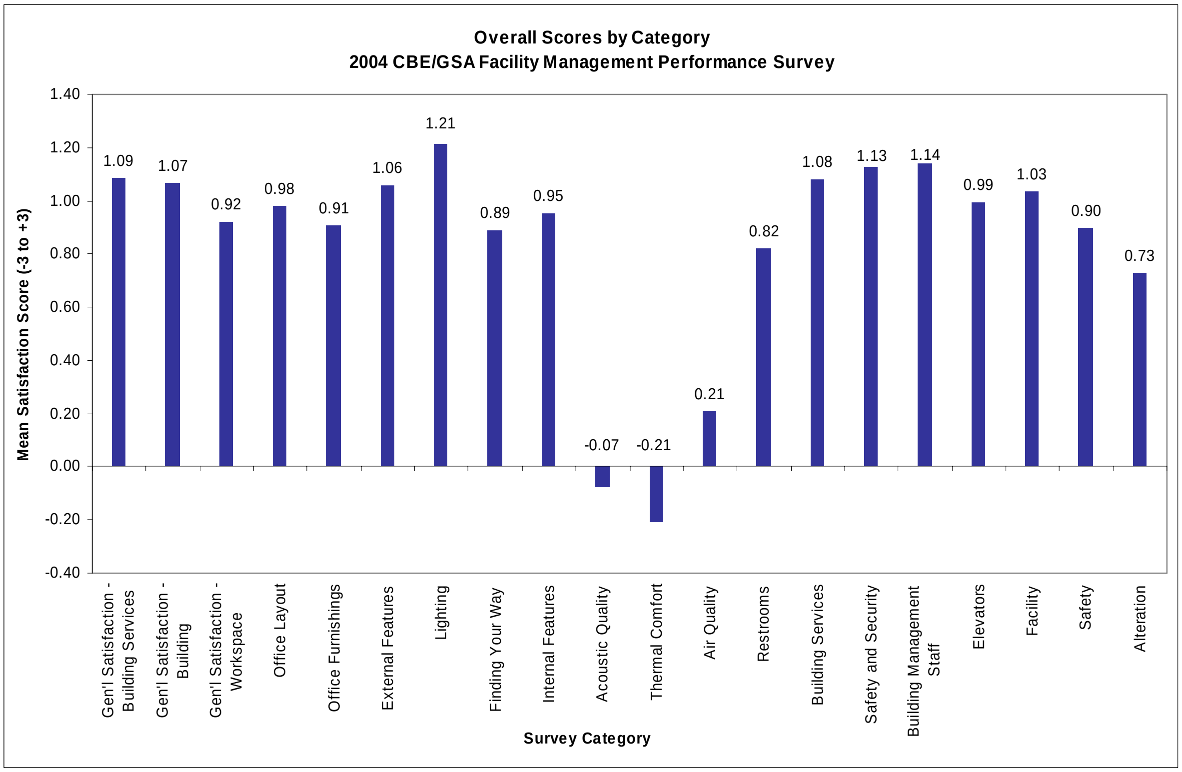

Figure 1: Occupant satisfaction survey results in 72 GSA buildings

A similar survey (not shown here) was conducted with building operations personnel (one per building) on GSA courthouse buildings. Respondents were asked about their satisfaction with the BMS, among other things. These results indicate that, by and large, operators are satisfied with the BMS in terms of the ease of use for operating and maintaining the building, but were not satisfied with availability of control capabilities (i.e., some critical control functions were not present). [Teitjen 2005]

A study of 11 buildings in New England [Fryer-Stein et al. 2004] found that, on average, the BMS systems were producing less than half of the expected savings due to a failure to use even common energy saving techniques like outdoor reset and optimal start/stop.

Other studies [Barksdale et al. 2004; Brown et al. 2000] of Federal facilities found, among other things, that 75% of equipment was operating in manual mode bypassing the time clock functions of the BMS. Other problems were attributed to lack of data archiving so historical data is not available for benchmarking to allow comparisons of performance over time, and ineffective management structures due to conflicts and cross purposes between technicians, engineers, and energy managers.

