Standards for Fault Detection, Diagnostics, and Optimization in Building Systems

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March 20, 2007

The Southern California Gas Company is funding the project under S.S.A. 5600011845. This report is the property of the Southern California Gas Company.

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Executive Summary

Today there is an unprecedented appetite for energy, driven by technological innovation and the rapid development of societies around the world. Global usage of natural gas and electricity has severely depleted traditional commodity supplies, creating an increase in price that most economies cannot bear. According to the U.S. Energy Information Administration, "Many would argue that the world is destined to move beyond fossil fuels eventually; if the threat of global climate change does not compel it, then exhausted supplies and rising prices might."[1]

In order to minimize energy usage and perform well, the HVAC systems in commercial, institutional, and industrial buildings must be commissioned and optimized. By "commissioning", we mean the process of ensuring that building systems are operating according to design specs, the needs of the building owner, and the age and configuration of equipment. By "optimization", we mean the process of ensuring that all building systems are running at peak efficiency. Recently, technology has been developed that can diagnose certain types of faults and identify areas for potential optimization in HVAC systems. In this report, "FDDO" means Fault Detection, Diagnosis and Optimization applied to electrical, mechanical and control equipment that regulate the environment inside buildings. A range of FDDO technology has been developed by various research and commercial organizations, and several companies offer FDDO products and services. Applying this technology leads to significant energy, maintenance and operational savings for building owners, but all California residents stand to benefit from pollution reduction from the decreased use of various fuels. Regulated electric utilities will benefit from lower peak demand for electricity, reducing the stress on their transmission and distribution infrastructure.

The Problem:

To date, FDDO technology has not yet been widely used for a variety of reasons.

- Building owners are generally not aware of the potential benefits of FDDO
- FDDO savings are often soft and thus difficult to quantify
- Technical barriers exist to acquisition of sufficient data
- The lack of standardization in many buildings increases FDDO connectivity and configuration costs
- There is an absence of studies demonstrating the long term effectiveness of FDDO systems

1 EIA, "Energy in the United States: 1635-2000, The U.S. Energy Outlook as of 2001", EIA website: http://www.eia.doe.gov/emeu/aer/eh/frame.html

For example, there are technical barriers to the use of this technology as well as problems that greatly increase the cost of deploying the technology, especially in buildings with older control systems. These cost barriers affect third-party FDDO software and service providers and their customers particularly.

This research report documents the barriers to use of FDDO technology and offers concrete recommendations for removing them. Our goal is to stimulate the creation of a competitive market for building diagnostics software and services. The tools for breaking down the barriers to this goal are standards and regulations, and even more importantly, the education of stakeholders in the benefits of implementing FDDO systems. This report concludes that financial incentives for early adopters of FDDO technology will significantly advance the process of education, market development, and the willingness of stakeholders to adopt the technology. Additionally, the report highlights the need for widespread adoption of standards. Our recommendations are found at the end of this report.

Findings: Barriers and Their Causes

This report will enumerate three types of barriers to widespread adoption: market barriers, technical barriers and economic barriers. Market barriers include education of building owners, consulting engineers, and controls companies. Technical barriers include FDDO system configuration issues such as data sufficiency issues due to "value engineering" of controls systems during construction, and data collection from non-standardized building system network protocols. Economic barriers include initial installation costs and the difficulty of quantifying soft savings such as occupant comfort.

Recommendations:

Recommendations include outreach and education to building owners, consulting engineers and controls companies; accurate FDDO testing tools for result verification; and industry standardization including point naming conventions (see appendix, page 55), sequencing conventions, network protocols and data models. Incentives such as rebates and incorporation of FDDO services into LEED or EnergyStar requirements will help popularize the technology, as will the pairing of FDDO with Demand Response systems. FDDO tools need to be further refined and developed to include easy user interfaces and simplified configuration. We believe that through a combination of technical maturation of FDDO systems, marketplace priming, the implementation of standards, and rebates and incentives, FDDO systems will attain a substantial market presence.

Introduction

This report was commissioned by the Southern California Gas Company to provide an overview of the current market for Fault Detection, Diagnosis and Optimization (FDDO) Systems. Cimetrics has been a major participant in this market for several years, with our own entry being our Infometrics FDDO system. We were tasked with identifying barriers to widespread adoption of FDDO technology and positing recommendations for overcoming them.

While we performed a comparative analysis of FDDO products and services (with the help of an independent consultant), late in the process we were asked to provide more specific information about each FDDO offering. We were not able to obtain information regarding areas such as pricing, maintenance costs, specific energy savings and persistence of savings. This information is not only confidential but is, in most cases, building-specific rather than formulaic. While we cannot discuss particulars in these realms, we have offered general statements about them, as well as offering some specifics about our own Infometrics system where appropriate.

Introduction to FDDO

The fundamental purpose of FDDO technology is to help improve the performance of buildings. There are a number of measures of building performance, as well as audiences for those measures. Cost-bearing building owners, building occupants, and regulatory bodies are just some of the parties interested in building performance indicators such as environmental quality for building users, energy consumption, operating costs, capital asset condition, and adherence to building codes or other regulations.

The need for improved building performance

How well are building mechanical systems and control systems designed, installed, maintained and operated today? According to managers in the EPA's Energy Star program, there is a wide range of building energy performance, even among commercial buildings that have HVAC control systems. A study of Energy Star buildings in 1999 suggests that technology alone, such as the presence of an energy management and control system in a particular building, does not necessarily lead to an energy efficient building[2] EPA staff concluded that the characteristics that seem to differentiate buildings that perform well from those that do not include strong management commitment to energy efficiency and attention to operation and maintenance practices[3] . Anecdotal evidence

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2 Hicks, T.W. and von Neida, B. 2000. "An Evaluation of America's First ENERGY STAR® Buildings: The Class of 1999." ACEEE 2000 Summer Study on Energy Efficiency in Buildings Proceedings: Commercial Buildings: Program Design, Implementation, and Evaluation. American Council for an Energy Efficient Economy: Washington, D.C.

3 Lupinacci, J. M. 2001. "The Importance of Commissioning in Achieving Excellence in Energy Performance." Proceedings of the National Conference on Building Commissioning. Cherry Hill, New Jersey.

further suggests that a substantial fraction of commercial buildings have significant problems that adversely affect the building environment or operating cost. Problems can go undetected for a long time if there are no complaints from building users, and often even if such complaints do arise.

Sub-optimal building operations are caused by issues such as poor commissioning, inadequate maintenance, hardware failures, and the overriding of control settings in response to occupant complaints. A 1994 study of 60 commercial buildings found that over 50% had control problems, 40% had problems with HVAC equipment, and 33% had sensors that were not operating correctly. Almost 25% had EMCS (Energy Management Control Systems), economizers, and variable speed drives that were not operating properly.[4] Cimetrics' experience is consistent with this finding.

Although building owners and occupants are most directly affected by these problems, their effects are widespread. Excess energy consumption necessitates excess energy production, which generally results in avoidable pollution. Poor air quality within and outside of buildings can lead to illness and loss of productivity. Uncomfortable environmental conditions caused by sub-optimized HVAC systems can also decrease occupants' efficiency and enjoyment of their surroundings.

Ultimately, building owners and managers are responsible for providing a safe, comfortable environment for the users of their buildings. Most building owners and managers also want to reduce the cost of operating their facilities. Fault Detection, Diagnostics and Optimization (FDDO) technology can help them improve the operation of a building's mechanical systems and control systems and reduce operating costs. Less than 5% of building owners are currently making use of this technology,[5] however, for reasons such as short-term or hard ROI cost prioritization and lack of market education, both of which will be discussed later in this report.

Features and Benefits of FDDO Systems

Although there is considerable variation in the features and design of FDDO systems we can make some general statements about how they function (see Table 1, page 6). While fault detection is an intrinsic feature of FDDO systems, and it is generally easier than fault diagnosis, which can be complicated by inadequate data or nonstandard installations, most FDDO systems attempt to do both. Detected faults can result from a variety of problems, including broken or inaccurate sensors, making fault diagnosis challenging.

Faults can have similar symptoms, and in real buildings data are often not sufficient to allow an FDDO system to determine (diagnose) the cause of a detected fault reliably.

