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Governor

PERFORMANCE MONITORING IN LARGE COMMERCIAL BUILDINGS

PIER FINAL PROJECT REPORT

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Legal Disclaimer

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Performance Monitoring in Large Commercial Buildings is the final report for the Performance Monitoring in Large Commercial Buildings project in the High Performance Commercial Buildings Program 2 (contract number 500-03-022) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

This is the final report of a research and development project on performance monitoring in large commercial buildings. This project was to promote the adoption of continuous performance monitoring systems in large commercial buildings to provide building operators with ready access to improved information to operate buildings more efficiently and reduce other operating costs. The primary product of the project is a specification for continuous performance monitoring systems that can be bid competitively in both new construction and control system retrofits and that can be used routinely by a variety of organizations. The project involved working with a number of organizations to implement continuous performance monitoring capabilities in test building sites. Case studies were undertaken to assess the costs and benefits of such capabilities and to better understand the process by which large organizations adopt this type of innovative technology.

Keywords: Performance monitoring systems, continuous performance monitoring, commercial buildings, specifications, control systems, building automation systems

Executive Summary

This is the final report of a research and development project on performance monitoring in large commercial buildings. Building commissioning and related studies have shown that numerous operational and control problems exist in most buildings. One approach to improving the identification of such problems, and hence facilitating remedial action, is to provide continuous performance monitoring. This approach has been shown to produce practical benefits in daily operations by allowing the identification of problems such as equipment cycling or inefficient operating strategies (Piette *et al.* 2001, Smothers and Kinney 2002). This study was to promote the presentation of better information to operators and others responsible for the operation of buildings. Another potential benefit of improved instrumentation and archiving is better support for automated diagnostic tools. These tools are only just beginning to appear on the market; according to a survey of relevant stakeholders performed in a separate project, one important barrier to the widespread adoption of automated diagnostic tools is the difficulty of accessing the performance data of these tools typically provided by third party vendors (Xu *et al.* 2006). The problem is that current building control systems were not designed for measuring performance, although archiving and other capabilities have recently improved substantially. However, for these capabilities to be installed and used, owners and design engineers need to value them and then need to be able to specify them effectively.

This project was to promote continuous performance monitoring systems in large commercial buildings to provide building operators with ready access to improved information to operate buildings more effectively, reducing energy and other operating costs and improving indoor environmental quality. The project involved working with a number of organizations to implement continuous performance monitoring capabilities at building test sites. Lessons learned from these interactions informed the development of a specifications guide for performance monitoring systems. Substantial effort was applied to obtaining review and feedback from a group of specifying engineers, manufacturers and building owners and operators and then developing general specifications language for the guide. Case studies were undertaken to assess the costs and benefits of performance monitoring capabilities and to better understand the process by which large organizations adopt this type of innovative technology.

The primary outcome of this project is a specifications guide intended to assist commercial and institutional building owners in specifying effective performance monitoring systems as part of new construction or building systems retrofit. The "Specifications Guide for Performance Monitoring Systems" is available at the following Web site: http://cbs.lbl.gov/performance-monitoring/specifications/

As the specifications guide was being developed, the project team interacted with a number of interested owners and property managers, helping develop site-specific specifications for new control systems and control system upgrades. These interactions, which required a number of iterations, helped refine the current version of the specifications guide. Overall, the project team interfaced with facility personal from eleven sites including state and federal facilities, university campuses and two buildings that were privately owned and operated.

The duration of this research project did not allow sufficient time to evaluate the costs and benefits of implementing a performance monitoring system at participating sites; in retrospect, this would have required a project of four or five years duration. A number of test sites have only recently installed performance monitoring upgrades or have yet to install them. However, it should be noted that the process of working with these sites to specify upgrades did contribute significantly to the development of the specification guide. In addition, it proved problematical to extract cost and benefit data specific to performance monitoring capabilities from other monitoring-related efforts such as the Monitoring-Based Commissioning program. A number of anecdotal examples of continuous performance monitoring that led to building operations intervention and resulted in benefits valued by building owners, property managers, occupants, or operators are described in this report and references are made to other efforts in this area.

A case study of technology innovation and adoption in large organizations was undertaken to better understand the process by which organizations might be encouraged to promote performance monitoring within their buildings. The numerous changes related to sustainability and energy performance that state agencies and other agencies such as the Federal Energy Management Program are charged with initiating are both a barrier and an opportunity. The number of changes that are required is a barrier to the adoption of any specific measure, such as performance monitoring, that is not perceived as essential. The opportunity is that achieving the various energy performance goals will require building-specific information on actual performance to manage energy consumption so as to meet the adopted goals. The expectation is that the Performance Monitoring System Specification Guide will be adopted and actively used when performance monitoring becomes an explicit high priority for government agencies and other owners charged with achieving aggressive energy performance goals.

Conclusions

Specifying and installing a performance monitoring system requires a level of rigor above that of the average installed building control system. Performance monitoring systems are data-dependent, requiring a more robust data acquisition capability than is typically used for control, which needs to be clearly specified. The building owner and/or operator needs to have a good understanding of their data needs. These needs will drive which performance metrics need to be provided. The specification guide for performance monitoring systems developed in the work reported here provides a context for determining these factors and example specification language for inclusion in a project request for bids, thereby enabling building owners and consulting engineers who do not have detailed specialist knowledge of performance monitoring to specify performance monitoring capabilities.

Owners are most likely to adopt performance monitoring if they are motivated to manage and improve the performance of their buildings and they either have used ENERGYSTAR® or some other benchmark or are incentivized by a utility program or some other external driver.

Barriers to adoption include a lack of the necessary skills on the part of design engineers, controls contractors and facilities personnel and, for some agencies, a plethora of different demands for change.

Recommendations

1. The California Energy Commission, the United States Department of Energy and other agencies should explicitly endorse and advance the use of cost-effective performance monitoring as a necessary part of efficient building operation.
2. The California Energy Commission, the California Public Utilities Commission, the United States Department of Energy and other agencies should develop education and training programs addressing design, installation, and use of performance monitoring systems. On-going peer support for operators and others should be provided through an on-line list server.
3. All stakeholders in the project should continue to track developments in the industry that offer opportunities to disseminate and deploy the specification guide and actively pursue these opportunities to the maximum extent that circumstances and resources permit.
4. Performance monitoring should be used by default as a technology verification and cost-effective dissemination tool in all publicly funded demonstration projects
5. Further research is required to evaluate performance metrics in practice – metrics should indicate clearly if the monitored system is working correctly, should be actionable, and should have a demonstrably positive effect on performance.

Benefits to California

Performance monitoring systems facilitate more efficient operation of commercial buildings by providing owners and operators with information that enables them to detect and isolate equipment faults and operational problems. By providing a specification guide to performance monitoring systems for designers and owners, the project has removed one significant barrier to the adoption of performance monitoring systems, in California and beyond. Work with owners and organizations such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers has helped increase awareness of the benefits of performance monitoring and disseminate the technical information contained in the specification guide.

1.0 Introduction

Building commissioning and related studies have shown that numerous operational and control problems exist in most buildings. One approach to improving the identification of such problems, and hence facilitating their repair, is to provide continuous performance monitoring (Piette *et al.* 2001). This approach has been shown to produce practical benefits in daily operations by allowing the identification of problems such as equipment cycling or inefficient operating strategies. Current building control system installations typically have very limited data collection, archiving and visualization capabilities, largely because these capabilities have not been valued and specified by owners or design engineers.

Those who evaluate the performance of buildings and their energy using systems have long known that it takes the attention of a knowledgeable and dedicated team, which may include a measurement analyst, instrumentation vendors, an installation contractor and owner's staff, to obtain the quality of data necessary to determine how well a building is actually performing as well as identify means for improving performance. The control systems installed in existing buildings typically have very limited data collection, archiving and visualization capabilities. However, for new construction or control system replacement, most controls vendors now provide SQL databases as optional extras for their current control system offerings. Current products are also better able to accommodate protocols, such as Modbus, that facilitate connection to additional instrumentation, such as flow meters and power meters.

As building systems become inherently more complex with the advance of technology, and energy costs continue to rise, owners require better information to benchmark the performance of their buildings and energy using systems and to troubleshoot problems. This is complicated by the fact that few specifying engineers and installation contractors are trained to understand good measurement practice, thus driving costs up when they are specified. It is hoped that building a case for such systems, whether they are applied as part of the direct digital control system or a separate energy information system, and providing some insight into best practices, will promote their use, help educate the user, and drive costs down.

One application of this idea is the monitoring-based retro-commissioning program that has been implemented by California's investor owned utilities in the University of California and California State University campus systems with funding by the California Public Utilities Commission. It is believed that the installation of permanent instrumentation in conjunction with a disciplined retro-commissioning activity will lead to sustainable energy savings.

Another is the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) green building rating system. LEED-EB (Existing Buildings)[1] offers 2 credits for Water Efficiency for monitoring various types of water usage, 3 credits under Energy and Atmosphere for performance monitoring of specific equipment, systems and controls, 4 credits under Indoor Environmental Quality for demonstrating certain IAQ criteria are met, and up to 4 credits under Innovation in Upgrades, Operations and Maintenance that use performance metrics to help demonstrate environmental benefit.

1. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=221

The primary objective of this project was to promote continuous performance monitoring systems in large commercial buildings in order to provide building operators with ready access to improved information to operate buildings more effectively, reducing energy and other operating costs and improving aspects of indoor environmental quality. A secondary objective was to facilitate better support for automated diagnostic tools by improving instrumentation and archiving in commercial buildings. Automated diagnostic tools are only just beginning to appear on the market; according to a survey of relevant stakeholders performed in a separate project, one important barrier to the widespread adoption of such tools is the difficulty of accessing performance data by third party tools (Xu *et al.* 2006).