Expert interviews

We contacted nine people known by the authors to have considerable experience in some aspect of BMS technology; this experience ranged from application/deployment and commissioning, to research. They provide a "higher level" view different from that obtained from operations personnel in the case studies. We solicited their views in open ended discussions but used the same interview guide that we used for operations personnel as a general guide in conjunction with our working hypothesis that these systems could be more effectively used. These interviews identified a long list of issues that limit the effectiveness of these systems and there was considerably consistency between the respondents. We organized the consensus opinions into categories and present them in a detailed list in Appendix A. These results focus on why a BMS is not fully utilized and are generalized in the following summaries:

Design, installation, and commissioning
There is a complex relationship between the team players for these activities. Although the owner (in this case a Federal agency) has the most vested interest in achieving a good solution, he must rely on and trust his representatives to perform since he lacks the technical expertise to evaluate the options well. The mechanical designers frequently outsource the controls and BMS work to controls contractors with minimal specifications; i.e., control logic specifications come in the form of general sequences of operation and BMS instrumentation and data management issues are only minimally addressed if at all. This situation results in the controls contractors being in the driver's seat for the design and installation. These contractors (some of whom are vendor-contractors) are motivated mostly to provide basic operations that meet the minimum requirements and to "get off the job" as soon as possible while locking-in future service work. This usually results in a short-changed commissioning period, or possibly an extended, costly one because design deficiencies emerge later through problems that operators encounter. This is all compounded by a lack of or deficient commissioning specifications.

Personal experience of the author confirms difficulties in this area. In a recent project, the system and BMS commissioning was delayed by almost three years due largely to lack of accountability by several players in meeting the spirit and letter of the commissioning intent and the unwillingness to take responsibility for mistakes. It was only the needs of researchers conducting an energy study that became the primary motivator to complete the work.

A worst case view of BMS implementations can be represented by a relationship structure shown in Table 3. [Watson 2005] Given this interplay of vested interests, lack of continuity and top down control over the process, it seems inevitable that a BMS will get installed that does not live up to is full potential. Achieving an effective result depends on a high degree of trust in the relationships and on the professionalism of all parties. This is not always realized, especially when financial interests are the primary motivating factor for each player.

Table 3: Industry hierarchy for BMS design and deployment

Player	Issues and attitudes
Owner/architect	Do not understand controls and BMS technology
Mechanical engineer	Inadequate resources (and/or controls

	knowledge) to specify quality solutions
BMS vendors	Sell the potential, lock-in proprietary solutions and on-going service
Mechanical and controls contractors	Incentive is to meet minimum requirements and get off the job
Facilities services group	No clout; limited influence or involvement in decision making about BMS solutions

Building operations
Since building operators and chief engineers are by and large not degreed engineers, and work for bottom-line-oriented outsourced property management firms, their expertise only goes so far in their ability to fully understand the complexities of building systems and the BMS. This is compounded by generally inadequate in-depth training and lack of or inappropriate documentation of HVAC and BMS systems. Operators spend considerable time in chasing trouble calls and responding to alarms, leaving little time for more proactive analysis and problem solving. Operators have a tendency to reduce the confusion inherent in the "black box" nature of the inner workings of the BMS, and assert their control, by using manual overrides of automatic functions.

Building management
Management functions are characterized by a reactive vs. proactive orientation. At all levels - agency, property management, and on-site - there is a lack of knowledge and understanding as well as prioritization of getting the most out of the BMS since these operations and energy issues do not seem to be highly valued in terms of bottom line interests.

Energy performance
There is a large untapped potential for improved energy performance. In general, operations staff pay little attention to energy issues. Capabilities available in the BMS to support energy saving features or sequences are little used. However, these capabilities are sometimes used by third party consultants contracted specifically to address energy performance or to conduct re-commissioning projects; the bulk of energy improvement come through this avenue.

BMS capabilities
Although perceived to be more sensitive and less bullet-proof than older systems, they are indeed sophisticated and capable in terms of controlling equipment and supporting operations. In most cases the primary problem is not the capabilities of the BMS but the fact that many of the capabilities are underutilized. This results from systems being too complex for inadequately trained operators to understand, or the lack of implementation and/or documentation of sophisticated control and management functions. Some other capabilities are best served by other systems (e.g., reporting and operating logging with computerized maintenance management systems (CMMS)). Energy functions appear to be more and more relegated to EIS systems rather than being incorporated into the BMS. Existing systems do appear to be underpowered for supporting advanced applications

such as centralized monitoring or analysis functions that require robust data monitoring and data management capabilities.