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4 Piette, Mary Ann, "Quantifying Energy Savings from Commissioning: Preliminary Results from the Northwest," Presentation at the 4th National Conference on Building Commissioning, 1994

5 Mills, Friedman, et al., „The Cost-Effectiveness of Commercial Buildings Commissioning„, 2004, page 3

Some fault detection techniques can identify possible design problems and operator errors as well as equipment or system faults. An example of a design problem that is sometimes detectable is an incorrect sequence of operations. A common operator error that can lead to wasted energy is leaving a piece of equipment on when it does not need to be on. Frequently, just getting a system working the way it was intended to work can yield substantial savings. Optimization of system or equipment operation is another feature of some FDDO systems. An example of this optimization is the adjustment of set points or equipment operating schedules in order to reduce energy consumption.

Most FDDO systems are passive, meaning that they do not directly affect the operation of the building; these systems provide information about faults, requiring building management personnel to make any necessary changes to building operation. Some FDDO systems are active, in that they may change the operation of the building control system (or a particular piece of equipment) with little or no human intervention. Some fault detection tools exercise a particular piece of equipment or system over a range of operating conditions in order to detect faults that would take a much longer time to detect using purely passive techniques. Other tools change system operation in order to collect data that can be used to build a model. Still other tools are passive until a fault is found, then change the system's operation in order to better diagnose the fault. Active optimization is also possible.

In regard to user interface, the information generated by FDDO systems can be presented to building operators and managers in ways that vary greatly from system to system. The volume of data that is potentially available from a building is huge, so FDDO systems attempt to reduce that data to information that can be quickly reviewed and efficiently acted upon by the system user. This information then enables the user to make better decisions about how to improve resource utilization. The authors believe that most building managers would like FDDO systems to present specific and accurate recommendations about prioritizing operation changes (with benefit estimates!) while allowing the user to drill down to the specific data and reasoning used to generate the recommendations. Based on Cimetrics' experience, for building owners whose staffs are inadequate to handle increased workflow (which is the norm), results must be presented in an actionable format so that staff can incorporate fixes into their pre-existing systems and workflow, without false alarms. Therefore, there is room in the market for a variety of products, such as systems that allow different levels of end-user sophistication, a range of expertise, different staffing levels, etc.

The features and benefits of FDDO systems are summarized in Table 1, on the next page.

Table 1: Features and Benefits of FDDO Systems

Feature	Benefit
Fault Detection	Find equipment problems which result in excess energy consumption
Fault Diagnosis	Identify operator errors and design problems (improper sequencing, etc.)
Optimization	Reduce energy consumption by adjusting setpoints or operating schedules
Passive Systems	Provide information about building system operations so that staff can act on issues
Active Systems	Change building controls with little or no human intervention, sometimes testing systems over a range of operating conditions or creating models
Passive/Active Combination Systems	Passive until a fault is found, then change operation to better diagnose fault, sometimes optimizing
Variable User Interface	Depending on user's sophistication level, interface allows for simpler or more detailed investigation

The FDDO Value Proposition

FDDO systems offer building owners and occupants considerable benefits. Some of these benefits are tangible and offer immediate financial rewards; others are less immediately apparent but offer equally important long-term financial and material paybacks. FDDO can offer energy savings, improve a building's environment (including temperature, humidity, ventilation, etc.), reduce maintenance costs, improve longevity of capital equipment, enhance productivity through improved indoor air quality and comfort, and improve regulatory compliance. The barriers and perceived costs of implementing FDDO in the short term should be put into clear perspective when balanced against these significant long-term benefits, summarized in Table 2, on the next page.

Table 2: Commissioning and Optimization Cost Savings

Commissioning & Optimization Cost Savings

Study/Agency	Finding
TIAX Report for US Department of Energy (DOE)	**5 – 20% (energy alone)***
Federal Energy Management Program (FEMP)	**20% on average (based on Texas A&M study of 130 facilities)****
California Commissioning Market Characterization Study (CCMCS)	**15% (existing facilities)** **9% (new construction)†**
National Institute of Standards and Technology (NIST)	**$.16 per square foot (energy alone)††**

*TIAX report for the DOE , “Energy Impact of Commerical Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential”, November, 2005, page 9-137
** Liu, Minsheng, David Claridge and Dan Turner, “Continuous Commissioning Guidebook”, October, 2002, page v.
† Haasl, Tudi and Rafael Friedmann, “California Commissioning Market Characterization Study”, Proceedings of the 9th National Conference on Building Commissioning, Cherry Hill, NJ, May 9-11, 2001.
†† Chapman, Robert. “The Benefits and Costs of Research: A Case Study of Cybernetic Building Systems”, NISTIR 6303, March 1999, page 80.

Fault detection, diagnostics and optimization systems exist today in various forms, but all FDDO systems differ from building control systems, energy information systems and building commissioning in significant ways. **This is important because many building owners believe that these systems' functionalities overlap enough to be redundant.** In this section, FDDO systems will be compared to those other systems, and the section will conclude with an overview of ten existing FDDO systems, including three developed by research organizations, one developed by a research/commercial hybrid organization, and six developed by commercial companies.

FDDO Systems Compared to Building Control Systems, Energy Information Systems and HVAC Commissioning

FDDO systems generally supplement existing heating, ventilation and air conditioning (HVAC) control systems, energy information systems (EIS), and HVAC commissioning, although there are some areas of overlapping functionality.

Building HVAC control systems (BCS) are widely used in larger commercial, industrial and institutional buildings. These systems control the building's HVAC equipment in order to regulate temperature, ventilation and humidity within the building. HVAC control systems vary greatly in their capabilities. Virtually all such systems attempt to regulate the air temperature within different zones of a building, and many also attempt to regulate ventilation and humidity. Most HVAC systems can be configured to detect various types of equipment failures using simple algorithms. Many sophisticated HVAC control systems may be programmed with algorithms that are designed to reduce energy consumption within buildings. This programming potential is infrequently used, however, and often works poorly when actually utilized. In a National Building Controls Information Program study published in 2002, the findings were that "…problems associated with building controls and operation are a primary cause of inefficient energy usage." [6] Further, they "... identified software programming as the subcategory having the largest impact on energy use." [7] The more sophisticated systems are usually capable of collecting and storing time-series building performance data. These sophisticated systems are deployed in most larger, new buildings today, and the comfort they offer is expected by tenants. There are many companies which offer HVAC control systems and related services, such as maintenance; a few of the largest of these companies are Honeywell, Johnson Controls, and Siemens.

Energy Information Systems (EIS) collect, display and store information about energy consumption using data collected primarily from either pre-existing or specially installed

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5 Barwig, House, et. al., National Building Controls Information Program, proceedings from the 2002 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy: Washington, D.C., vol. 3, pages 1-14 (page 12)

6 Ibid

energy meters. These systems include tools that provide information that can reveal potential opportunities for achieving reductions in energy cost. They may also create various reports for energy cost accounting and budgeting. Some common functions of these systems are:

- Load profiling
- Rate analysis
- Load aggregation

A number of companies offer energy information systems, including Silicon Energy and eLutions. This market sector has been slow to develop, although demand response options have gained market traction recently.

HVAC (or building) commissioning is a quality assurance process for HVAC systems that are already installed in buildings. Building commissioning is generally performed once immediately following the installation of a new BCS in order to determine whether it is performing as designed, and to correct any significant problems. The benefits of building commissioning are well documented, but some research suggests that building performance often degrades following commissioning[8], so some building owners re-commission buildings several years after initial commissioning.

Finally, we turn to the last of our systems, FDDO. A wide variety of FDDO tools and systems have already been developed. These tools and systems are discussed in detail in the next section. Some focus on a particular type of equipment, and others are designed to find problems related to interactions between different pieces of equipment in a system. Here are some typical FDDO features:

- Detection of operating faults by comparison of operating data to the behavior of a model device or system
- Detection of operating faults by applying rules to operating data
- Detection of performance problems by comparing operating data to baseline data for the same device or system
- Diagnosis of operating faults
- Identification of possible operator errors and design errors
- Presentation of alternative operating parameters or sequences of operation that may improve performance
- Display of graphs or charts that summarize operating data
- Estimation of potential energy cost savings that could be realized if particular changes are implemented.

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8 Potter, Amanda et al. 2002. "Investigation of the Persistence of New Building Commissioning," LBNL-51068

Comparing FDDO Systems and Building Control Systems

Building Control Systems (BCS) and Energy Management and Control Systems (EMCS) are primarily designed to maintain a comfortable and safe environment for a building's occupants by controlling the building's mechanical and electrical systems. A BCS is a network of digital controllers which provide the ability, through a workstation, to centralize monitoring and management of building systems such as HVAC, lighting, steam, etc. An EMCS also centralizes monitoring and management of building systems with the addition of utility meter monitoring. These systems are capable of implementing control strategies that are designed to reduce energy consumption. FDDO systems make use of data from building control systems, and typically a large percentage of faults identified by FDDO systems are the result of problems in the BCS, so these systems are quite complementary.