Major barriers to the adoption of continuous performance monitoring systems had been identified as including:

- Inadequate performance monitoring and data visualization capabilities in control systems
- Lack of knowledge in specifying performance monitoring capabilities
- Lack of knowledge by controls engineers and installation contractors
- Lack of operator training
- Unknown costs and benefits of performance monitoring
- Hesitancy in adopting innovative technology

The rest of the report describes how the project has directly addressed the specification barrier and has indirectly addressed some of the other barriers.

2.0 Project Approach

To address the major hurdles identified above, the project included working with a number of organizations to implement continuous performance monitoring capabilities in demonstration building sites. Lessons learned from this interaction were fed into the development of a specifications guide for performance monitoring systems. Additional effort was given to obtaining review and feedback from a group of specifying engineers, manufacturers, and building owners and operators and then developing general specifications language for the guide.

The resulting guide was used as the basis for developing a comprehensive set of performance monitoring capability specifications that was reviewed by facility staff at a Sacramento government office building and integrated into a request for bids for an overall controls retrofit project. This retrofit project was successfully bid with the performance monitoring capabilities included as an "add alternate."

The development of the specifications guide was intended to address the first three major hurdles identified:

- Inadequate performance monitoring and data visualization capabilities in control systems
- Lack of knowledge in specifying performance monitoring capabilities
- Lack of knowledge on the part of controls engineers and installation contractors

In addition to the demonstration site and specifications guide activities, case studies were undertaken in the attempt to better assess the costs and benefits of performance monitoring capabilities, and to better understand the process by which large organizations adopt this type of innovative technology. These activities were intended to address the last two major hurdles:

- Unknown costs and benefits of performance monitoring
- Hesitancy in adopting innovative technology

To address the hurdle of lack of operator training, an additional effort was undertaken to develop data visualization guidelines, and implement a prototype advanced visualization tool for displaying monitored performance data. This tool was designed to demonstrate the presentation of data in easily accessible formats to support the operator decision-making process.

The project included the following activities:

- **Engage building owners.** Additional building owners and third party property managers were contacted and invited to join the initial group that consisted of GSA, California Department of General Services (DGS), the University of California (UC) and Jones Lang LaSalle (JLL). Those contacted included the U.S. Navy, California State University and Hines Properties.

- **Prepare draft specification**. Existing monitoring system specifications, including those prepared for UC Merced, PG&E's own facilities, the Naval Postgraduate Station at Monterey and the Information Monitoring and Diagnostic System (IMDS) were reviewed and a 'straw man' draft specification prepared for discussion in the participating owners working group. This draft was progressively refined during the course of the project and was used to generate specifications for specific test sites. Experience gained from using the draft specification at the test sites then informed the further refinement of the specification.

- **Develop enhanced visualization tool.** Existing visualization tools were reviewed and used to help define a specification for advanced data visualization capabilities. A prototype tool was developed to illustrate these capabilities. A number of different applications, including automated diagnostics and education and training were identified and the prototype tool incorporated in examples of this application.

- **Assess costs and benefits of performance monitoring capabilities.** Information on installed costs of enhanced instrumentation was obtained from a number of test sites. Quantitative information on benefits proved more difficult to obtain. Some information on the costs and benefits of monitoring-based commissioning projects was obtained, although it was not possible to separate the benefits of performance monitoring from the benefits of the retro-commissioning activities in these projects.

- **Technology innovation and adoption case study.** A public sector organization that owns and operates office buildings was studied. Decision-making processes were characterized and barriers to the adoption of innovative technology, such as performance monitoring, were identified.

- **Test, revise and publish specification.** The specification was tested in real procurement situations and published.

- **Disseminate specification.** The members of the project team worked with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to incorporate appropriate parts of the specification in relevant Guidelines and with CEC to pursue inclusion of selected parts in Title 24. The team worked to have other guides reference the specification and also disseminated the specification through magazine articles (Gillespie et al., 2006a & 2006b; Haves et al., 2006) and contacts with individual practitioners and owners.

3.0 Project Outcome

3.1 Specifications Guide for Performance Monitoring Systems

A primary outcome of this project is a 150-page specifications guide for performance monitoring systems. Development of the guide involved producing a draft general performance monitoring specification in collaboration with several large building owners. This draft was reviewed by a number of stakeholders, including specifying engineers, manufacturers and building owners and operators. The specification was then revised and used as a resource in a number of demonstration projects. Feedback from these efforts prompted the project team to convert the general specification into a specifications guide. Activities related to using the specifications guide document as the basis of technology transfer efforts are discussed in the following section of this report.

The specifications guide is intended primarily to define functionality; however, it is prescriptive where necessary to ensure the required functionality is obtained with currently available industry products, e.g. certain types of sensors are specified for particular applications. In other areas, e.g. networking, the guide only specifies functionality and does not prescribe how that functionality is to be achieved.

The first part of the guide document presents an overview of performance monitoring; recommendations for different levels, or classes, of performance monitoring; and general issues to consider when specifying the requirements for your performance monitoring system. Sections within this first part include the following:

Overview: What is a performance monitoring system? What are its overall requirements? What are some of its benefits?

Recommended Requirements for Three Classes of Performance Monitoring: Not all buildings will require the same level of monitoring. This section makes recommendations for three classes of monitoring: basic, intermediate, and advanced. These recommendations are a starting point for identifying the requirements for a particular performance monitoring system.

General Issues to Consider: Several issues that must be considered from the outset of planning a performance monitoring system specification are discussed, including scope, implementation approach, system rigor, data visualization, commissioning, and training.

The remainder of the guide document is divided into appendixes that deal with the details of specifying a performance monitoring system that meets the specific needs of a given project:

A. Glossary: A glossary of technical terms used throughout the document.

B. System Performance Capabilities and Functional Requirements: An outline of recommended performance monitoring system capabilities and functional requirements. Most of these capabilities and functional requirements apply to both DDC based systems and those that might be included in or managed by an Energy Information System (EIS) product.

C. Performance Metrics by Class: Detailed specifications for performance metrics from the whole-building level down to the equipment component level. Each performance metric is defined along with the data points that are necessary for calculating and reporting the metric.

This list of performance metrics is categorized under the three classes of performance monitoring: basic, intermediate, and advanced.

D. Example Basic Level General Specifications: A complete example specification for a performance monitoring system based on Class 1 (Basic) requirements. This example can serve as a starting point for developing performance monitoring system specifications for new construction or a control system upgrade. These specifications can be used standalone, integrated into a traditional control system specification, or as an add-on option. Sections of this example include: performance monitoring system description; instrumentation and data acquisition requirements; details of sensors, meters, and calculated values; data point naming convention; required trends; data archival and retrieval requirements; graphic display requirements; commissioning quality assurance tasks; training requirements; and submittal requirements.

E. Options and Add Alternates to Consider: Some options to consider in specifying performance monitoring system requirements.

F. Other Measurements, Metrics and XY Plots to Consider: Some metric and graphics options to consider in specifying performance monitoring system requirements.

G. Example Basic Level Specification Language Based on ASHRAE Guideline 13-2000: Specifying Direct Digital Controls Systems: Example basic level performance monitoring specification language for use in DDC system application that replaces or adds to example specifications found in ASHRAE Guideline 13-2000: Specifying Direct Digital Controls Systems.

H. Example Graphic and Data Displays: A more concise description of data visualization capabilities than that given as part of Appendix D.

I. Example Point Naming Conventions: A more complete description of a recommended point naming convention than that given as part of Appendix D.

J. Demonstration Site Case Studies: A brief summary of activities at a few demonstration sites is included in the guide document. These activities are discussed in more detail in this report below.

K. Trend Data Extraction Tool Using XML: A batch method for acquiring trend data from direct digital control systems using eXtensible Markup Language (XML) technologies.

L. VizTool: An open-source developmental software toolkit for acquiring and visualizing performance monitored data. VizTool is discussed in more detail below.

3.2 Technology Transfer Activities

The specifications guide document described above was used as the basis of numerous technology transfer activities.

The California Department of General Services (DGS) developed a bid specifications package for an upgrade of the EMCS in the Office of the Attorney General building in Sacramento. The bid package included specifications taken directly from the specifications guide for performance monitoring systems developed in this research project. The performance monitoring portion of the upgrade project was included as an “add alternate.” The DGS project manager has reported that the performance monitoring component of the project was bid at a price in the expected range, the State obtained the additional funding for the performance monitoring component and the upgrade project was successfully completed. Use of the specifications guide on this project was a significant milestone in transferring this technology to industry.

The ASHRAE SGPC13 committee will include pieces of the specifications guide in the main body of the ASHRAE Guideline *Specifying DDC Systems* and a reduced version of the complete guide spec will be included as an appendix. ASHRAE GPC22P is including relevant parts of the specifications guide in *Guideline for the Determination of the In Situ Coefficient of Performance for Electric Motor Driven Central Chilled Water Plant*s. The specifications guide was also requested by ASHRAE Technical Committee 1.4 – Control Theory and Application, which is developing a *Green Controls Guide*.

The specifications guide is also being considered for inclusion in the DDC Online website http://www.ddc-online.org which will allow specifiers to investigate the relationship between these specifications and product offerings from different controls vendors.

An effort to add a credit in the 2008 Title 24 Nonresidential Building Energy Efficiency Standards for specifying, installing, and using enhanced performance monitoring in buildings was undertaken. A Measure Information Template for adding such a credit was presented at a public CEC Staff Workshop in February 2006. This measure was not adopted for the 2008 update but the project has influenced the green building standards that the California Building Standards Commission will be adding to Part 11 of Title 24.

Team members interacted with the US General Services Administration (GSA) Region IX to review the specifications document and assess its application to GSA projects. GSA Region IX has indicated its intention to incorporate material from the specifications guide document in the updated Region IX control system specifications.

The City of Oakland requested and received a copy of the specifications guide for use in planning a controls upgrade for the group of city administration buildings in downtown Oakland and indicated a desire to work with the project team to define specific enhanced monitoring capabilities for the City.

The California State University (CSU) mechanical review board is developing a metering guide for CSU campuses. The group developing this metering guide has been given a copy of the performance monitoring guide specifications and is considering including material in their guide.