"Mini" Case studies

To provide further insight into real world performance of BMS, we obtained information from operations management personnel using the guide shown in Appendix B, Tables B1-B5. These discussions attempt to capture an operations view with respect to how the system is actually used, what barriers to greater utilization exist, how it was deployed, and what the management environment is like. We contacted five buildings in GSA Region 9 and attempted to quantify the results by applying scoring to the information collected. Although limited (due to the small sample size) in the degree to which these results can be considered "representative" for all Federal buildings, they do provide interesting insights into a number of relevant issues, and are a rich source of anecdotal information.

Table B6 shows a categorical summary of results. A high score indicates better effectiveness. Percentages are a better indicator because the maximum score for each section is not necessarily the same for all buildings since some capabilities were not available on some systems (and were therefore not scored; i.e., percentages were based on questions answered). We arbitrarily assume that average scores below 50% and/or variances above 40% indicate a low scoring category. Therefore, energy management, deployment success, and owner management categories score low. All other categories score relatively high indicating that the systems are moderately effective in terms of functionality. There are differences across buildings for the items within a category that tend to get averaged in the results; no weighting was used on the items. However, when the individual items in each category are reviewed, it is apparent that some items consistently receive low scores (50% or less) or exhibited high variance across buildings. Table B7 shows the average score and variance (i.e., standard deviation (SD)) for those items.[5] These results are in general agreement with the opinions expressed by experts.

From these results we can see that, in general, the BMSs studied are reasonably effective in keeping a building operating smoothly but the level of effectiveness varies building to building and there are a number of areas where effectiveness could be improved (Table B7). This indicates that they are useful in serving the basic functions required to operate the building.

One case stands out and bears special mention. The San Francisco building received the highest scores of all. However, this building was unique in several ways. An active retro-commissioning effort corrected many problems with both the mechanical systems and the BMS. In addition, the management firm is a newer firm that only performs technical management of operations and repair and the lead operator is a degreed mechanical engineer. This team also receives good support from building management. Since this team is technically savvy and has good support, they have been able to exploit the

[5] Individual items were scored on a scale of 1 (low effectiveness) to 5 (high effectiveness).

capabilities of the BMS to improve operations and comfort performance. Further study could illuminate this better.

Potential for Improvement

There are several development projects currently being conducted that are aimed at improving the effectiveness of BMS systems. The BMS of today would most likely serve as a platform for some of these, but others would require an upgrade in technology.

- *Centralized remote monitoring and analysis.* (GEMnet) This technology relies on an on-site BMS to deliver data from a number of sites to remote database servers where it can be analyzed by expert practitioners (usually part of an applications/energy service provider (A/ESP)) using sophisticated analyses tools for diagnostics, equipment performance tracking, and energy savings tracking. GEMnet is one early example of this technology, currently others are emerging with various levels of capability [Cimetrics 2005]. While central monitoring and analysis appears to have great potential, the underling BMS technology needs to be robust and capable enough to support it (i.e., communications bandwidth must be adequate to support acquisition of large amounts of monitored data) and the central monitoring tools must be robust enough to make analysis efficient (i.e., they must support high quality data management, presentation, and reporting capabilities. It is not clear whether the value proposition is ultimately realizable.
- *Energy information systems (EIS)/Enhanced Automation (EA)/Enterprise Energy Management (EEM) ().* These systems are similar to central monitoring systems but focus primarily on energy efficiency and demand responsiveness (DR). They can be web-based and therefore can be operated remotely to support ASP services. They can provide a variety of functions such as load profiling, billing analysis, forecasting, and load shifting and demand response. While there were many vendors who developed and sold this technology in the past, only a few exist today. DR has become the focus of development efforts in this area, primarily sponsored by the CEC. [Motegi et al. 2002] Some of these EIS functions can be added to or combined with an existing BMS platform relatively easily to provide for load shedding and energy tracking capabilities but without the sophisticated analysis tools. These generally fall in the Enhanced Automation category. [CEC 2002]
- *Advanced applications*. There are a number of new applications being developed that use the BMS to provide added capabilities such as data visualization, fault diagnostics, and occupant feedback. These are thoroughly reviewed in our 4th article of this series [Yee 2004].
- *Commissioning*. As evidenced by the many studies, conferences, and commissioning agents now available it is clear that commissioning has become more or less a standard practice in the industry. Although work still needs to be done to improve the outcomes from these efforts, these trends are in the right direction to improving overall building system performance and BMS effectiveness.
- *Advanced monitoring specifications.* The DOE and CEC have jointly sponsored the development of [Hitchcock 2005] advanced monitor specifications for BMS systems.