The table on the following page shows a number of points of comparison between the two types of systems, highlighting areas in which FDDO can go beyond BCS.

Table 3: Building Control Systems vs. FDDO Systems

Issue	Building Control Systems	FDDO
Focus	Limited interest in energy efficiency, primary focus is on occupant comfort and environmental control.	Focus on energy efficiency and maintenance and operations.
Feedback	Limited set of tools to provide operator with system performance feedback. Overwhelming (inadequately filtered) number of alarms; seldom used capability to collect trend-logs; lack of graphical system for performance representation.	Well-developed set of reports and graphical feedback features in products such as PACRAT. Carefully prioritized alarm system. Organized, standardized log production.
Usability	Intent of system design (i.e., optimization) not understood and thus not utilized by customers (EMCS operators).	Potentially similar barrier, because FDDO algorithms tend to be even more sophisticated; however, FDDO systems usually come with training, and feedback information is designed to be read with minimal expertise (i.e., the operator should see a graphic comparison between design intent and actual operation).
Use of trends or historic data	EMCS operator always works from screen snap-shots. Trend logs are usually not set, and/or have limited retrospective view capability, leading to a lack of historical perspective on system performance – the only way to address long-term system inefficiency and/or slow degradation issues.	Strong focus on data archiving and retrospective comparative data representation. Measuring deviation from the expected system performance is the main method of FDD/Whole Building Diagnostics (WBD).
Data Processing	No data processing, because of lack of data archiving and historical comparisons.	Focus on data processing based on current and historical data to create actionable recommendations.
Benchmarking	Lack of benchmarking/expected operation features. At a maximum, ranges of acceptable values of control parameters are presented by some EMCS systems. The BCS do not look at whether interactions between different components are functioning correctly and do not monitor whole system integrity.	Baseline development is a priority in FDDO systems; clear presentation of expected performance and acceptable values are immediately available to the operator.
Sensitivity	Focus on major faults.	Focus on slow system degradation faults and long-term energy utilization efficiency/inefficiency.
Use of energy cost data	Operator lacks interest in energy and energy cost data. For example, utility meter information is usually not included in EMCS as a "control" (or "monitored") point. Similarly, most EMCS operators are ignorant of the rate structure and components of energy cost. For example, most EMCS operators do not use Load Factor as an important control parameter.	Energy data is used to help building manager prioritize decisions; energy cost data can be incorporated to make actionable recommendations.
Data sources	Sensors are often inadequate for data collection: low accuracy sensors, non-calibrated sensors, and inadequate number of sensors. For example, in chilled water control systems, flow meters are very often out of calibration, or not installed at all.	Sensors used in addition to utility meters, sub-meters, other meters, weather data, design data
Analytics	Algorithms are simple, based on engineering expertise and simple conventional logic. Older EMCS systems are limited in implementation of even relatively simple logical sequences	FDDO implements a range of both highly sophisticated and simple logical sequences and pattern recognition algorithms. It is necessary to program—and reprogram—systems in order to achieve system optimization.

Comparing FDDO Systems and Energy Information Systems

Energy Information Systems (EIS) are primarily designed to provide information about energy consumption as measured by energy meters. The information is typically used for energy accounting, purchasing and forecasting, but it may also be used to detect certain types of problems in buildings that result in abnormal energy consumption patterns. The following types of systems are related to Energy Information Systems:

- Load Profiling Systems (LPS)
- Load Control/Curtailment Systems (LCS)
- Load Aggregation Systems (LAS)
- Demand Response Systems (DRS)
- Real-Time Pricing Support Systems (RTPS)
- Rate Analysis Systems
- Enterprise Energy Management (EEM) systems

Demand Response Systems bear particular mention because of their inherently complementary relationship with FDDO systems. Because of the large amount of data collected by FDDO systems, they may be used to devise customized automated response strategies which facilitate greater savings. In large facilities, Demand Response software can be made to function more effectively through analysis of the data collected by FDDO systems. For instance, rather than simply turning off lights or turning on a generator, data collected by FDDO systems allow building owners to plan precise strategies which preserve occupant comfort and offer more aggressive demand reduction. Additionally, analysis of building systems' response to past Demand Response events can be performed using FDDO systems, so that automated response strategies can be quickly optimized based on actual system performance. While FDDO is not required for Demand Response, it facilitates greater savings and greater comfort.

The table on the following page compares FDDO systems and Energy Information Systems.

Table 4: Energy Information Systems vs. FDDO Systems

Issue	EIS	FDDO
Focus	Focus on energy management. Limited interest in equipment performance.	Priority focus on energy efficiency and equipment and system performance.
Feedback	15-minute or hourly data collection; daily or monthly data delivery, except LCS, DRS and RTPS.	Data collection intervals: minutes or seconds. Often real-time reports delivery.
Use of trends or historic data	Strong data archiving focus.	Same, but archives used to look for changes over time.
Communications	Strong experience in data communication (EEM systems).	Required focus on data communication and compatibility issues.
Data source	Collection of meter data only in many systems.	Both utility and non-utility data (control parameters, IAQ data, virtual points, etc.) collected.
Analytics	Weak in terms of data analysis algorithms applied. EIS is often used by people interested only in financial aspects of energy, rather than technical aspects of the system.	Highly sophisticated reports and algorithms, intended for use by technical staff.
Use of energy cost data	Financially successful EIS companies based on utility-driven incentive mechanisms (load curtailment, demand response, RTP, demand limiting rebates). M&V systems are an exception, developed as a performance contracting support tool.	Cost data used in some cases to establish potential savings to be gained by correcting problems, enabling cost/benefit analysis.

Comparing FDDO Systems and HVAC Commissioning

HVAC system commissioning has many of the same potential benefits as FDDO. Despite the existence of numerous studies documenting the benefits of commissioning, many buildings are never commissioned. Nonetheless, commissioning is applied to many more buildings than FDDO at this time. A key difference between HVAC commissioning and FDDO is how each is performed. Commissioning is typically a labor-intensive task performed by skilled HVAC technicians following the installation of a new HVAC system. Future tune-ups require further site visits by skilled technicians. FDDO requires specialized software that is designed to detect faults automatically (after the software is properly configured) over an extended period of time. A human must review the output of the FDDO system, and resolution of the faults detected by the FDDO system also requires labor from skilled HVAC technicians. This process allows for continuous monitoring and optimization, preventing the backsliding which is often seen in buildings that have been commissioned.

Table 5 on the following page compares HVAC Commissioning and FDDO Systems.

Table 5: HVAC Commissioning vs. FDDO Systems

Issue	HVAC Commissioning	FDDO
Feedback	One-time data collection. Report generated through human analysis.	Ongoing data collection intervals: minutes or seconds. Real-time reports generated through human and algorithmic analysis.
Use of trends or historic data	One-time analysis, further analysis requires additional site visits.	Data archiving used to look for changes over time, remotely.
Analytics	Simple analysis performed by trained technicians.	Highly sophisticated reports and algorithms, intended for use by technical staff.

FDDO is a potential replacement for or complement to traditional building commissioning. FDDO systems (both active and passive) can be used as a part of a commissioning process, and passive FDDO systems can be used continuously during a building's operation in order to help facility managers improve and maintain building performance.

We believe that the building efficiency improvements that result from FDDO monitoring and from HVAC commissioning often persist for several years or more, although there is little published research on this subject[9,10]. However, FDDO, when applied continuously, should result in better long-term building energy efficiency because it will permit new problems to be identified soon after they occur.

In summary, FDDO is a new approach to improving facility performance that is fundamentally different from building controls, energy information systems, and HVAC commissioning. FDDO technology complements each of these strategies well, however, allowing for additional insight into building operations without scrapping an existing system. FDDO is a distinct, developing technology which promises to offer great benefits to building owners. The table on the following page summarizes the differences between FDDO and other systems.

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[9] Turner, Claridge, Deng *et al*, *Persistence of Savings Obtained from Continuous Commissioning,* National Conference on Building Commissioning, May, 2001

[10] Bourassa, Piette and Motegi, *Evaluation of Persistence of Savings from SMUD Retrocommissioning Program - Final Report*, LBNL No. 54984, May, 2004.