LBNL and the Building Performance Lab (BPL) of the City University of New York (CUNY) Institute for Urban Systems are seeking funding to support development of the CUNY TOMCAT ("The O&M Computer Assisted Toolkit") through technology transfer of the LBNL "Specifications Guide for Performance Monitoring Systems." The TOMCAT will be designed to improve operational performance in CUNY's facilities and in the broader New York City (NYC) real estate market by assessing and enhancing the performance monitoring capabilities of current building automation systems (BAS) installed in existing facilities.

A presentation of this project was given at the inaugural fm/IT Federal Conference in Washington, DC in December 2005. This conference invited facility management professionals to assemble to participate in a strategically crafted program, offering information strategies and solutions for government, public, and private sectors.

Papers and presentations on the performance monitoring project and the guide specifications were delivered at two highly visible venues, the National Conference on Building Commissioning (NCBC) in April 2006 (Gillespie et al., 2006a), and The American Council for an Energy-Efficient Economy (ACEEE) Summer Study in August 2006 (Haves et al., 2006). An article, based on the NCBC paper, was published in the Heating Piping and Air Conditioning (HPAC) and Networked Controls magazines in November 2006 (Gillespie et al., 2006b & 2006c).

A publicly accessible web page for describing the performance monitoring guide specifications, and making the document available for download, has been created by LBNL at http://cbs.lbl.gov/performance-monitoring/specifications.

Dominique Fernandez, Director of Whole Building Design Guide and Construction Criteria Base (WBDG/CCB) Programs at the National Institute of Building Sciences (NIBS) added a link to the guide specifications web site from the Whole Building Design Guide (WBDG) under Tools category "Specification Aids". See http://www.wbdg.org/tools/sgpms.php?c=5

3.3 Test Sites and Case Studies

The objectives of working with test sites were to:

- Obtain first-hand information on different approaches to performance monitoring and how well these approaches are supported by current control products and by legacy systems.
- Obtain insights into owner requirements and decision-making processes related to performance monitoring.
- Understand owners' needs for a guide specification.
- Obtain cost information on performance monitoring systems.
- Assess the actual benefits of installing performance monitoring systems.
- Obtain information on practical problems encountered in the installation and use of performance monitoring systems.

The original intent, as described in the Scope of Work, was to initiate the installation of performance monitoring systems in a number of commercial buildings. It then transpired that a number of University of California (UC) and California State University (CSU) campuses were about to install additional instrumentation and/or archiving capabilities as part of the first phase of the UC/CSU/IOU Monitoring-Based Commissioning program funded by the California Public Utilities Commission through the investor-owned utilities. A number of these sites were tracked in order to obtain information on different approaches to performance monitoring and to assess the impact of the performance monitoring additions on the operation of the buildings and/or central plants. The attributes of the various demonstration sites studied in the project are listed in Table 1. Sites where performance monitoring system installations did not materialize are included if significant information or insights were obtained from engaging with the building owners or operators.

Table 1. Demonstration Sites

Site	Owner/ manager	Control system	Performance monitoring system	Significance to this project
Attorney General's Building, Sacramento	California Department of General Services	Alerton	The specification produced in this project was used to procure metering, archiving and visualization extensions to the Alerton system that was procured to replace the previous control system	First test of the guide specification in a real procurement – no problems were encountered. Provided cost data - too early to identify operational benefits.
National Courts Building, Washington DC	GSA	Johnson Controls	Instrumentation and visualization upgrades were put out to bid using an early version of the guide specification. The upgrades were not implemented because the expected support from GSA'a Energy Center of Expertise did not materialize.	Provided experience with specifying performance monitoring upgrades to Johnson Controls Metasys systems. Illustrated the importance of understanding decision-making processes for operational retrofits.
Naval Postgraduate Station, Monterey	US Navy	Automated Logic	The new control system that was procured just before the start of this project has significant performance monitoring capabilities	Provides confirmation of operational benefits of performance monitoring that are valued by the owner.
Sacramento Central Plant	California Department of General Services	Invensys	Tridium's Vykon Energy Suite monitoring software has been installed to monitor the central plant and some of the buildings it serves. DGS is continuing to configure the software to meet its needs.	Illustrated the challenges in establishing performance monitoring capabilities for a central plant and the associated buildings that have legacy control systems.
Santa Rosa Federal Building	GSA	Alerton	Additional instrumentation was specified at the time of a chilled water system replacement but not installed due to financial constraints	Allowed a direct comparison of parts of the guide specification with the instrumentation specification produced by a leading controls consulting firm
Schultz Building, Sonoma State University	CSU	Alerton	Additional power metering and archiving	Performance monitoring established the benefits of operational changes, in particular, fan energy savings and is expected to enhance persistence of these savings.
UC Berkeley	UC	Barrington, Broadwin	The whole building electricity and steam meters on five campus buildings upgraded to provide interval data.	These data were used to inform the selection of one of the five buildings for retro-commissioning as part of the UC/CSU/IOU

				program.
UCLA	UC	Siemens	Electric power meters and chilled water and hot water BTU meters installed in a significant number of campus buildings. The control system was upgraded with an SQL data base and a comprehensive report-writing tool.	The instrumentation and archiving upgrade were funded internally, indicating confidence that anticipated benefits would be realized.
UC San Diego	UC	Johnson Controls, PML	Data archiving and analysis capabilities were added to the Power Measurement data acquisition system for the meters on the campus buildings and the central plant	Provided cost/benefit data via the UC/CSU/IOU program. Illustrated that the HVAC control system may not be the first choice as the platform for performance monitoring, particularly on a campus with significant cogeneration.
Ziggurat Building, Sacramento	Wacovia / Jones Lang LaSalle, CB Richard Ellis	Automated Logic	Instrumentation and visualization upgrades were put out to bid using the guide specification. Implementation was put on hold due to a change in the property management firm.	Provided cost data.
925 L Street, Sacramento	Jones Lang LaSalle	Invensys	Hybrid system, consisting of an Enflex data acquisition system with dedicated instrumentation and data links to the HVAC control system and the chiller panels, together with the Electric Eye data visualization tool	Illustrated the advantages and disadvantages of standalone performance monitoring systems compared to those based on the HVAC control system / EMCS.

Source: Berkeley National Laboratory

Significant efforts were made to establish demonstration sites at a number of other buildings, including the Cohen Building in Washington, DC (GSA) and 101 California Street in San Francisco (Hines). The control system in the Cohen Building turned out to be too expensive to upgrade to support data archiving. Staffing issues prevented the establishment of a demonstration site at 101 California Street.

3.4 Costs and Benefits Assessment

Assessing the costs and benefits of innovative performance monitoring capabilities turned out to be much more difficult than anticipated. The duration of this research project did not allow sufficient time to evaluate the costs and benefits of implementing performance monitoring systems at participating sites. This would require a project of 3 to 5 years duration. A number of the test sites have only recently installed instrumentation or have yet to install it. Additionally, it was impossible to deduce detailed cost and benefit data specific to performance monitoring capabilities from other monitoring-related efforts such as the Monitoring-Based Commissioning (MBCx) program due to the intermixing of monitoring and commissioning activities. This intermixing makes it impossible to attribute specific benefits to monitoring-only costs. The description of two specific projects performed under the MBCx program presented in Jump *et al.* (2007) provides useful background and insights.

As originally envisioned, this task involved collecting and analyzing cost and savings data from the test sites. To this end, the case study survey form (see Appendix A) was developed and distributed to several sites that had expressed interest in supporting this task. Subsequent revisions were made to this survey form, simplifying it to a three-page protocol, in the interest of encouraging responses to this request for information. No responses were received. Several factors contributed to this lack of response. Several test site projects were delayed due to the overall process of specifying, procuring, implementing, and employing the enhanced performance monitoring capabilities. As a result of these delays, usable pre- and post-monitoring data are generally not yet available. Also, as projects developed, in-house (i.e. site) resources were often mixed with outside work on implementation, making it difficult to sort out the true costs of implementation. Additionally, changes in building occupancy and operation often occurred simultaneously with performance monitoring implementation, making it difficult to quantify the benefits directly attributable to performance monitoring. Finally, personnel at the demonstration sites tend to be overloaded with higher priority tasks than responding to requests for detailed cost and benefit data.

The approach to this task was therefore modified. The primary intent of this task was to bolster adoption of the performance monitoring system specifications by documenting the expected costs of implementation and the benefits accrued from continuous performance monitoring. The project team believes that this intent can be partially achieved through the documentation of anecdotal examples of continuous performance monitoring that led to building operations intervention and resulted in benefits valued by building owners, property managers, occupants, or operators. Five such vignettes are included below under the *Performance Monitoring Benefit Examples* section.

Potential benefits must be evaluated against the costs of achieving those benefits. In the attempt to assess the costs of procuring performance monitoring system capabilities necessary to routinely achieve the types of benefits associated with the anecdotal examples, a combination of approaches has been pursued. Data from test sites from this project have been documented where available. Cost data from previous continuous monitoring projects have been documented and updated with estimated current costs. These data are included under the *Costs Assessment* section below.

3.4.1. Performance Monitoring Benefit Examples

This section contains several anecdotal vignettes of benefits accrued from continuous performance monitoring in buildings. These examples have been collected from test sites from this project, and from the Monitoring-Based Commissioning (MBCx) program, a collaboration among the University of California (UC), California State University (CSU), Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Southern California Gas (SCG).

Vignette #1 – Chilled Water Distribution Problem

All data points available from the building management systems in a newly constructed building were trended. The evaluation of data from the first air handler identified supply air and chilled water temperatures outside the expected performance range. The team investigated and found that chilled water from the central plant was not being drawn into the building loop. As a result, the building air handlers were delivering air at an elevated temperature, causing the fans to operate at high speeds to meet the cooling load of the building. The team modified the set points on the loop pressure control and the VFD controller, resulting in a proper air handler supply air temperature and an appropriately high chilled water temperature returning to the campus loop. The metering system observed a reduction in the building electric load and an increase in the building chilled water load. The effect of the increased load on the chiller plant was calculated to offset about 20% of the fan savings. The increased chiller electricity use occurs at night because the campus uses a thermal energy storage system at the central plant. This is an example of the analysis of trended building energy performance data leading directly to reduced energy use and cost at the building, and increased comfort.