This project attempts to address many of the outstanding issues discussed in this article by developing requirements not only for instrumentation specifications, but also data visualization, performance metrics, training, and commissioning. The realization of these objectives would go a long way toward improving those specific aspects that scored low in our results and toward correcting the issues that experts cite as being significant constraints. However, it is an open question as to how much impact these specifications would have because of the joint constraints of operations staff expertise and management orientation. For example, without a concomitant increase in the qualifications of operating staff and management knowledge, or a major improvement in "user friendliness" of BMS monitoring and analysis tools, the same constraints that now exist are likely to continue; i.e., operators have limited time or expertise to use these tools effectively and the business interests of the industry players will continue to dominate the implementation.

Analysis and Discussion

Evaluation of accepted beliefs

The following summarizes the degree to which the results of our study substantiate the accepted beliefs.

1. *Almost all larger Federal buildings use a BMS; these systems are considered key to operating a building well.*
   - Table 1 indicates that this is not true; for buildings over 10k GSF only 21% of buildings and 39% of total building floor area have BMSs installed. The incidence is no greater than in the private commercial sector.
   - However, building personnel and experts agree that operating large buildings without a BMS would be difficult.
2. *Keeping the occupant's satisfied and systems operational is the primary focus of operations staff. These systems are considered effective in this regard.*
   - Case study Utilization results show that a major use of the BMS is to help manage occupant complaints. However, the occupant survey results suggest that operators are unaware of the generally low ratings that comfort gets.
   - Experts confirm this, emphasizing that operators are so busy responding to trouble calls that little time is left for other tasks such as evaluating and improving comfort and energy performance.
3. *The energy saving potential of BMSs is not fully realized.*
   - Case study results show a very low (37% score) for utilization of BMS for energy management functions.
   - Expert and operations interviews indicate that these functions are not a routine part of the operators work, and that when it is done it is more often performed by third party experts.
4. *The implementation/deployment process for BMSs is very difficult and fraught with problems.*

- The case studies results indicate a mixed view of this issue. While deployment success and appropriate functionality on average are rated moderately high at ~60%, deployment success variability is high (SD = 50%).
- Experts, however, maintain the process is chaotic and difficult due to the overlapping and competing interests of the providers of services and equipment.

5. *In practice, there is a mismatch between the capabilities and sophistication of BMS technology and the ability to exploit it.*
   - Operators indicate that the more complex capabilities of the BMS are little used. The results of discussions with them also indicate that barriers to more effective use are due to lack of training, time availability, and documentation rather than the operator's ability to use the BMS.
   - The two issues of operator expertise and inability to use complex BMS capabilities go hand-in-hand. Experts confirm that the mismatch has to do with operator's expertise; complex problems and analyses are often left to third party experts to solve.
6. *Vendors tend to hype the potential compared to what is actually delivered.*
   - This has not been confirmed; technology is robust enough for many functions simple and complex at least to the degree that operators use them. Even for experts, these systems are capable of supporting some level of analyses with trends, plotting, etc. In general, the operators indicate that functionality delivered is appropriate for their needs.
   - However, experts indicate that existing systems are lacking in terms of support for robust data management necessary for higher end analysis such as benchmarking, central monitoring, and continuous commissioning functions.
7. *Despite many claims and much hype, true interoperability has not been achieved.*
   - Confirmed by everybody; the availability of BACnet and other technologies still does not translate into true interoperable solutions. There still is a tendency for vendors to make the systems proprietary to lock-in the customers. *Integration* into the BMS of lighting and access control, on the other hand, appears to be relatively common.