Table 6: FDDO Systems vs. Other Energy-Saving Approaches

	FDDO	Building Controls	Energy Information Systems	HVAC Commissioning
Focus	Energy efficiency/ equipment & system performance	Comfort & environmental control	Energy management	Equipment & system performance
Feedback	Comprehensive reports, graphical feedback, some on-demand, others periodic	Some graphical representation of trends, system status, alarm logs	Graphical representation of utility usage, some reporting	Comprehensive one-time report
Usability	Some systems require substantial training	Advanced features require training	Generally simple interface for cost analysis	One-time use, then performance degradation will occur
Use of Trends or Historic Data	Capture and use of trends is central to observing changes over time	Trend logs used infrequently, limited capacity	Strong data archiving focus	Short-term trending used, no long-term history collected
Data Processing	Used to provide diagnosis and recommendations	No	Application-specific	Infrequently, as needed for diagnosis
Benchmarking	Established in order to assess variances over time	Limited	Limited, application-specific	No
Sensitivity	Higher sensitivity	Low sensitivity-detects major faults	Low sensitivity	High sensitivity one-time snapshot
Use of Energy Cost Data	Often used to prioritize issues/recommendations	No	Frequently used	Infrequent
Data Source	Utility meters, sub-meters, other meters, sensors, weather, design data	Sensors, some meters	Utility meters and sub-meters	Utility meters, sub-meters, other meters, sensors, short-term weather, design data
Analytics	Sophisticated algorithms, systems must be programmed	Simple algorithms	Sophisticated, application-specific	Simple

FDDO Technologies and Research Activities

For more than ten years, numerous research organizations (domestic and international) have been engaged in developing and commercializing fault detection and diagnostic technologies for HVAC systems. These efforts are summarized below, with emphasis placed on recent activities and/or current FDDO tools.[11]

11 Because Cimetrics has created its own FDDO system, these assessments were provided by an outside consultant.

National Laboratories

We will discuss the following research organizations, tools and interests in this section:

Table 7: FDDO Research Organizations, Tools and Interests

Organization	Tool	Research Interests
Pacific Northwest National Laboratory (PNNL)	Whole Building Diagnostician (WBD)	Primary focus on energy research
National Institute of Standards and Technology (NIST)	AHU Performance Assessment Rules (APAR), VAV box Performance Assessment Control Charts (VPACC)	Focus on standards. Does not develop FDDO tools, rather algorithms which controls companies can embed. Non-partisan.
Lawrence Berkeley National Laboratory (LBNL)	Model-based approach, Information Monitoring and Diagnostic System (IMDS)	Energy research, often funded by the California Energy Commission (CEC). Primary interest in diagnostics, not interface.
University of Tennessee, University of Nebraska, Texas A&M, Purdue University	Researching FDDO, not likely to develop commercial tools	Model-based performance testing, diagnostic tools, active participants in American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) research
Massachusetts Institute of Technology (MIT)	Non-Intrusive Load Monitor (NILM)	Scheduling, electric loads
Architectural Energy Corporation (AEC)	Enforma	Funded by the CEC, model-based fault detection and visualization

Pacific Northwest National Laboratory

Pacific Northwest National Laboratory (PNNL) is a US government research laboratory based in Washington State which conducts research for the Federal government focusing on energy (such as electrical distribution transmission services). PNNL is the creator of the Whole Building Diagnostician (WBD), a tool which is available for licensing. The WBD consists of an outdoor-air economizer (OAE) module and a whole building energy (WBE) module. The OAE module is the more mature of the two, having undergone more extensive field testing both in terms of number of sites and length of testing. The "brain" behind the OAE module is a fault tree that interrogates the data, branching to additional questions based on each answer, until eventually arriving at a decision concerning the data (normal or faulty; if faulty, what are the likely causes). The OAE module has a similar appearance and functionality to PACRAT's AHU module. (For a discussion of PACRAT, see section on Facility Dynamics Engineering, below) The WBE module uses a look-up table of past data to predict whole building energy use and alert operators to unexpected changes. Thus, there is a training period in which the tool must learn the energy characteristics of a particular building. The developers of the WBE module indicate that useful information (i.e., reasonable estimates of building energy use) can be obtained after approximately six weeks of tool training, with performance of the tool improving with further training. Although this tool is not a polished product, it is well known due to effective promotion by its creators. Advantages and disadvantages of the WBD are listed below:

Table 8: WBD Advantages and Disadvantages

Advantages	Disadvantages
• Uses commonly available sensors • Well developed graphical interface that effectively conveys information to users • Capable of identifying many common faults in HVAC equipment and controls • Provides estimates of the energy cost associated with identified faults • Has successfully interfaced with products made by several building control systems manufacturers • OAE is a relatively mature tool with the capability to accommodate different economizer strategies without reconfiguration; the WBD is considerably less mature	• It is not clear how faulty data is identified and removed during the training phase for the WBE; without such filtering, energy estimates would be influenced by faulty operation • Uses hourly averages; this makes it difficult to identify unstable control loops • Despite having addressed communication interface challenges, configuration time is significant • AEC's PIER Report P500-03-096-rev2-final.pdf, page 46 has some interesting conclusions: "The time and cost of diagnostic-tool installation is a significant component to implementing diagnostic technologies. Labor costs to set up tools like the WBD (~1 week) will likely exceed the purchase cost of commercialized software."

National Institute of Standards and Technology

The National Institute of Standard and Technology (NIST) is a governmental research laboratory with a standards focus, and a broad technological purview, encompassing much more than energy issues. Their Building and Fire Research Laboratory has developed two FDDO tools:

- APAR (AHU Performance Assessment Rules), and
- VPACC (VAV box Performance Assessment Control Charts)

APAR and VPACC differ from PACRAT and the WBD in that the former tools are simply diagnostic inference engines intended to be embedded in building controllers, while the latter tools consist of the diagnostic inference engine, communication interfaces, graphical user-interfaces, and other supporting utilities and are intended to interface to building controllers.

APAR is based on small sets of rules tailored to various AHU operating modes. Control signals and occupancy indicators are used to identify the mode of operation, and to choose a particular rule set (heating, cooling with outdoor air, mechanical cooling with 100 percent outdoor air, and mechanical cooling with minimum outdoor air). Data are collected at one-minute intervals and hourly averages are utilized to assess whether or not applicable rules are satisfied. By collecting one-minute data and monitoring mode switches, behavior associated with unstable control loops can be identified.

The VAV box Performance Assessment Control Charts (VPACC) is a diagnostic method that uses statistical quality control techniques to detect faults or control problems in VAV (Variable Air Volume) boxes. VPACC is designed to be directly implemented in VAV box controllers. NIST is pursuing Cooperative Research and Development Agreements with several manufacturers of building control systems to embed the tools in commercial controllers and test them in the field. Embedding the tools eliminates the challenges associated with extracting data from building controllers and greatly simplifies tool configuration. On the research front, as of July 2006, NIST has been investigating parameter values for their VAV fault diagnosis algorithm. The advantages and disadvantages of APAR and VPACC are listed below:

Table 9: APAR and VPACC Advantages and Disadvantages

Advantages	Disadvantages
• Uses commonly available sensors • Capable of identifying many common faults in HVAC equipment and controls • The underlying diagnostic inference engines are easy to understand, making technology transfer less challenging • Both tools have been embedded in products of at least one manufacturer (Automated Logic) and tied into the controller alarm function • Configuration time is reduced considerably if tools are embedded in control products	• Testing has been limited in terms of the number of installations and the number of system types considered • Thresholds are set using heuristics • APAR prototype user interface is less refined than that of PACRAT and the WBD; control companies that adopt all or parts of these tools would need to develop their own user interfaces

NIST is not in the FDDO tool business. APAR and VPACC are more appropriately viewed as designs for algorithms that could be implemented in software, rather than tools like PACRAT or WBD. So unlike PACRAT, which is marketed to building owners, NIST engages building controls providers to encourage them to implement these technologies. For instance, Facility Dynamics has studied VPACC for GSA Region 9 and produced a report regarding its implementation in a facility in Oakland, CA.[12] Thus NIST is a non-partisan promoter of FDDO, a "pure" research organization (unlike others).