Vignette #2 – Poor VAV Zone Control

The building has 28 zones served by air handling units and a single boiler and chiller. The zone temperatures are controlled by VAV terminal boxes with reheat using pneumatic thermostats and actuators. The presence of pneumatic controls means there is no monitoring available for temperatures in the spaces, VAV box airflow, or reheat coil valve position. The project installed temperature sensors in multiple rooms in the building, connected into an energy management system. Large variations in temperatures were trended in the various rooms. One room might be at 79°F while another similar room was 70 °F. This led to an investigation of the pneumatic thermostats and VAV boxes. Roughly 80% of the zones were found not to be controlling temperature properly. A number of thermostats were found to be out of calibration. A number of VAV boxes were found to have inoperative actuators on the air dampers or hot water valves. There was a significant amount of unproductive energy use in heating, cooling, and distributing air unnecessarily. Discomfort in the building led to the chiller being manually started during some hours when comfort could have been maintained without chilled water, given properly operating zone controls. The controls were calibrated and malfunctioning actuators replaced where possible. The recommendation was made to convert to direct digital controls at the zone level in the future. A project under consideration initially was the replacement of the chiller with a more efficient unit. The metering determined that the annual load on the chiller was lower than expected and that it was likely to be lower still after repair of the zone controls. As a result it was determined that there was an inadequate annual electric load to justify the replacement of the chiller on the basis of energy savings.

Vignette #3 – Continuous Operation, Intermittent Occupancy

When the existing electric and gas meters at the building were tied into the campus energy management systems and their energy use was trended, high nighttime electricity and natural gas use were immediately obvious. Further investigation revealed that the air handlers operated continuously although the building was empty at night. The chiller also operated at night, as well as the boiler, performing simultaneous heating and cooling. Much of the lighting was also found to operate after hours. Once identified, the nighttime operation was easily addressed by reprogramming the EMS. The building has had electric and gas meters for a number of years. The monthly manual meter readings apparently had not triggered any alarms. This seemingly obvious problem was not identified until the monitoring was in place. The project also included installation of a Btu meter on the hot water output of the building boiler. The readings from this meter revealed that the calibration factor used for the gas meter was not properly corrected for gas pressure. All of the historical gas meter readings were incorrect. The new gas readings that are based on the correct multiplier now compare properly with the metered hot water use.

Vignette #4 – Unstable Control

Monitoring identified significant instability in the control of supply air temperatures in two air handlers. The trending data showed that the preheat valve cycled every 15 minutes between 75% open and fully closed. This resulted in a variation in supply air temperature of 9 or 10 degrees in the heating mode for the air handlers that serve the biological sciences building. The chilled water valve was found to have a similar, though smaller, control instability, causing the supply air temperature to vary by 4 or 5 degrees every 15 minutes in the cooling mode. This cyclic variation in supply air temperature makes control of space temperatures difficult, and potentially causes unnecessary heating and cooling.

Vignette #5 – Unnecessary Chiller Operation

A building was equipped with two separate transformers, one serving plug loads and lighting, and the other serving HVAC equipment. Each transformer was monitored using a simple data acquisition device that allows standard web browser access to, and trend visualization of, collected data. The building operator noticed spikes in HVAC equipment energy consumption that were recognized as being caused by the chiller. Subsequent inspection revealed that the chiller lockout based on temperature had been disabled resulting in unnecessary cycling of the chiller. Re-enabling the lockout is estimated to save approximately 300,000 kWh annually.

3.4.2. Costs Assessment

This section contains documentation of the costs associated with installing instrumentation required to support continuous performance monitoring. These example costs have been taken from one test site from this project and from earlier projects on continuous monitoring.

Santa Rosa Federal Building Monitoring Instrumentation Upgrade Estimated Costs

The following tables were created to provide design guidance for performance monitoring sensor upgrades to the existing control system at the Santa Rosa Federal Building in conjunction with an HVAC retrofit project. The intent was to upgrade the sensor suite to provide accurate performance monitoring of building systems and a new chilled water plant. To meet these requirements, some new sensors were required, some sensors were identified for replacement with higher accuracy sensors, and other sensors needing to be calibrated were identified. Additional EMCS connection hardware and software were required to maintain the spare point capacity in the existing specifications. It was also advised that new specifications should call for bi-annual calibration of all sensors, and any necessary calibration equipment and training.

Total costs of monitoring instrumentation for the Santa Rosa Federal Building chiller retrofit project were estimated for three priority levels for each of two sections of the building. These estimated costs are shown in Table 2.

Table 2. Estimated Total Costs of Monitoring Instrumentation for a Chiller Retrofit Project

Priority	West Wing Chilled Water	Other	Total Cost
1	$5,500	$3,400	$8,900
2	$9,300	$11,600	$20,900
3	$2,100	$7,000	$9,100
Total	$16,900	$22,000	$38,900

Source: Berkeley National Laboratory

The estimated costs of individual data point instrumentation for the Santa Rosa Federal Building chiller retrofit project are listed in Table 3.

Table 3. Estimated Costs of Individual Data Point Instrumentation for the Santa Rosa Federal Building Chiller Retrofit Project

Point Description Summary	Accuracy	Type	Est Cost	Priority 1=high
Main Power (if required)	+/- 1.0 %	True RMS, Three Phase stand alone analog output or networked power meter	$1000	1
Lighting Riser Power	+/- 1.0 %	True RMS, Three Phase stand alone analog output or networked power meter	$1200	1
Plug Riser Power	+/- 1.0 %	True RMS, Three Phase stand alone analog output or networked power meter	$1200	1
Chiller 1 Power	+/- 1.0 %	True RMS, Three Phase, integrated equipment, stand alone analog output or networked power meter	$1000	1
Chiller 2 Power	+/- 1.0 %	True RMS, Three Phase, integrated equipment, stand alone analog output or networked power meter	$1000	1
Chiller 1 Primary CHW Pump Amps	+/- 0.5 %	Split core loop powered devices	$150	3
Chiller 2 Primary CHW Pump Amps	+/- 0.5 %	Split core loop powered devices	$150	3
Chiller 1 Primary CW Pump Amps	+/- 0.5 %	Split core loop powered devices	$150	3
Chiller 2 Primary CW Pump Amps	+/- 0.5 %	Split core loop powered devices	$150	3
AHU Supply Fan 1 Power from VFD	+/- 3.0 %	Reprogram Existing VFD analog output for kW	$350	2
AHU Supply Fan 2 Power from VFD	+/- 3.0 %	Reprogram Existing VFD analog output for kW	$350	2
AHU Return Fan 1 Power from VFD	+/- 3.0 %	Reprogram Existing VFD analog output for kW	$350	2
AHU Return Fan 2 Power from VFD	+/- 3.0 %	Reprogram Existing VFD analog output for kW	$350	2
Cooling Tower Fan 1 Power (VFD) or Amps (const speed)	+/- 3.0 %	?	$350	3
Cooling Tower Fan 2 Power (VFD) or Amps (const speed)	+/- 3.0 %	?	$350	3

Point Description Summary	Accuracy	Type	Est Cost	Priority 1=high
Chiller 1 Primary CHW Pump Power	+/- 5.0 %	(calculated point)	$200	3
Chiller 2 Primary CHW Pump Power	+/- 5.0 %	(calculated point)	$200	3
Chiller 1 Primary CW Pump Power	+/- 5.0 %	(calculated point)	$200	3
Chiller 2 Primary CW Pump Power	+/- 5.0 %	(calculated point)	$200	3
Chiller 1 CHWS Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 1 CHWR Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 1 CWS Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 1 CWR Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 2 CHWS Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 2 CHWR Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 2 CWS Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Chiller 2 CWR Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	2
Ambient Web Bulb Temperature	+/- 0.05 F	Sensor compatible with Alerton BACTalk or specified controllers	$500	1
Ambient Dry Bulb Temperature	+/- 0.05 F	Sensor compatible with Alerton BACTalk or specified controllers	$500	1
CHW Header Supply Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	1
CHW Header Return Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	1
CW Header Supply Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	1
CW Header Return Temperature	+/- 0.01 F	Sensor compatible with Alerton BACTalk or specified controllers	$150	1
CHW Header Flow	+/- 1.0 %	Hot Tapped insertion vortex shedding (or insertion mag)	$1900	(1)
CW Header Flow	+/- 0.75 %	Full bore magnetic meter with analog display	$2700	2
Chiller 1 CHW Flow	+/- 0.75 %	Full bore magnetic meter with analog display	$2700	(2)
Chiller 2 CHW Flow	+/- 0.75 %	Full bore magnetic meter with analog display	$2700	(2)
AHU Supply Fan 1 Airflow Rate	+/- 5.0 %	Vortex shedding sensor on fan inlet	$3500	2
AHU Supply Fan 2 Airflow Rate	+/- 5.0 %	Vortex shedding sensor on fan inlet	$3500	2
AHU Return Fan 1 Airflow Rate	+/- 5.0 %	Vortex shedding sensor on fan inlet	$3500	3

Point Description Summary	Accuracy	Type	Est Cost	Priority 1=high
AHU Return Fan 2 Airflow Rate	+/- 5.0 %	Vortex shedding sensor on fan inlet	$3500	3
Solar Radiation	+/- 3.0 to 5.0 %	Pyranometers to determine solar radiation on horizontal and four vertical building orientations, plus one spare for rotating calibration.	$3200	2

Source: Berkeley National Laboratory

3.4.3. DGS Office of the Attorney General Building Performance Monitoring Costs

An initial draft of this project's performance monitoring system specifications was provided to the manager of a general control system upgrade at the Department of General Services (DGS) Office of the Attorney General Building in Sacramento in 2006. DGS integrated the performance monitoring specifications into their overall control system upgrade specifications as add alternates in the request for bids. A contract was awarded with additional funding from DGS for the performance monitoring 'add alternates'. Team members have interviewed the DGS manager and the contractor on this control system upgrade. The main conclusions from these interviews were that the performance monitoring specifications were clear and straightforward to bid on, no major problems were encountered in installing these additional capabilities, and the price of the enhancements was approximately as expected ($75-80k).