Revised perspective

Besides generally confirming the accepted beliefs above, our study revealed several other perspectives about effectiveness. The following summarizes our revised perspective of the state of practice of BMS implementations based on the results of this study.

- *Demographics:* Most large Federal buildings use a BMS of some sort to operate the building; it is standard practice to use DDC technology and BMS functions to service buildings. But there is still significant potential for deployment of BMS technology in these buildings.
- *Overall effectiveness:* Evaluating effectiveness must be more broadly based than simply focusing on the technical aspects of the BMS because these systems are installed and operated in a complex design, services, and management environment.

In the following, we have annotated the three categories of effectiveness that we have used to capture this broader view to summarize overall effectiveness:

- *Technical effectiveness is moderate* - Newer systems have adequate technical capabilities to support primary service functions and even more sophisticated functions if the expertise is available to exploit them.
- *Operational effectiveness is high* – Operational effectiveness is high for general and routine building management functions and keeping occupants satisfied (e.g., trouble calls and low level diagnosis) but is low in terms of proactive improvements in energy and comfort performance. Operators appear unaware of the generally low comfort performance of these systems. The level of operator expertise is relatively low compared to the complexity and capabilities of the HVAC and BMS systems, but lack of training and inadequate time devoted to using the BMS also militate against more effective use.
- *Organizational effectiveness is low* - This factor has a strong impact on constraining use of the full range of capabilities. Inadequate management structures result in operators being overburdened, under trained, or not having the required background expertise. There are few higher level practitioners (e.g., HVAC/mechanical engineers, or highly skilled operating engineers) to solve complex problems and actively exploit the functionality available, therefore these tasks are generally outsourced.

- *Distribution of functions:* Most analysis, commissioning, performance improvements, and control sequences programming are accomplished by third party specialists on an as needed basis. Likewise, reporting and logging functions are performed in CMMS applications
- *Design and deployment:* Good design and installation is crucial in getting high performance systems installed but the process is fraught with industry related problems.
- *Energy savings:* Most BMSs are not actively used to manage energy; this function is being accomplished more and more by EIS systems or is the result of third party studies or various types of commissioning.
- *Integration and interoperability:* These are not robust in the industry at large. Integration occurs more frequently, but true ("plug and play") interoperability is not being practiced and in fact is being resisted by vendors intent on maintaining vendor lock-in.
- *Improvements coming:* Steps are being taken in various research and business concerns to improve the performance of these systems. These efforts are targeted at the primary issues of better operator tools and training, commissioning, and high quality instrumentation, and robust data monitoring and management.

Summary and Conclusions

An evaluation of effectiveness of BMS focused on *technology* is too narrow a view. A more systematic approach considers how the systems are used in a services environment made up of building operators and managers and industry players such as vendors, contractors, and engineers and architects -- all with different levels of expertise and vested interests. A full assessment must consider these issues and their interrelationship because they all impact BMS effectiveness. We have organized these issues into three key categories: technical, operational and organizational. We have evaluated these key areas by collecting opinions from building technology experts, reviewing pertinent literature, and by talking to operations personnel. Considered together the interviews, literature review, and the case studies results reveal a perspective about what is useful about these systems, what areas are underutilized and what the constraints are that limit them from being used to their full potential.

The operator discussions indicate that, although individual buildings vary, overall they rate moderately in all the key effectiveness categories. However, these results mask those viewed on an individual item basis. Combining these results and the category results, with the interview and literature review as well as our own experience, we found that:

1. In general, effectiveness is limited more by operational and organizational problems than by technical capabilities, although improvements could help here also. The technology is adequate for the level at which a BMS is commonly used, but for more demanding applications, such as central monitoring, further development is needed.
2. On the other hand, some functions that are available are under utilized mostly because operations personnel lack the required expertise and/or training to program sequences or fully understand the consequences to the system of sequences they might develop. Systems tend to be used at the level of expertise of operators; they use the BMS primarily to address faults and trouble calls/complaints and for scheduling and manual control of equipment. Sometimes the BMS is used by outside consultants for more comprehensive analysis or diagnostics. Programming when required is mostly done by the vendor or independent specialists. Finally, there seems to be a disconnect between what operators believe about occupant comfort compared to what the occupants think; thermal comfort and air quality receive the lowest scores of all building indoor environmental factors except acoustics.
3. Decision makers in the building management structure (both agency personnel and outsourced services management) are, in general, not very knowledgeable about BMS technology. Controls and building operations are not a highly valued function so resources (training and level of expertise) are not well matched with complexity and capabilities of available BMS technology. These managers are more interested in other asset management functions and are more reactive than proactive when it comes to BMS issues. This has resulted in increased outsourcing for the more complex functions of energy, equipment performance analysis, programming improvements, and difficult problem solving.
4. Despite the fact that case study results indicate that the systems installed turn out to meet the owners specifications and the functionality is generally appropriate to the site needs, the design and installation process is such that many systems are