12 Lister, Larry; Briggs, Steve; Young, Eric, "Letter Report: Review and Implementation of VPACC Code (VAV Diagnostics), August 3, 2005, Facility Dynamics

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory (LBNL), managed by the University of California for the Department of Energy, like PNNL, is a laboratory pursuing diagnostic research. This group does energy research, much of it funded by the California Energy Commission (CEC). Their model-based approach uses first principles models (i.e., models rooted in physics). Initially configured with design data, predictions from the model-based approach can be used to identify operational problems at the time of commissioning. After fixing all identified problems, the models are tuned to that particular building by adjusting model parameters. The tuned models then form the basis for ongoing passive monitoring of building performance. This approach has been applied to AHU and chiller diagnostics. Like the NIST tools, LBNL has been focusing on developing the underlying diagnostic method. Much less attention has been given to interfacing the tool to the building control system and the user interface. The advantages and disadvantages of the LBNL model-based approach are presented below:

Table 10: LBNL Model-Based Approach Advantages and Disadvantages

Advantages	Disadvantages
• Uses commonly available sensors • Capable of identifying many common faults in HVAC equipment and controls • Model-based approach allows degradation faults such as valve leakage and coil fouling to be identified at any time; approaches that do not use models can only detect these problems at specific operating conditions • Models are based on physical laws, therefore their parameters have physical meaning and the models are less susceptible to extrapolation problems associated with operation outside the operating conditions used to tune the models	• Testing has been limited in terms of the number of installations and the number of system types considered • Requires design data to "tune" the models – this data can be difficult to obtain or locate • Method is more sophisticated than most and, as such, development is somewhat slower and technology transfer will be more difficult

LBNL has also been pursuing advanced data monitoring and visualization capabilities to improve the quality of the information available to the building operator. LBNL's Information Monitoring and Diagnostic System (IMDS) consists of a dedicated data acquisition system, web-based remote access, high quality sensors, and a high frequency data archive to which diagnostic tools could be interfaced. Electric Eye, the data visualization software integrated into the IMDS, has the capability to create a time series plot of up to eight points at one-minute intervals for a full year. It also has other advanced data visualization capabilities that far exceed those of today's building control systems. Since the IMDS does not have automated diagnostic capabilities, it will not be discussed further.

University Research Labs

The University of Tennessee (model-based functional performance tests for AHU's, similar to approach used by LBNL), the University of Nebraska and Texas A&M (whole-building diagnostic tools and air-handling diagnostic tools under development with support from DOE and NYSERDA), and Purdue University (FDD for roof-top units) are organizations that have active, continuing research projects in the FDDO arena and are active participants in ASHRAE research activities and conferences. These respected research efforts are not likely to develop commercial tools at this time.

MIT has taken an unusual approach to FDDO. They have developed the Non-Intrusive Load Monitor (NILM) which provides centralized monitoring of electric loads (at service entry or motor control center) at high frequencies, enabling detection of equipment's turning on and off. This can be correlated with scheduled events to detect scheduling problems. Their approach is certainly novel, but considerably more engineering effort is needed to get from a prototype that the developer can use with some success, to a robust diagnostic tool that is transparent to the end user.

Other Initiatives

Architectural Energy Corporation (AEC)

AEC is a hybrid organization which operates commercially but has been funded by the CEC to develop a web-based diagnostic tool. This tool, ENFORMA, is diagnostic software which allows users to visualize information collected from data loggers (the AEC Micro Data Logger) and compare them to data collected under normal operation and in the presence of various faults. Currently, the tool only performs short-term analysis; a future step may be to analyze data collected over a longer term. AEC hopes to commercialize their technology, although it has not yet achieved any significant market acceptance.

Table 11: ENFORMA Advantages and Disadvantages[13]

Advantages	Disadvantages
• Stores raw data, plus performance metrics and diagnostic results in central database • Strong data filtering capabilities • Works with real-time data • Strong rule-assisted visualization tool	• Time-consuming configuration: requires specially formatted headers to specify data collection frequency and time range • Assumes sequential data; does not import timestamps • Requires data analysis by outside expert-primarily a visualization tool • Not currently designed to connect directly to BAS • Short-term data collection

Commercial Players

In examining commercial FDDO development, we will discuss the following 6 companies and their 8 tools:

Table 12: FDDO Commercial Players and Tools

Commercial Entity	Tool
Cimetrics Inc.	Infometrics
Facility Dynamics Engineering (FDE)	Performance and Continuous Re-Commissioning Analysis Tool (PACRAT)
Johnson Controls Inc. (JCI)	Facility Performance Indexing (FPI)
Field Diagnostic Services	Service Assistant (marketed by Honeywell), ACRx ServiceTool
Honeywell	Atrium, Enterprise Buildings Integrator (EBI)
Interval Data Systems, Inc. (IDS)	Energy Witness (EW)

13 "Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems„, by H. Friedman and M. A. Piette. LBNL Report 48629, Lawrence Berkeley National Laboratory, Berkeley, CA. May 2001

Cimetrics Inc.

Cimetrics is a Boston-based company that provides FDDO services to building owners in an ongoing commissioning process called Infometrics. Cimetrics is the leading supplier of BACnet technology, tools and communication consulting to building automation controls companies and is active in developing and promoting the BACnet standard for building automation and control networks.

A leader in open systems networking for building automation, Cimetrics has leveraged their knowledge of building controls systems and BACnet to develop their FDDO consulting service. Infometrics provides independent data analysis and portfolio-wide consolidated reporting. They collect information portfolio–wide and transmit it to a centralized database where Cimetrics' engineers use a set of proprietary algorithms to analyze and mine the data for value. Reports with prioritized recommendations and savings are issued periodically, and on-staff analysts are dedicated to each customer, making Infometrics a high-touch consultancy. Cimetrics also has the advantage of being able to connect to disparate control systems to extract information from almost any facility with a modern BAS. Cimetrics has a strategic alliance with Siemens to offer FDDO services to Siemens customers under the "Anthem" brand name.

Table 13: Infometrics Advantages and Disadvantages

Advantages	Disadvantages
• Capable of collecting data from a wide range of modern building automation systems • Has demonstrated ability to collect and transmit large number of trend logs in 15 minute intervals (and at higher frequency as necessary) without overloading communications network	• Only sold as a service • Monthly reporting rather than immediate, on-demand information access

Facility Dynamics Engineering

Facility Dynamics Engineering (FDE) is a small engineering company based in Maryland which specializes in HVAC systems. FDE is the creator of PACRAT, an acronym for the Performance and Continuous Re-Commissioning Analysis Tool. It has been marketed for several years and installed in numerous facilities. Originally it was developed to perform fault detection and diagnostics for air handling units (AHUs), but has since been expanded to include diagnostics for chillers, hydronic systems, whole building energy and zone distribution. PACRAT runs on a server (either on-site or at a remote location) and processes trend data that have been collected by the building control system. It is offered as a rebranded tool by other providers. Advantages and disadvantages of PACRAT are listed below.[14]

Table 14: PACRAT Advantages and Disadvantages

Advantages	Disadvantages
• Uses commonly available sensors • Well developed graphical interface that effectively conveys information to users • Capable of identifying many common faults in HVAC equipment and controls • Provides estimates of the energy cost associated with identified faults • Communication interfaces allow access to trend data from products of many manufacturers of building control systems • Relatively mature tool	• Relies on trend data collected by other systems • Despite communication interfaces, configuration time is significant • Uses only batch files, no real-time data capabilities

Friedman and Piette suggest that "while PACRAT is the most advanced [FDDO tool] in its scope and automated diagnostic capabilities, it is also a complex tool that requires significant involvement from the developers to apply it….PACRAT has extensive help files that describe configuration, but since the process is quite involved, a Facility Dynamics engineer typically performs the configuration."[15]

Johnson Controls

Johnson Controls' primary FDDO offering is called Facility Performance Indexing (FPI).[16] FPI is a product that generally works in conjunction with a Metasys control system to diagnose equipment problems and system efficiency. The primary purpose of the tool is to benchmark the performance of a building. Significant configuration is necessary to use the tool. Probabilities are assigned to the certainty of issues that are diagnosed by FPI.

Johnson Controls has also worked on equipment and product-centric FDDO technologies such as VAV box "performance indices" embedded in VMA controllers. They have also developed diagnostic capabilities for AHUs based on finite state machine sequencing logic.

14 "Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems," by H. Friedman and M. A. Piette. LBNL Report 48629, Lawrence Berkeley National Laboratory, Berkeley, CA. May 2001

15 Ibid.

16 Note: Neither Cimetrics nor the outside consultant has been able to ascertain the current status of the FPI offering as of March, 2006.

Table 15: FPI Advantages and Disadvantages

Advantages	Disadvantages
• In conjunction with JCI performance contract, uses maintenance management software to structure maintenance plans and optimize building systems • Performance guarantee ensures that work is performed per system information obtained	• Not in widespread use- no independent testing has been performed • Link with performance guarantee makes a "closed loop"; maintenance contractor performs diagnostics, no 3rd party validation

Field Diagnostic Services

Field Diagnostic Services is a small company that has produced some FDDO products, particularly a hand-held diagnostic tool for packaged equipment intended for use by field service technicians. Honeywell markets the tool as the HVAC Service Assistant.