Instrumentation Costs

Table 4 lists the performance monitoring enhancements that were part of the DGS set of specifications for this project. It is important to note that the entire control system was being upgraded, and so some of these capabilities may have already been included in the overall upgrade.

Table 4. Performance Monitoring Enhancements for DGS Attorney General Building

Data Displays	
Equipment/ System Graphics	Floor plans with zones temperatures, HVAC system graphics
Data Tables	Building air handler summary tables, metrics results table
Time Series Group Trend Plots XY Group Trend Plots	System performance plots 1. ChW Plant Delta-T, ChW Plant tons vs. OA Temp 2. ChWPlant kW vs. ChWPlant tons 3. ChW Plant kW/ton vs. OA Temp, OA Wb Temp, ChW Plant tons 4. HVAC Power vs. OA Temp, OA Wb Temp, ChW Plant tons 5. Total Gas Flow vs. OA Temp 6. OA Temp Fraction vs. OA Damper Fraction 7. Daily Whole Bldg Electric EUI; Whole Bldg Natural Gas EUI; Whole Bldg Water EUI vs. Avg. Daily OA Temp
Data Points	
Measured	OA Temp OA WB-Temp Main Power Main Natural Gas Flow Main Water Flow Chiller # Power Other ChW plant equipment power Plant ChWST Plant ChWRT Plant ChW flow (gpm) Air handler # MA Temp, RA Temp, SA Temp Air handler # SF & RF power Air handler # flow (cfm) Zone temperatures
Control	Air Handler # OA Damper %, Return Damper %, SF Mode, SF status, ChW Valve %, SA Temp Sp
Calculated – Whole Building Calculated – Chilled Water Calculated – Supply Air	Avg. Daily OA Temp Whole Bldg Peak Power Total HVAC Electric Power Whole Bldg Electric EUI Whole Bldg Natural Gas EUI Whole Bldg Water WUI ChW Plant (loop #) Delta T ChW Plant Power ChW Loop # tons Total ChW Plant tons ChW Plant Efficiency (kW/ton) AH# Outside Air Temp Faction AH# Outside Air Damper Fraction Total Air Handler Power Total Air Handler Volume Air Handling System Specific Power (kW/cfm)
Software	
Database	Sequel Server/ MS SQL Server 2000

Source: Berkeley National Laboratory

3.4.4. Information Monitoring and Diagnostic Systems (IMDS) Costs and Savings

The Information Monitoring and Diagnostic System (IMDS) has been previously reported on in Motegi, et al (2003). Excerpts from that report are repeated here as an introduction to the detailed cost and savings data given below.

The IMDS (Information Monitoring and Diagnostic System) was developed and evaluated as a collaborative effort among researchers, building property managers, and private industry. The IMDS consists of a set of high-quality sensors, data acquisition software and hardware, and data visualization software, including a web-based remote access system.

While a typical EIS focuses on whole building energy management for a single or multiple buildings, IMDS focuses on building system and component level of diagnosis. The IMDS's trending points include component-level electricity consumption data and many other data types that are typically not available from an EMCS such as an equipment electric demand. The data trended by the high-quality sensors in short intervals (1 minute) is desirable to detect various system malfunctions and failures.

The IMDS demonstration sites were carefully chosen based on the innovation of the on-site staff. These demonstrations were intended to illustrate the value of high quality performance monitoring systems to innovative building operators. Both of the two IMDS demonstration sites were office buildings operated by third party property management firms where tenants pay the electricity costs. In both sites we found strong interests by the operators to minimize energy use although they did not directly reduce their company's costs with such savings.

A summary of costs and savings from the IMDS project are given in Table 5. Table 6 gives costs for the sensor only portion of the original IMDS installation, and estimated comparative costs for the same sensors today and for commercially available sensors of the quality specified in these performance monitoring system specifications.

Table 5. IMDS Project Cost and Savings Summary

Project	Project Cost[1] ($)	Cost per Rentable SF[2] ($)	Energy Savings ($)	Energy Savings (%)	Payback (yrs)
IMDS Base Install	91,577	0.96	13,867	8%	6.60
IMDS to Control and Full Oversight (includes Base Install)	201,577	2.12	39,867	31%	5.06

Source: Berkeley National Laboratory

Notes:

1. Project Cost included Data Acquisition, Sensors, Client Labor, Contractor Labor, and Donated Visualization Software.

2. Rentable square feet was 95,200.

Table 6. Estimated Cost Comparisons for Original, Performance Spec, and Commercial Quality Sensors

Project	IMDS Original[1] ($)	IMDS Today[2] ($)	PMS Commercial[3] ($)
IMDS Base Install	43,577	41,915	25,718
IMDS to Control and Full Oversight	44,814	43,759	27,374

Source: Berkeley National Laboratory

Notes:

1. Cost is for sensors only, prices referenced from original installation.

2. Cost is for sensors only, prices referencing IMDS technology with current pricing.

3. Cost is for sensors only, prices referencing Performance Monitoring Specification requirements with commercially available sensors.

The types of energy saving issues discovered through use of the IMDS Base Install include the following:

- Loose Belts on main fans.
- Leaking Steam Valve heating up building.
- Fan and Building static pressure and power data used to tune Barber.
- Barber Colman fan control system.
- Closed damper near cooling tower to remove warmer re-circulated exhaust air from reducing tower efficiency.
- Identified large air bubble in chilled water loop, affected the cooling coil and pump performance.
- Identified false loading on chillers, data pointed to low refrigerant level leak on one chiller, switched lead status.
- Identified building Miscellaneous loads.
- Simultaneous heating and cooling identified.
- Building ran and conditioned from 5:45 AM to 6 PM every working weekday.
- IMDS points, calculations, metrics and diagnostic points trended at one minute intervals.
- IMDS provided overall building information to define and tune the operation of the three existing control systems.
- Dual pump operation evaluated.
- Economizer system set-points identified.

Additional types of energy saving issues discovered through use of the IMDS Control and Full Oversight system include the following:

- Fan static pressure reduction

- Steam valve size reduced
- Optimized control logic implemented
- Optimized start / stop implemented
- Runtime Schedules optimized
- Temperature lockouts and resets implemented
- Simultaneous heating and cooling removed via control
- All points, calculations, metrics and diagnostic points trended at one minute intervals
- Zone level tenant comfort improved and complaints reduced
- Elevator motor fault identified from main meter data
- Identified pressure loss, excessive runtime and failure mode on EMCS pneumatic air compressor
- Less equipment cycling to maintain set points and conditioning
- Three systems merged into one EMCS system

3.4.5. Case Studies of Energy Information Systems

A report on case studies of energy information systems (EIS) published by Motegi, et al (2003) includes costs and energy cost savings from installation and use of a web-based energy monitoring and analysis tool linked to an existing campus energy management and control system (EMCS). Since the EIS costs only include new hardware and software added to an existing EMCS, they do not reflect total costs for the resulting performance monitoring system. Also, these costs are for the University of California, Santa Barbara (UCSB) campus, with 4.5 million square feet of building area, serving approximately 22,000 students, faculty, and staff. However, the breakdown of costs in Table 7 is a useful reference for this type of upgrade. For further details, see the original publication.

Table 7. Example Costs of Performance Monitoring Enhancements (Motegi, et al, 2003)

Component	Cost
Software License for Itron EEM Suite™	$84,000
Software License Additional Modules	$97,000
EMCS two-way gateway hardware	$12,000
Additional Sensors	$50,000
Installation and Setup	$52,000
Annual Maintenance and Support (18% of license fees)	$35,000
Networking	$11,500
Grand Total	$341,500

Source: Berkeley National Laboratory

According to the referenced report, “The benefits of EIS can be separated into (1) energy savings, (2) peak electric demand reduction savings, and (3) human resources savings. Energy savings include the costs of electricity and gas saved by operational changes directed by the EIS. The demand reduction savings include the costs saved by reduction of peak electric demand charge and additional incentives received for participation in a demand reduction program. The human resource savings include the costs saved by reducing the number of hours worked by staff members.”

Also according to the referenced report, Table 8 below “summarizes the campus energy cost savings between May-2000-to-April-2001 period and May-2001-to-April-2002 period. The cost savings were estimated by applying $0.05/kWh for electric consumption and $13/kW (June to September, $6/kW in other months) for monthly demand charge. As a result, the electricity cost savings were $430,000 and the demand cost savings were $160,000. Based on the energy manager’s insight that 50% of energy savings came from operational optimization helped by the EIS, the total energy cost savings attributable to the EIS were $295,000 for the first year, resulting in an estimated payback period of 1.2 years.”

Table 8. Estimated Energy Cost Savings Attributable to EIS Performance Monitoring (Motegi, et al, 2003)

	Electricity [MWH]	Peak demand [kW]*	Total
May00–April01	83,700	12,742	
May01–April02	75,100	11,362	
Saving	8,600	1,300	
Cost saved	$430,000 (10.3%)	$160,000 (12.4%)	$590,000 (10.8%)
Due to EIS (50%)	$215,000	$80,000	$295,000

Source: Berkeley National Laboratory

* Peak demand [kW] shows average of 12 months. Saved cost shows annual total.

3.5. Technology Adoption Case Study

A case study of technology innovation and adoption in large organizations was undertaken to better understand the process by which organizations might be encouraged to promote performance monitoring within their buildings.

Large organizations such as governmental agencies can be important facilitators for adoption of new technologies. Federal and State agencies can provide a test bed for new tools and expertise. In the area of energy policy, California governmental agencies have been called upon to provide leadership in building energy efficiency through addressing goals set out in Executive Order S-20-04. This directive, also identified as the Green Building Initiative, incorporates by reference many other energy programs; it has emerged as both a source of direction and a cause of uncertainty in the methods of achieving its goals.