inadequately, procured, installed and commissioned. This results in poorly functioning equipment, inadequate documentation to support operators, and more costly repairs and upgrades in the future. However, commissioning is more commonly accepted so that deficiencies are being corrected in many older systems during retro-commissioning projects.

5. Although early efforts at advancing the state of practice to improve operations support, energy performance, and comfort did not achieve their potential, newer efforts appear to be poised to achieve these goals.

We believe that the conclusions reached in this study will convey to facility managers (and indeed all practitioners involved) that maximizing the potential of BMS technology requires adopting a comprehensive view of the entire environment within which the deployment of these systems exists. It is not just an issue of technological capabilities; design, installation, commissioning, operations, the building management structure and the interactions between all of these must be considered as well. Aligning all of these elements into a well-integrated team supportive of the overall goals is essential to achieving a highly effective system.

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Appendix A. Experts interviews detail [6]

Design, installation, and commissioning

- Design engineers lack controls knowledge; tend to "farm out" controls work to controls contractors.
- Controls contractors tend to treat control systems like a commodity, and work to minimize their costs which results in meeting minimal requirements and "getting off the job" as soon as possible.
- Controls contractors/vendors work to "lock-in" service contracts by holding access keys, programmed logic, and other technical expertise. However, this may be important to maintaining "version control" of control software since operations staff appear to have little understanding (possible reflecting lack of training) or time or motivation to maintain documentation of this sort. Lock-in is furthered when the system requires parts only the BMS vendor can provide.
- Controls contractors are more rewarded by low bids than good job performance.
- Controls contractors are not generally independent; they represent a select few vendors or are part of a vendor's local field organization.
- Little continuity in implementation from design through commissioning; the owner is not sufficiently capable of understanding technical issues to be able to evaluate success. Owners (or owner's agent) must prove deficiency rather than contractors proving success.
- Commissioning stops when the money runs out. However, commissioning is more frequently being accepted and budgeted for in recent years.
- In some instances there is a conflict of interest between contractors. For example, when the mechanical contractor or general hires the test and balance (TAB) contractor, it is unlikely that the owner's interest will be best served.
- Since owners are under fiscal constraints or architectural issues dominate concerns and budget, systems are first cost driven and therefore designer's resources are so limited that first class solutions are compromised.

Building operations

- Operating engineers are not really professional engineers and therefore lack the knowledge to understand intricacies of HVAC processes and BMS technology.
- Technical managers are not engineers but are capable operating engineers that have moved up to corporate responsibilities.
- Most buildings operations are outsourced to for-profit companies. There is very little in-house quality control expertise left. Only minor repairs and upgrades are performed by onsite operations staffs, larger ones are outsourced to contractors.
- A limited number of operators are highly capable so they become overburdened with problems since they are the only ones with enough expertise to solve complex issues.

[6] None of these statements are universally true, there will always be exceptions.

- Lack of training of operations personnel is endemic to the industry. Property management firms are not motivated to invest because their interest is on larger fiscal issues and profit margins. [Shockman et al. 2000]
- Due to the limited expertise and lack of operator training BMSs tend to be viewed as "black boxes." This results in simple more "brute force" approaches to solving problems or disabling/overriding controls logic in an attempt to achieve understandable performance; i.e., reducing the system operations to the operators level of understanding.
- Lack of BMS and HVAC system documentation and control sequences in operator friendly format is a severe problem. Details of control sequences are largely unknown by operators or are embedded in large tomes of programming minutiae. However, lack of operator expertise in this area tends to confound the problem.
- Operators do not use documentation and logging capabilities typically included in a modern BMS. Sometimes paper logs are used and/or a CMMS; without these logs there is a loss of "institutional memory" (especially if the operator leaves) that makes problem solving more difficult.