Table 16: Service Assistant™ Advantages and Disadvantages

Advantages	Disadvantages
• Can implement some pre-programmed "expert logic", perform checks, alarm and sense faults • Combines handheld PDA and pressure/temperature gauges in a single tool to automate field data collection • Calculates "Efficiency Index" which includes projected savings and maintenance prioritization • Associated web-based reports available	• Not a proactive system degradation diagnostic tool • Controller-based • Must be used by technician on-site

In addition to the Service Assistant™, Field Diagnostics offers other products, such as the ACRx® Servicetool. The Servicetool is an instrument designed to be temporarily installed on a commercial rooftop air-conditioning unit, especially one with operational problems that are intermittent and have not been diagnosable using ordinary means.

It incorporates the same fault detection and diagnosis technologies embedded in the Service Assistant™. However, the Servicetool also provides extended data logging, and wireless communications to the office. When a notable event occurs, the service contractor or facility manager is paged, and the associated data is transmitted to the office for review.

Honeywell

Honeywell was the first controls company to offer an enterprise FDDO product. The product, called Atrium, was a platform for applications including enterprise management and FDDO.   Pilot projects were conducted at Target stores and the product has found some application in the pharmaceutical manufacturing market, but the offering has generally been unsuccessful in the marketplace due to its inability to connect to disparate systems, the difficulty of its configuration and its lack of applications.

Table 17: Atrium Advantages and Disadvantages

Advantages	Disadvantages
• As a suite of services, facilitates vendor tracking and evaluation • Honeywell Global Service Response Center handles alarm response and dispatch functions • User can remotely implement load shedding and demand limiting strategies through the Atrium web site	• Difficult configuration • Inability to connect to disparate systems

Honeywell now also offers the Honeywell Enterprise Buildings Integrator (EBI), a software package which integrates BAS information, security systems information, life safety systems information, and personnel and financial records to enable enterprise-wide management.

Interval Data Systems, Inc.

IDS, founded in 2003, offers solutions covering Diagnostics, Monitoring, Continuous Commissioning, M&V, and Financial Assistance areas, and services including Data Collection / Configuration, Diagnostics, and Monitoring. Interval Data Systems' currently unfinished FDDO offering will be called Energy Witness (EW).[17] The Energy Witness suite will consist of the following packages: EW Data Collector, EW Data Warehousing, EW Viewer, EW Issue Tracker, and EW Utility Billing. EW will connect through an OPC (OLE for Process Control) server and will be able to bridge to BACnet, Modbus or LonWorks systems. The system will be built on an MS Windows platform and will be able to integrate with FAMIS space planning software and the HEGIS (Higher Education General Information Survey) classification system for Universities. Energy Witness will offer on-site staff the ability to overlay trend data from the start of collection to spot ongoing issues. The tool collects a vast amount of data and offers tracking and analysis options, but analysis is not automated and requires user specification. The tool is most useful for visualizing and archiving trend data. The tool may eventually offer more automated services in its finished state.

17 Note: The outside consultant who prepared these comments was tangentially involved in the development of IDS Energy Witness

Table 18: EW Advantages and Disadvantages

Advantages	Disadvantages
• Integrates with FAMIS software and HEGIS systems • Immediately available information • Data representation and reporting interface clear and well automated • Collects a large amount of data • Organizes and archives data in a convenient visual format	• Requires on-site staff to perform skilled diagnosis and analysis • Significant configuration process • No capability for automatic fault recognition • Not yet finished (as of 3/06) • Requires a great deal of operator intervention to organize data

Summary

LBNL and NIST have been perhaps the most proactive organizations from the standpoint of providing vision for dealing with issues that affect ease of FDDO configuration. Both organizations have been involved in the efforts of ASHRAE GPC 20 in developing standard data models for HVAC equipment and devices. Data models can be used to characterize the important physical characteristics of the components (e.g., a data model of a cooling coil might include information such as the number of rows of tubes, fin spacing, etc.; a data model of a temperature sensor might include information such as the accuracy of the sensor, whether it is a point or averaging sensor, etc.) and could be populated with information for a specific system at the time of its design. FDDO tools could then access the data models to automatically extract information needed to configure models, etc. The universities have active and productive research programs which will continue to contribute to the development of FDDO technology.

The commercial sector is still in its infancy, but growing rapidly. Many of the available tools are already viable and being used, while others are still in development stages. Current problems involve limited functionality more than missing tools or features. Whole building organizational systems are weak, whereas specific areas are better covered by existing tools (see page 28, Barriers Related to FDDO Technical Requirements, for further discussion). Some tools offered by controls companies have led to concerns about independent verification. For broad market acceptance, system costs will need to be reduced and potential users will need to be better educated about the benefits of FDDO tools. Currently, the market is populated with early adopters. With additional time and attention, tools will be further developed to capitalize on the opportunities afforded by FDDO technology.

Please see the Appendix (page 51) for a table of the advantages and disadvantages of all FDDO tools discussed in this section.

There are significant barriers to the widespread implementation of FDDO technology. Understanding these barriers is essential to formulating an action plan to promote FDDO in the future. Our discussion below lists the problems as well as some possible steps that stakeholders can take in order to reduce resistance to a wider adoption of this technology.

Market Barriers

Market barriers include the lack of education of potential users regarding this technology, the prevalence of short-term ROI building strategies, and the need to recruit advocates in the consulting engineering and controls systems fields.

The first part of the equation in increasing FDDO acceptance is the human element. Education and adoption incentives must be provided to potential customers. There are three constituencies important to making FDDO a success: building owners/managers, consulting engineers, and controls companies.

Cimetrics' experience suggests that most building owners are not aware of the potential benefits of FDDO; this is a problem of education. More complicated is the fact that the realizable benefits of FDDO are often difficult to quantify at the beginning of a project, and many of the benefits of FDDO are soft (such as improved productivity, streamlined maintenance strategies, prevention of downtime, etc.). Thus owners who insist on predictable, "hard" ROI savings before making an investment will probably be reluctant to invest in FDDO in the short term. As the benefits of FDDO become increasingly well known and demonstrated in the field, however, we predict that this barrier will simultaneously break down.

The second market barrier to FDDO acceptance is related to quick-turnaround financial strategies. Short-term building owners are less promising candidates for FDDO—or any other long-term improvement—unless they can recoup their investments quickly by driving up sales prices. Although it stands to reason that lower operating costs might increase asset value, these numbers are frequently so malleable as to be deemed unreliable and thus discounted. But short-term building owners do want to reduce costs while they own assets, so FDDO systems offering quick payback results would be attractive to them. We are not currently aware of the existence of any such systems, and because energy costs are passed on to tenants, energy cost savings would not be the focus of short-term owners. In fact, many building owners, whether short- or long-term, are more concerned about reducing their initial cost of construction than about managing the long-term cost of owning a building, according to Ed Rockstroh of Technical Building Services, Inc.(see interview in Appendix, page 58). This group may respond favorably to financial incentives for adopting FDDO technologies, similar to current programs offering energy efficiency rebates.

Long-term building owners, especially those who occupy their own buildings, are generally better candidates for FDDO. These owners tend to make long-term investments in their properties and thus can realize the full spectrum of FDDO benefits. Education of the market's end-use customers, such as long-term building owners, is critical to the success of FDDO technology.

The fourth and final market barrier is another constituency which must be recruited to promote FDDO: the controls companies. Very few of these companies offer sophisticated FDDO tools or services, although this situation is beginning to change (with the addition of Siemens' "Anthem" offering, a repackaging of Cimetrics' Infometrics service, for example). Furthermore, these companies have traditionally designed controls as closed systems, making it difficult to use add-on third-party FDDO software (see section on Barriers Related to FDDO Technical Requirements, below). This situation is ripe for change, with major industry players leading the charge. In Cimetrics' opinion, bundling FDDO tools with building controls might create a competitive advantage for a controls company.