Increasing complexity of the operating environment is a frequent motivator for organizational change. Organizations that have a low level of complexity and many routine functions usually have organizational structures to match this environment. In the event of changing requirements, especially requirements that introduce more complex technologies and more complex reporting systems, the effective organization changes to meet the new environmental complexities. California agencies are in the process of responding to a new, more complex environment that has been triggered by Executive Order S-20-04. Part of this process is the adoption of new technologies that support efforts to achieve the goals of this directive.

New technologies require new expertise. If technological expertise is outsourced, policy makers need to be careful to maintain control of key technologies. Even outsourced systems need oversight, and if the organization does not contain some sophisticated users of technology, they are unlikely to outsource optimally. Failure to keep core competencies within an organization can lead to long term "satisficing" rather than optimal decision-making. In "satisficing," managers are inclined to accept the first acceptable choice rather than reviewing changes thoroughly and selecting the best option.

The specific target of the technology adoption review in this study is the adoption of performance monitoring technologies, in particular a specification that can be used in the procurement of performance monitoring systems. It is clear that the major impediment at present is the large number of changes in related areas that agencies are charged with initiating. On the other hand, these changes, including many items in the Green Building Initiative, may also allow managers to develop new methods of evaluating and testing innovations. Many of the programs identified in the Green Building Initiative could benefit from the enhanced automation of performance data collection provided by performance monitoring systems. Performance monitoring could be interwoven into the existing programs if agency upper management properly champions it.

The use of a tool that helps to standardize measurement and performance reviews is a likely to be an advantage for those buildings (and their managers) able to make best use of it. The widespread adoption of commissioning and benchmarking may leave building managers in a situation in which projects that do not meet performance targets are deemed to have fallen short due to management and operator errors. Monitoring building performance to obtain accurate and trustworthy data is the only sure way to deflect discussion from opinion and entrenched beliefs about the building's operation problems and possible operational errors to fact-based discussions resulting in energy-saving solutions to problems.

The Performance Monitoring System Specification Guide should be accompanied by an explanation of why the addition of performance monitoring systems on projects will reduce risk, improve service to customers and protect the staff from outside criticism. To be most effective, the performance monitoring system needs to be able to measure with sufficient accuracy to provide clear indications of the source of operational problems. The Performance Monitoring System Specification Guide could assist in defining the skills and education necessary for critical personnel to more effectively evaluate the performance of their buildings.

3.6. VizTool Data Visualization Tool

An assessment of the performance monitoring capabilities of building control systems performed prior to the start of the project indicated that the greatest weakness was a lack of data visualization capabilities for both real-time display and for regular reporting. In particular, there was poor support for interactive tasks such as troubleshooting. All the major control vendors' products were limited to time series displays with, for example, no X-Y display capability, and most still have this limitation. It was proposed to develop a prototype visualization tool to identify the visualization that would be most useful to include in the specification guide. Initial activities included:

- Surveying existing visualization tools to determine strengths and weaknesses, and to identify potential resources for the proposed visualization tool.
- Identifying stakeholders' perceptions of visualization tool requirements by interviewing experts.
- Producing a detailed performance specification for the visualization tool, including development environments, graphical user interface (GUI) features, training requirements, data handling requirements, visualization requirements, evaluation and fault-detection requirements, etc.
- Developing a functional, demonstration prototype for key features of the tool.
- Identify commercialization vehicles for subsequent stages of development.

The survey of existing visualization tools examined the following tools:

- Visualize-IT (http://www.rlw.com/pro_visualize.htm)
- PACRAT (http://www.facilitydynamics.com/pacrat.html)
- ElectricEye (developed by Supersymmetry and used in the Information Monitoring and Diagnostic System (IMDS) project)
- ChartFX (http://www.softwarefx.com)
- DecisionSite (http://www.spotfire.com/products/decision.asp)
- WebFocus B1 (http://www.informationbuilders.com/products/webfocus/index.html)

Survey results indicated that:

- Good visualization tools are available but that none of them currently have the combination of specifications needed for widespread application to the performance monitoring of building HVAC systems.
- Some existing visualization tools for general business applications are potentially useful resources for developing at least rudimentary building-oriented visualization applications; an example is ChartFX.
- Other existing visualization tools already have building-oriented applications and good features sets (e.g., Visualize-IT from RLW, PACRAT from Facility Dynamics). Visualize-IT is focused on analyzing building level energy efficiency; thus, it does not use small enough time steps (e.g., 1 hour minimum). If it would be converted to smaller time steps, it is likely that it would be too slow for the intended uses.
- Still other building-oriented applications (such as ElectricEye) have good technical specs and speed, but are likely to be much too expensive for widespread use; so that they are likely to be used for only the largest buildings and commercial/industrial clients.

Based on the survey results, a performance specification for the enhanced visualization tool was developed and is included as Appendix B. Viztool is intended to be an open-source toolkit that raises the level of visualization techniques that are widely available for monitoring the performance of buildings and for diagnosing the operation of building systems, especially HVAC systems and their controls. Key initial objectives were to be able to display data on a PC that might be located at a building operator's station in a building, including:

- Data collected at one-minute intervals or more for up to a full year duration.
- Up to 10 variables extracted from a database and displayed simultaneously.
- Display of both static historical data as well as dynamic current data.
- Display of data using a variety of formats.
- Ability to flag outlier or faulty data in different views.
- Allow the user to focus in on specific time intervals within the data set.

The current VizTool implementation is an alpha version work in progress. Some capabilities are reasonably well implemented; other capabilities are currently implemented either in prototype or proof-of-concept form or are only partly implemented, thus serving as placeholders or to capture ideas for consideration and future development.

VizTool has been implemented using the freeware plot generation library Matplotlib and wxPython for the GUI. The freeware relational database MySQL is used to store a local copy of the data being plotted, which allows rapid refreshing of plots as the display requirements are changed by the user. In particular, it allows identification of outliers in different views of the same data. This can be done in two ways: (1) allowing an external program such as an automated diagnostics tool to tag outliers within data set imported to VizTool, and (2) by allowing a user to use a mouse to manually identify outliers within areas on the plot being presented. This allows the characteristics of outliers to be investigated interactively; for example, an X-Y plot of chiller efficiency *vs.* load may contain points of particularly low efficiency. Tagging these points and highlighting them on a time-series plot or an X-Y plot with another independent variable, such as condenser water temperature, may quickly provide clues as to the cause of the inefficient operation.

VizTool also includes a Windows Explorer style browser to facilitate navigation of large data sets. An XML structure is used to situate data points and graphs within a tree of building system components – the actual schema for this XML document still needs to be defined explicitly. VizTool reads in this XML structure and uses it to generate the browser content as well as to store meta-data about data points, graphs, building components and object graphics.

The following graph types are currently implemented:

- Time-series: this plot displays one or more variables along the Y-Axis , with Time displayed along the X-Axis. See Figure 1.

- XY Scatter Plot: this plot displays the relationships of 2 or more variables. One variable is scaled along the X-Axis. One or two variables can be scaled along the Y-Axis. See Figure 2.
- Carpet plot: this plot "wraps" time-series data into 24-hour intervals. Each vertical line represents a day. Figure 3 shows weather data for a typical year in Chicago. Dry bulb temperature on the top, solar radiation on the bottom.
- 3D Surface Plot: see Figure 4.