Building management

- There are two levels of management that influence BMS issues. Owner management i.e., GSA or other Federal agencies consists of on-site or regional level building managers; they usually are not technical people and thus have little understanding of BMS and HVAC issues. Property management firms to which building operations have been outsourced consist of on-site operating engineers and maintenance staff. Firm management are typically technical managers that were previously operating engineers [Shockman et al. 2000]
- Contracts are highly structured and negotiated to minimize management firm and agency risk. Large upgrades or BMS commissioning, programming, complex diagnostics and system modifications are usually outsourced to third party contractors and consultants.
- Upgrades are relegated to "routine technologies" i.e., known and understood additions that are embellishments that perform the same functions in a new way as opposed to those that perform new and different functions. [Shockman et al. 2000] Innovations come from new buildings, not upgrades to existing.
- Buildings operations and management orientation is predominately reactive as opposed to proactive.

Energy performance

- Potential is large; most (approximately 80%) of energy savings are controls related. [Claridge et al. 2002]
- High quality monitoring can result in significant energy savings [Piette et al. 1999]
- Energy cost is not a driver; compared to other facility costs and keeping occupants happy, it is a low priority. There is little real incentive to use less energy and few benchmarking procedures for comparisons.

- Equipment performance tracking, i.e., chiller kw/ton, is virtually non-existent.
- Active energy performance tracking is negligible, even when data is available.
- Best opportunity for good energy performance is initial design and installation; after that it becomes difficult and expensive via retro-commissioning activities.

BMS capabilities

- Modern BMS technology is more capable, complex and sensitive; older systems are more “bullet proof.”
- Technical effectiveness/capabilities for most buildings operations are available in modern product offerings. The typically support routine operations needs well; it is hard to imagine running a building today without one.
- Off-the-shelf system capabilities are not quite ready for advanced applications such as centralized monitoring; networking and software technology is not robust enough and is too expensive. (See Potential Improvement Section)
- Reporting functions are often not used; nobody is interested in the content.
- No true interoperability, not like IT industry, mostly data exchange/monitoring. Problems can be increased if BMS control sequences attempt to override or interfere with equipment unit controller functions.
- Security issues are not a serious issue for dedicated networks, but may become more critical when combined with IT.
- Operators rarely program either logic or graphics screens; these functions are normally done by outside third party contractors or vendor field offices.

Appendix B. Operators discussion guide

Table B1: Building characteristics

Building characteristics
- Location/City
- Description
- Type/use
- Vintage
- Size, GSF

HVAC Systems
- Description
- Type(s)
- Vintage
- Schedules

BMS
- Description
- Brand
- Vintage
- # of points
- Network architecture
- Energy information system (EIS)?

Table B2: Utilization

Occupant satisfaction
- Responding to complaints/service calls
- Improving occupant comfort

Maintenance and repair
- Monitoring of operations (with or without graphics)
- Change setpoints, schedules, manual control
- Use graphical displays
- Create/program graphical displays
- Programming closed loop control of processes
- Programming of sequences of operations
- Diagnostics/troubleshooting with trend logs
- Diagnostics/troubleshooting with spreadsheets (and/or other software tools)
- Alarms management
- Safeties (software) setting management
- Documentation and logging of O&M activities
- Report generation
- Remote access for alarms or monitoring (via phone or otherwise)

Energy & equipment performance
- Track and monitor equipment performance
- Track/document energy use and savings
- To improve energy use and cost

Table B3: Barriers to effective use

Lack of operator training
Operator distrust of system to perform properly
Operator resistance
Interference from others
System reliability (do components and front-ends fail frequently)
Slow response
Erroneous information (false readings/scaling, sensor calibration)
Nuisance alarms
Requires constant "tweeking"
Difficult or complicated to setup and/or use
Software cannot be configured to perform functions needed
Difficult to understand operations via information available
Data access and management (lack of tools, access, storage, archiving)
Limited resources, no time to use system effectively (too many fires)
Lack of documentation on equipment, systems, control sequences
System was oversold or misrepresented by vendor
Other comments