Barriers Related to FDDO Technical Requirements

Currently, the technical requirements for implementing FDDO can be daunting. Solutions exist, and are enumerated in the next section. But it is important to understand what these hurdles are. They include:

- Data Acquisition
- Data Sufficiency
- FDDO System Configuration

Data Acquisition

The first issue is one of data acquisition for analysis. Correct hardware must be installed for the FDDO system to work: for example, sensors of the proper accuracy must be available to collect the necessary data from the BAS system. Adequate data must then be collected at correct frequencies, in concert—not in competition—with the BAS system. This data must be accessible and analyzable and ultimately must be able to reveal to users the benefit of its collection. In addition, there is additional equipment and energy data that must be made available to FDDO users, such as system design data, energy price data, etc., in order to enable calculations for implementation as well as analysis.

Getting data into the FDDO system is a well-known problem. Different groups have attacked this problem in varied ways. The Cimetrics Infometrics system relies on a connection to the building control system's network. Other groups have attempted to access the data stored in a database populated by the building control system. Some manufacturers provide an interface to their building control system, but this approach has not yet proven to be a reliable general solution.

The advantage of the FDDO connecting to the building control system's network is that the FDDO has reasonable control over the collection of data. Although network protocol standards such as BACnet have been developed, most building control systems installed in existing buildings do not use a standard network protocol, and pneumatic building control systems may not have any network communication interface at all. For computerized building control systems that are less than 10 years old, it is usually possible to purchase a communications gateway that will allow the FDDO system to communicate with the building control system using a standard protocol, but gateways may be expensive to purchase, configure, and maintain. The cost of obtaining live data from building control systems will be significantly reduced if BACnet or another standard protocol is commonly used in the future.

Increasingly, Cimetrics finds that customers are asking for I.T.-friendly interfaces to building control systems in order to permit integration with other systems. FDDO systems could benefit from such interfaces, especially if standards emerge.

Data Sufficiency

Fault detection often requires data that is not needed for control. Because of the tendency of building owners to try to minimize the cost of construction, it is common for instrumentation and data points that are not required for control to be omitted from the design of a building control system. For example, most boilers are not adequately equipped with sensors to allow for effective optimization. Additionally, facilities with central steam plants will not achieve maximum benefits unless the source of the steam (the plant) is monitored along with the buildings. Calibration of instrumentation is also an issue. All diagnostic algorithms need certain data, and if the data available are not sufficient for a particular algorithm, then that algorithm cannot be run. We refer to this as the data sufficiency problem.

For many customers, this problem is so significant that it represents a deal-breaker because implementing FDDO would require a major controls system upgrade. For universities and other owner-occupants, this isn't as much of a problem. For retailers or lessees of office space, it is a major barrier because cost-cutting (or "value engineering") in construction is geared to optimizing short-term construction costs, not operating or long-term costs. Although it is far less expensive to install additional sensors during construction, this is not necessarily part of the mindset of short-term owners or lessees.

If the results of running an algorithm have a high expected value to the building owner, then it may be worthwhile to add the necessary instrumentation and data points to an existing building control system or calibrate existing instrumentation. Generally speaking, economy of scale makes it cheaper to add sensors during new construction or during a major HVAC system retrofit than to add them to an existing system. There are currently no industry standards pertaining to sensor sufficiency for FDDO, so every building that is a candidate for FDDO must be surveyed in order to identify potential data sufficiency issues. Fortunately, LBNL is in the process of developing a "Specification Guide for

Performance Monitoring Systems" (currently in draft 7, as of June, 2006)[18], funded by the DOE and the CEC, to be considered for inclusion in California Title 24 in the future. It is our hope that these specifications, identifying appropriate sensor minimums to allow for FDDO applications, might become standard industry practice in the future.

A developing technology which may render sensor sufficiency financially feasible is that of the wireless sensor. Currently, the industry is young and the sensors are still costly. But the labor cost advantage of not running wires is clear, and as the industry matures, we would expect per-sensor costs to come down. According to the Pacific Northwest National Laboratory, "The availability of low-cost wireless sensor systems could not only reduce costs overall, but also lead to increased use of sensors."[19] And according to the ASHRAE Journal, March, 2006, "Wireless technology for building controls seems to be past the early adopter stage and is in the transition stage to mainstream acceptance…Contributing to this trend is that first costs of wireless are approaching the costs of traditional controls." [20]

There are some reliability concerns related to the widespread adoption of wireless sensor technology. Mesh networking makes these sensors most reliable in high-density installations. It is possible that wired and wireless technologies might coexist in some applications, but we expect that as this technology develops and is integrated into existing buildings, some issues may arise. For example, there is no advantage to adding wireless sensors to a building already equipped with wired sensors if a controller exists but a sensor is missing. If, however, a large area of a building is un-sensored, there may be a cost advantage to adding wireless sensors rather than running wires. The hope is that the addition of wireless sensors to the marketplace will encourage greater use of sensors and less value-engineering of BAS systems, aiding in resolving the data sufficiency problem.

Below are two recent case studies of Cimetrics Infometrics clients that illustrate how data sufficiency impacts the benefits reaped from FDDO deployment. In Case Study 1, data sufficiency allows effective analysis and substantial cost savings, while in Case Study 2, insufficient data prevents proactive analysis and maintenance.

Case Study #1:

A large New England casino has nearly 600 Variable Air Volume (VAV) boxes in its facility with an average of seven points per VAV. The FDDO monitoring of those points over an eight-month period revealed that 40% of the VAVs had operational issues. Once those issues were identified and corrections implemented, the end user saved $100 to $500 annually per VAV, for estimated savings of approximately $120,000/year. Additionally,

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18 Gillespie, Kenneth L, Jr.; Haves, Philip, et al., „ Specification Guide for Performance Monitoring Systems", March 1, 2006, c2005-2006, The Regents of the University of California through Ernest Orlando Lawrence Berkeley National Laboratory

19 http://www.buildingsystemsprogram.pnl.gov/wireless/

20 ASHRAE Journal, "Wireless Products Turning Mainstream", March, 2006, page 11

the analysis was streamlined to focus on issues deemed important by the service contractor and the maintenance staff.

This kind of attention to large quantities of equipment (such as the 600 VAVs) simply cannot be achieved by staff on a daily basis. It is also important to note that the RIGHT points needed to be added to equipment to discover value. In this case, the points providing valuable information enabling cost savings were the following:

- Zone Temperature
- Zone Set Point
- Discharge Air Temperature (see discussion below)
- Damper (Signal and Position)
- Electric Heat Point
- Hot Water Value (Signal and Position)
- Flow Point

Discharge air temperature (DAT), by which we mean the air temperature upon discharge from the air handling unit (AHU), is a point which bears particular discussion. Often the DAT point after each coil is value-engineered out of a project. The result is the inability to identify excessive energy usage. In calculations, a "proxy" is often used which then affects the accuracy of the final analysis. In this case, DAT was essential in identifying over $750,000.00 worth of savings which would otherwise have been unrealized.

Case Study #2:

An end user with over 1700 VAVs who has an average of only 3 points per VAV also sees a high failure rate, but in this case, only after operational problems have already become a serious issue. There is no ability to foresee equipment failure, and thus conduct preventive maintenance in a focused or productive manner. This situation leads to a scenario in which equipment failure rates are high, comfort complaints are even higher, and the staff is in an emergency situation all the time.

Despite the obvious advantages of installing FDDO technology as illustrated in Case Study 1, the technical difficulties of acquiring and analyzing the necessary data inhibit many stakeholders from investing in the system. Financial costs—real and perceived—also play a significant role, even though in practice, FDDO systems may pay for themselves in just a few months.

These cases illustrate the benefits of operating FDDO systems with full data sufficiency. Although it may have been less expensive for the user in Case Study #2 to install fewer data points in the construction phase, the costs of operating with insufficient information quickly become clear in contrast with a building owner with proper BAS points. Not only is the owner in Case Study 2 unable to realize energy savings, but maintenance staff is burdened with "putting out fires", reacting to equipment failure rather than preventing it. In order for FDDO systems to gain market acceptance, potential customers will need to understand the life cycle cost benefits of complete BAS systems.

FDDO System Configuration

One of the most labor-intensive (and thus costly) processes of the FDDO system is configuring it for each building. Data points in the building control system must be identified and associated with variables used in the FDDO system (see the proposed BAS Point Naming Convention, Appendix page 66). Many FDDO algorithms also require information about the HVAC system design and HVAC equipment performance specifications in order to provide meaningful results. Although this information can usually be obtained through a careful survey of a building and examination of system documentation, this typically requires many hours of analysis performed by a skilled technician, adding cost to a project. Additionally, building control systems change over time, requiring corresponding changes to the configuration of the FDDO system. The cost of configuring or reconfiguring an FDDO system could be reduced if the data required for configuration could be exported from the building management system in a standard, machine-readable format. Finally, communication between the BAS and the FDDO is often complicated by the use of different communication protocols and the difficulty of ensuring smooth communication between disparate systems. Gateways are commonly installed (at an additional cost) to mediate between systems which do not communicate easily with one another. If communications protocols were standardized, this would not be necessary.