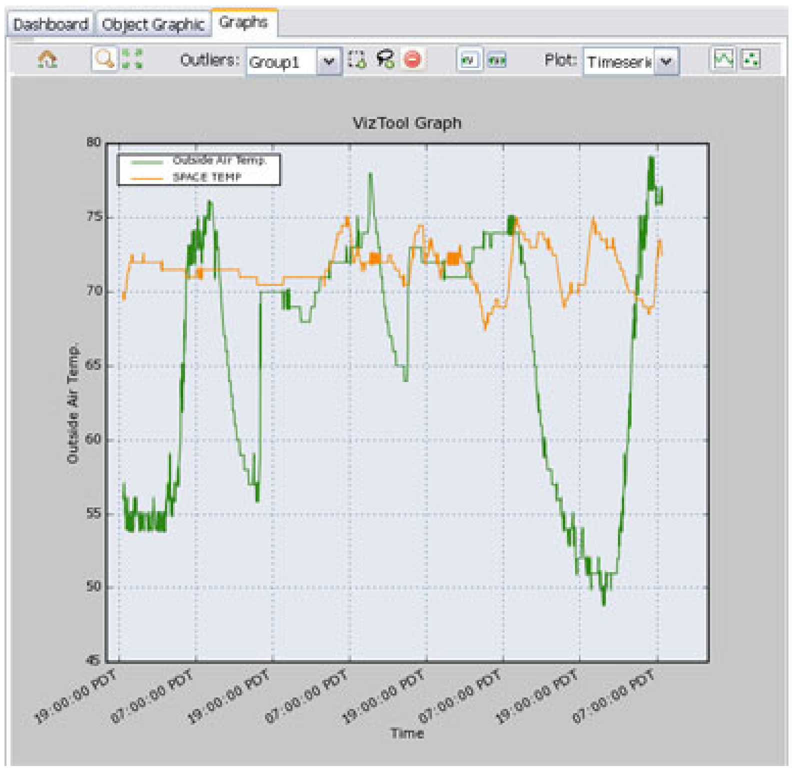

Figure 1. Example VizTool Time Series Plot
Source: Berkeley National Laboratory

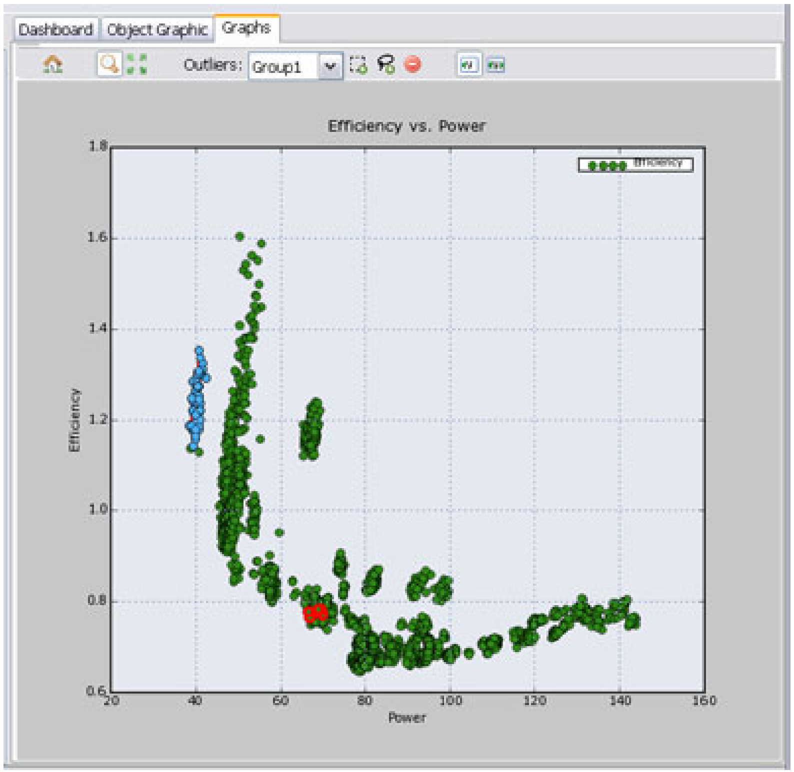

Figure 2. Example VizTool X-Y Plot Showing Tagged Outliers
Source: Berkeley National Laboratory

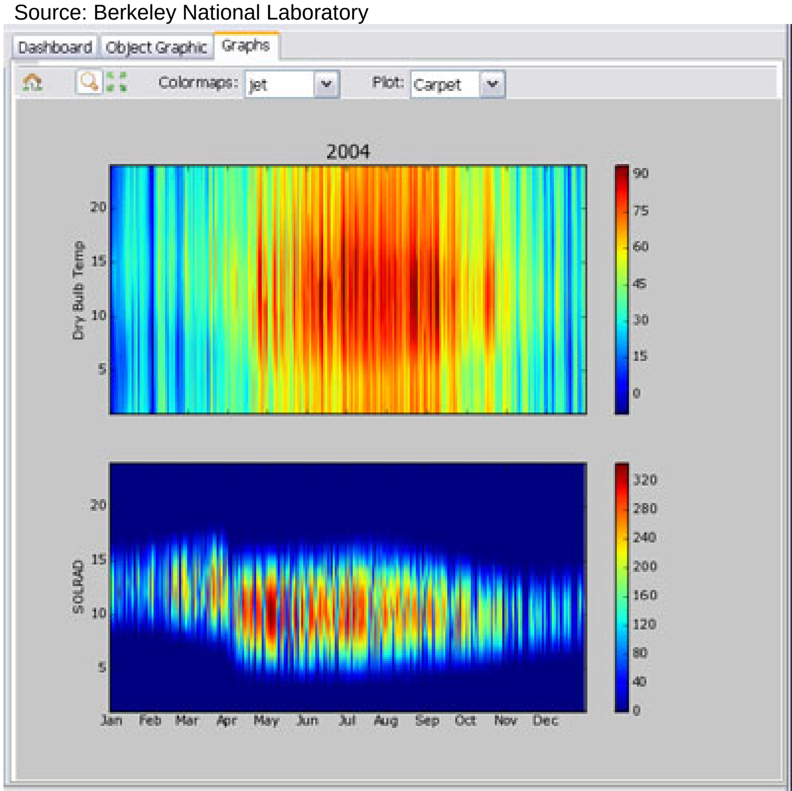

Figure 3. Example VizTool Carpet Plot
Source: Berkeley National Laboratory

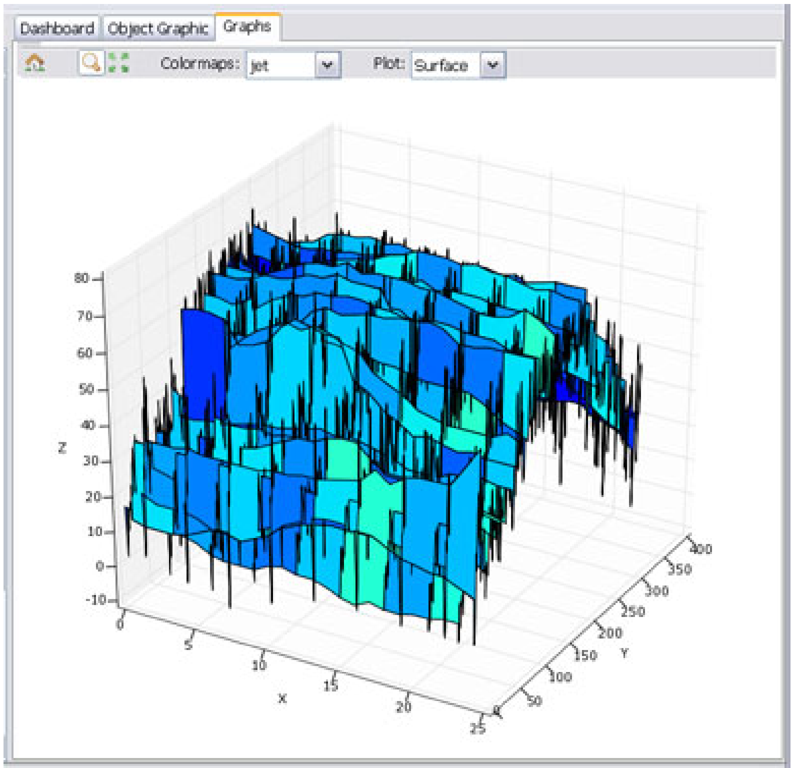

Figure 4. Example VizTool Surface Plot
Source: Berkeley National Laboratory

Commercialization Vehicles:

Promotional Website: The www.viztool.org website has been developed to advertise the existence of the VizTool and to describe its capabilities to potential users and developers.

Data Visualization for Automated Diagnostics. VizTool is being linked to the automated diagnostic tools developed by LBNL. The first application is the control loop diagnostic tool currently being developed for the California Energy Commission.

Performance Monitoring and Diagnostics Visualization for Target Stores. It is planned to use VizTool for the visualization of the performance of Target stores as part of LBNL's project with Target.

HVAC ePrimer as a Commercialization Vehicle for VizTool: HVAC ePrimer is a training tool for community college students preparing to be HVAC technicians, developed by The Deringer Group, LBNL, and Laney College with funding from NSF. HVAC ePrimer will use VizTool to display time-series plot and scatter plots of the values of key operational variables generated by the embedded SPARK simulation.

The Universal Translator: It is planned to incorporate VizTool in PG&E's Universal Translator data management tool for building control systems.

4.0 Conclusions and Recommendations

4.1. Conclusions

Specifying and installing a performance monitoring system requires a level of rigor above that of the average installed DDC system. Performance monitoring systems need to be clearly specified because they are data dependent, requiring a more robust data acquisition capability than is typically used for control. The building owner and/or operator needs to have a good understanding of their data needs. This includes desired performance metrics, point naming convention, data accuracy requirements and data displays and actionable objectives in how the data is to be used. The specification guide for performance monitoring systems developed in the work reported here provides a context for determining these factors and example specification language for inclusion in a project request for bids, thereby enabling building owners and consulting engineers who do not have detailed specialist knowledge of performance monitoring to specify performance monitoring capabilities. The control system replacement project for the Office of the Attorney General Building in Sacramento described in Chapter 3 demonstrated that the specification guide is an effective vehicle for procuring performance monitoring capabilities for a large commercial building.

Based on observations in the project, drivers for building owners to add performance monitoring capabilities include:

- Awareness of whole building energy performance from EnergyStar or other benchmarking, prompting a desire the manage and improve performance.
- Institutional need to manage and improve energy performance, e.g. the California State University system's model-based performance tracking, utility-funded monitoring-based commissioning programs [Brown et al. 2006].
- Need to identify the more problematic facility in a suite of facilities.
- Desire to evaluate pilot installations of new equipment or systems prior to wider deployment.
- Demonstrate savings at the system level from energy efficiency measures.
- Manage maintenance contractors by verifying correction of equipment faults and operational problems.
- Incentivize staff by rewarding performance – preventative maintenance, sustainability, energy performance, quality of service to tenants.

Conversely, it appears to be difficult to get adoption of performance monitoring in the absence of one of these (overlapping) drivers. Other impediments are a lack of the necessary skills on the part of design engineers, controls contractors and facilities personnel.

4.2. Recommendations

1. CEC, DOE and other agencies should explicitly endorse and advance the use of cost-effective performance monitoring as a necessary part of efficient building operation.

2. CEC, CPUC, DOE and other agencies should develop education and training programs addressing design, installation and use of performance monitoring systems. On-going peer support for operators and others should be provided through an on-line list server.
3. All stakeholders in the project should continue to track developments in the industry that offer opportunities to disseminate and deploy the specification guide and actively pursue these opportunities to the maximum extent that circumstances and resources permit.
4. Performance monitoring should be used by default as a technology verification and cost-effective dissemination tool in all publicly-funded demonstration projects.
5. Further research is required to evaluate performance metrics in practice – metrics should indicate clearly if the monitored system is working correctly, should be actionable and should have a demonstrably positive effect on performance.

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Appendix A. Cost Benefit Case Study Survey

Cost Benefit Case Study Survey

Objectives

The objectives of the Benefits and Costs Assessment of Performance Monitoring Systems include the following:

1. Assess the actual and 'mature market' costs of each installed system or system upgraded.
2. Assess the estimated energy savings attributable to each system/upgrade.
3. Assess other benefits resulting from each system/upgrade during its initial use.