Table B4: Deployment success and functionality

Deployment

Designed and specified according to owners intent
Procured, installed, and commissioned successfully

Functionality

System is functionality appropriate for site needs
System is flexible, adaptable
System can be replicated easily (multi-building/site, not custom)
Supports integration and interoperability

Table B5: Management responsiveness

Management is knowledge about BMS technology
Management makes BMS issues a priority
Management supports operator training
Management has adequate financial resources to support BMS infrastructure
Management has a proactive vs. reactive attitude about BMSs

Table B6: Case Study results, categories

Location	North CA		North CA		Arizona		North CA		South CA					
Building size/type	336k GSF, offices		500k GSF Labs, offices		130k GSF, offices		1,500k GSF, office/courts		216k GSF, offices					
BMS, vintage (points)	JCI Metasys, 1998 (2000)		JCI NCMS, ~1990 (3000)		JCI Metasys, 1995 (350)		Alerton, ~1995 (~50-70k)		Delta, 2000 (245)		Totals			
	Scores	%	Scores	%	Scores	%	Scores	%	Scores	%	Avg score	Avg %	SD score	SD score %
Utilization														
Occupant satisfaction	6	60%	6	60%	9	90%	10	100%	8	80%	7.8	78%	1.8	23%
M&R	32	58%	35	64%	24	40%	51	93%	33	55%	35	62%	9.9	28%
Energy management	4	27%	3	20%	8	53%	8	53%	5	33%	5.6	37%	2.3	41%
Barriers	61	76%	31	39%	67	84%	78	98%	72	90%	61.8	77%	18.3	30%
Deployment														
Deployment success	3	30%	3	30%	8	80%	6	60%	10	100%	6	60%	3.1	51%
Functionally appropriate	12	60%	12	60%	11	55%	11	55%	15	75%	12.2	61%	1.6	13%
Management														
Owner	2	8%	10	40%	12	48%	10	40%			8.5	34%	4.4	52%
Property firm	6	30%			17	68%	19	76%	11	55%	13.25	57%	5.9	45%
Building score	**126**	**60%**	**100**	**45%**	**156**	**73%**	**193**	**88%**	**154**	**72%**	**145.8**	**67%**	**35.0**	**24%**

Table B7: Case Study results, low scoring items (low score, high variance or both) based on a scale of 1 (low) to 5 (high)[7]

	Avg Score	Avg %	SD	SD%
Utilization				
Improving occupant comfort	**2.8**	**56%**	**1.79**	**64%**
Create/program graphical displays	**2.2**	**44%**	**1.64**	**75%**
Programming closed loop control of processes	**1.8**	**36%**	**1.79**	**99%**
Programming of sequences of operations	**1.8**	**36%**	**1.79**	**99%**
Diagnostics/troubleshooting with spreadsheets (and/or other software)	**1.5**	**30%**	**1.00**	**67%**
Documentation and logging of O&M activities	**1.3**	**25%**	**0.50**	**40%**
Report generation	**1.4**	**28%**	**0.89**	**64%**
Equipment performance tracking/monitoring	**2.0**	**40%**	**1.41**	**71%**
Track/document energy use and savings	**1.6**	**32%**	**0.55**	**34%**
Use BMS to improve energy use and cost	**2.0**	**40%**	**1.00**	**50%**
Barriers				
Operator training	**3.2**	**64%**	**2.05**	**64%**
Software configured to perform functions needed	**2.4**	**48%**	**1.67**	**70%**
Operations resources available	**2.6**	**52%**	**2.19**	**84%**
Documentation of equipment, systems, control sequences	**3.2**	**64%**	**1.30**	**41%**
Deployment				
Procured, installed, and commissioned successfully	**2.8**	**56%**	**1.79**	**64%**
System can be replicated easily (multi-building/site, not custom)	**2.8**	**56%**	**1.48**	**53%**
Supports integration and interoperability	**2.0**	**40%**	**1.22**	**61%**
Management				
Management is knowledge about BMS technology	**1.3**	**27%**	**0.58**	**43%**
Management has a proactive vs. reactive attitude about BMSs	**1.3**	**27%**	**0.58**	**43%**

[7] In the Barriers section the questions have been revised to be consistent with the scoring method and are therefore presented differently here than how they were asked in the survey itself.