Approach

The assessments will involve test site visits to inspect the performance monitoring systems in operation; interviews with operators, facility managers and vendors; and analysis of available utility bills, consumption information recorded by the monitoring systems, complaint logs and maintenance records.

The following issues will be addressed in the assessments:

1. Baseline Building, System, and Management Characteristics – what are the characteristics of the buildings, their pre-upgrade installed controls and building automation systems, and the building operators and managers who use the system? How are/were the pre-upgrade systems being used, how effective are they, is their actual use consistent with their capabilities? What types of problems, complaints, and frustrations have users encountered when using the existing systems? What are the pre-upgrade energy consumption, peak loads, and costs of the building?
2. Performance Monitoring System Upgrade – what was done to upgrade the existing system to add performance monitoring system capabilities? How were the upgrades procured, installed, and commissioned?
3. Performance Monitoring System Upgrade Costs – what were the actual incurred costs, on a component item basis, of upgrading the existing system to include performance monitoring capabilities? What would be the estimated costs in a mature market of procuring these enhanced capabilities, both as part of an initial system installation and as an upgrade?
4. Performance Monitoring System Effectiveness – how effective are the new capabilities of the upgraded system, how are these capabilities being (and/or not being) used. What are the perceived and actual (documented) benefits of these capabilities? How were onsite personnel trained in using the upgraded system?
5. Performance Monitoring System Energy Savings – what are the energy savings (consumption, peak load, and cost) that can be attributed to the performance monitoring system upgrade?
6. Suggested Improvements – What do users want that they still cannot do (or that is still too difficult to do)? What do users think are not valuable features of the upgraded system?

Research Hypothesis

Installing industry-leading cost-effective performance monitoring systems allows facility managers to better control their facilities; leading to energy savings and lower operating costs, without adverse impact on indoor environment.

Research Method: Pre-post multiple-case causal case studies

Using several buildings, we will observe energy consumption and operator behavior. We will then intervene with new performance monitoring systems capabilities. Finally, we will observe energy consumption and operator behavior post-intervention.

We will collect data on building energy performance and operator use of the pre-intervention facility control system to establish a pre-intervention baseline; install new performance monitoring system measures (including new monitoring points and new data archival and visualization tools), collecting data on associated costs of installation; and collect data on building energy performance and operator use of the new system.

Three main types of data need to be collected:
1. Pre/post building energy consumption data
2. Performance monitoring system measures installed and related costs
3. Pre/post system and operator behavior data

Interview Protocol for Collecting Proposed Information and Data

The following interview protocol will be used for collecting the data identified above. A spreadsheet template (see companion document "PMS Case Studies data template.xls") will be used for documenting pre/post building energy consumption data, and performance monitoring system measures installed and related costs. Textual responses to the remaining questions listed below will be documented within copies of this document.
Baseline Building and System Characteristics

1. Building
    - General Description
    - Type and Use
    - Vintage
    - Size
    - Location
    - Space Type Area Percentages
    - Occupancy Schedules
2. HVAC Systems
    - General Description
    - Type
    - Vintage
    - Components
    - Schedules
3. Control Systems
    - Overall Purpose (lighting, HVAC, process, security)

- Vendor & Model
- Vintage (year installed)
- Number of data points
- Communications protocols (type and speed, e.g., RS-485, 9600 bps)
- How were the pre-upgrade systems being used?
  - Manual/supervisory control of equipment
  - Graphical displays creation
  - Programming closed loop control of processes
  - Programming of sequences of operations
  - Change set points
  - Scheduling
  - Performance tracking/monitoring/adjusting
  - Diagnostics/troubleshooting analysis with trend logs
  - Diagnostics/troubleshooting and analysis with spreadsheets (logged data ported to spread sheet)
  - Alarms
  - Safeties
  - Documentation and logging of O&M activities
  - Monitoring of operations (with or without graphics)
  - Reports generation
  - Remote access (via phone or otherwise)
  - other ___________
- How effective are they and is their actual use consistent with their capabilities?
- What are the major benefits derived from having the existing systems
  - Reduced labor and/or improved productivity of operations personnel
  - Reduced energy use
  - Improved comfort
  - Increased responsiveness to complaints
  - Improved reliability of operations
  - Improved productivity of clients
  - Other ___________
- What types of problems, complaints, and frustrations have users encountered when using the existing systems?
  - Lack of training
  - Distrust of technology to perform correctly
  - Resistance/interference from other employees (e.g., operators, managers)
  - Slow response
  - Component failures
  - Erroneous information/false readings
  - Nuisance alarms
  - Calibration of sensors
  - Lack of data storage, and/or analysis capability
  - Difficult or complicated to setup and/or use
  - Too much data without effective tools to use it
  - Difficult to understand operations via information available

  - Too much “tweaking” required
  - Software cannot be configured to perform functions needed
  - Limited resources, not enough time to use system effectively (putting out too many fires)
  - Lack of documentation on specific equipment and systems and their intended operation.
  - System was oversold or misrepresented by vendor
  - Other ____________

4. Pre-upgrade Energy Use (monthly)
   - Consumption
   - Peak loads
   - Costs
5. Building Management and Operation
   - Management Organization and Location
   - Management Personnel
   - Operators
   - Level of training

Performance Monitoring System Upgrade

1. What was done to upgrade the existing system to add performance monitoring system capabilities?
   - Hardware Components
     - Meters
     - Sensors
     - Other
   - Software Components
   - Data Points
   - Performance Metrics
2. How were the upgrades procured, installed, and commissioned?

Performance Monitoring System Upgrade Costs

1. What were the actual incurred costs, on a component item basis, of upgrading the existing system to include performance monitoring capabilities?
2. What would be the estimated costs in a mature market of procuring these enhanced capabilities, both as part of an initial system installation and as an upgrade?

Performance Monitoring System Effectiveness

1. How are the new capabilities of the upgraded system being (and/or not being) used?
2. How effective are these new capabilities?
3. How were onsite personnel trained in using the upgraded system?
4. What are the perceived and actual (documented) benefits of these capabilities?

Performance Monitoring System Energy Savings

1. What are the energy savings that can be attributed to the performance monitoring system upgrade?
   - Consumption
   - Peak loads
   - Costs

Suggested Performance Monitoring System Improvements

1. What do users want that they still cannot do (or that is still too difficult to do)?

- Tools to automatically respond to energy price signals
- Remote access via the Internet
- Data visualization and plotting (x-y and or computed metrics)
- Tools for benchmarking the performance relative to past and other facilities
- Tools for analysis of energy operating costs under different utility rates
- Tools that simulate "what-if" examination of operating strategies and equipment changes/additions.
- Tools that allow global optimization of the energy systems, as well as tools for measuring the effectiveness of optimization.
- Tools that provide "virtual sub-metering."
- Tools that allow risk associated with technologies and operating strategies to be quantified and understood
- Tools to diagnose problems easily or automatically
- Automatic control loop tuning
- Better more precise control
- Tools that compute the cost impact of various problems
- Enterprise wide communications via web-based access to facility operations information and reports.
- Online access to facility design drawings, specifications, and operations information
- Comparisons of performance between vendor specifications and field installed conditions.
- Commissioning tools and procedures
- Graphical/block/object programming for control devices
- Tools and technologies to improve occupant comfort
- Other

2. What do users think are not valuable features of the upgraded system?

Appendix B. VizTool Specification

VizTool Specification

The Primary intended audience of the VizTool is the building operator / manager:

- It is assumed that this person has access to, and can monitor, the computer that processes the building's management information system.
- Thus, the visualization tool focuses on information that will assist a building operator / manager to efficiently control the building, to diagnose problems, and to identify solutions.
- Building engineers/operators should be able to use the tool with minimal training.
- Visualization tools for other audiences (e.g., occupants) might have radically different objectives and data presentations.

The VizTool has 3 key aspects or features

- Visualization
- Data gathering / manipulation
- Analysis / diagnosis

Each of these aspects can be quite complex. To date, efforts have focused primarily on the visualization aspects.

Within the above context, the VizTool should:

- Permit analysis using a 1-minute sampling interval. This will support analyses such as diagnostics of HVAC systems, components and many control situations, also evaluation of thermal comfort conditions. (One minute time steps will generate large amounts of data, and may not be needed for many types of analysis. Thus, other, less data-intensive time-steps should also be examined such as 5-minute, and 15-minute sampling interval. VizTool should allow the user to select among alternate time steps that are valid for the data set being examined.)
- Be able to analyze and display at least 1-year of data for 7-10 attributes. At a 1-minute sampling interval, that is at least 525,600 items per attribute. 10 attributes could involve the simultaneous analysis of 5,256,000 items. Typically, each item will involve multiple bytes of data. Ideally, the associated database for a building should store data for 15-18 months, unless old data are purged automatically.
- Have reasonably fast response: ideal – data analysis and display within 1-2 seconds. This is considered important to retain the attention of the user, as well as making efficient use of the user's time. This may ultimately limit the use of conventional relational databases, even the more powerful versions, and require the use of time-series databases, which are more expensive.
- Permit multiple simultaneous views of data for an HVAC system (e.g. times series and X-Y)
- Permit tagging of data selected interactively in one view so that they can be identified in other views (e.g. outliers in an X-Y plot can be selected with the mouse and then appear flashing in a time-series plot). This is very useful for trouble-shooting.
- Relate to HVAC equipment diagnostic tools being developed separately (e.g. detection of a fault by an automated tool triggers a graphical display for the operator that shows the data on which the detection is based).

- Be reasonably low cost. A target ultimate cost per seat of less than $500 is being proposed.
- Permit phased development of resources, relative to execution speed:
    - Phase 1 - Implement basic visualization features within a slower relational database environment
    - Phase 2 - Implement visualization features within a faster time-series database environment
- Permit phased development by building size and user expertise:
    - Phase 1 – target large buildings and multiple building institutions such as larger college campuses with skilled staff
    - Phase 2 – target medium sized buildings and smaller campuses with less sophisticated staff/ users
    - Phase 3 – target smaller buildings and much less sophisticated users