In short, the configuration data requirements of FDDO are as follows:

Configuration Requirements for Data Sufficiency:

- Sensors must be present and of sufficient accuracy/calibration
- Calculation of potential energy savings requires additional data (e.g. equipment name plate data and energy price information, occupancy schedules)

Configuration Requirements for Data Collection:

- Data must be collected at a reasonable frequency (analysis dependent)
- Data must be sufficiently co-temporal (depends on collection frequency)
- FDDO system must have access to the data (through BAS network, shared database, gateway or other interface)
- Data collection must not significantly affect performance of the BAS or the customer's IT network

Configuration Requirements for Data Analysis:

- Calculation of potential energy savings of fixing a problem requires energy and equipment data
- After a measure has been implemented, evaluation of actual benefit may be difficult unless the benefit can be directly calculated.

The collection of adequate data is required in order for FDDO systems to deliver their potential value. There is also a direct correlation between the number of control points assigned to a piece of equipment and the value deliverable to the system user. Additionally, the data must arrive in the correct hands, in an actionable format, to be useful.

FDDO Financial Issues

The initial costs of deploying FDDO technology often seem to be risky and excessive to potential stakeholders. First, the costs of programming the FDDO system for the building in which it is to be deployed are considerable (typically $5,000 to $10,000 in the case of Cimetrics), and include an inventory of the building's equipment and the points to be evaluated, collection of the relevant data, and configuration of the system. Next, the costs of the FDDO service itself, the training of the personnel who will be using the technology, and the interface between the two can be substantial. Additionally, most potential customers do not have existing budget allocations for commissioning or re-commissioning, much less for ongoing commissioning. While energy budgets are generally well-funded and malleable to allow for the inherent dynamism of energy prices, in Cimetrics' experience, energy savings and building performance measures budgets are more tightly controlled. Finally, the cost/benefit ratio of such a new technology in a tradition-bound field seems uncertain to many, especially when some benefits are considered "soft," such as occupant comfort (while others, such as improved energy efficiency—and thus decreased energy costs—are much more immediately quantifiable and appealing). There is a need to quantify and validate these "soft" benefits through research (discussed further in the Recommendations section, page 45, and in the Appendix, in Stakeholder Interviews with Mary Beth Tighe of FERC, Dave MacLellan of NStar, Jim Armstrong of NStar, Karen Curran of GSA Region 1, and Ed Rockstroh of Technical Building Services, Inc., page 52).

Case Study #3:

A large REIT (Real Estate Investment Trust) offered Cimetrics the opportunity to deploy their Infometrics program in three large office buildings. Building 1 had a low technical risk and a high value proposition. Building 2 required substantial control system upgrades, making the deployment too expensive and the payback timeline too long. And Building 3 also required a system upgrade to resolve a technical interface problem. Cimetrics thus chose to monitor only Building 1, the only one which promised a sufficient ROI and a quick enough payback.

Many technical barriers can be viewed as economic barriers when a high-cost solution exists. Communications gateways are an example of this—they permit a network connection to be established with a proprietary system, but the cost of installing an FDDO system is considerably less if a gateway is not necessary. Additionally, sensors may be added or controls systems upgraded, but these options are quite costly. The cost-per-sensor is considerably lower when installation occurs at the time of original construction.

In sum, the apparent financial inhibitors are as follows:

- Uncertainty of benefits and costs before the implementation of FDDO
- System configuration cost (teaching the FDDO system about the building) and software setup
- Enumerating equipment (loading and identification of name and function of points)
- Enumerating and classifying dynamic points
- Collection of necessary design data (equipment and component specs, system topology, design intent)
- Designing the dynamic data collection strategy
- Analysis configuration (conversion of inputs to normal form, configuration of summary graphs)
- Data collection interface cost (gateway, point mapping, configuration)
- Cost of FDDO software or service
- Training on how to use the FDDO software
- Staff time required to discuss faults identified and measures taken
- Difficulty of calculating the value of all potential benefits (especially soft benefits such as occupant comfort)
- Budgetary allocation restrictions

Technical Needs for Advancing FDDO Tools

In order to break down the previously mentioned barriers and thus to increase public acceptance of FDDO systems, the following measures need to be put into place: the establishment of an industry-wide infrastructure, point-naming conventions, standardization of controls sequences and FDDO tool testing.

Industry-Wide Infrastructure

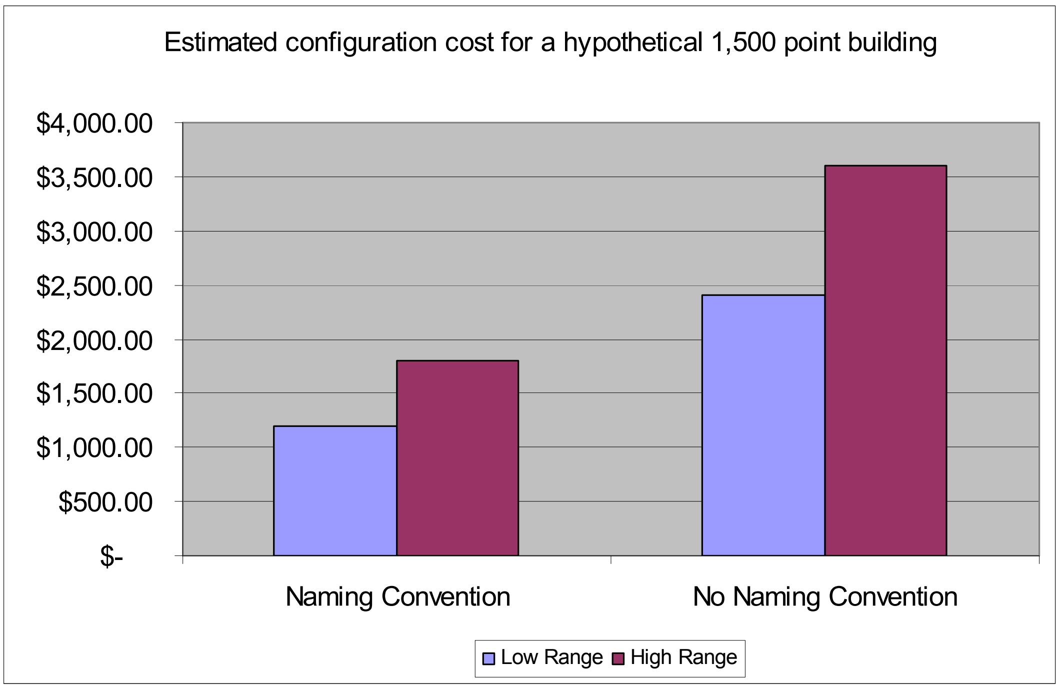
The lack of standardization across the industry has led to difficulties in accessing data and subsequently to increased costs in mining critical data. Standardizing the industry's infrastructure will lessen FDDO system implementation time and effort, reducing financial liabilities and making FDDO technologies a much more attractive proposition for building owners and managers. Four areas are particularly appropriate for industry-wide standardization: point-naming conventions, system control sequences, data models for HVAC equipment and control devices, and formatting for trend data.

Point-Naming Conventions

Standard point-naming conventions must be developed and their use encouraged in order to reduce configuration time and effort. Cimetrics' own experience has already confirmed that utilizing standard naming practices for identifying the points and data in a Building Control System substantially facilitates FDDO system configuration. (See chart #1, below.) The benefits of instituting a point-naming convention also include: uniformity across projects; lower training cost; lower configuration cost (less naming effort, less name rework, efficient naming tools); and easier configuration of analysis applications.

It is important that a few principles be kept in mind while establishing point-naming standards, however. When naming points, programmers should be flexible rather than rigid or deterministic. This is critical because different people will arrive at different names for a given point depending upon whether a location- or an equipment-based view dominates the naming process. Therefore, a list of point names will require automation-assisted analysis and possible modification before it may be considered complete. A point name is complete when it is assembled using predefined reserved words and alphabetic, numeric or alphanumeric indexes. Details are available in the Appendix (Page 66).

Chart 1: Configuration Cost Reductions Afforded by the Use of Naming Conventions



Other Areas for Standardization

Similarly, "standard" control sequences for common systems such as VAV systems would greatly reduce the degree of custom programming required to configure FDDO tools. Although some customization would still be necessary, it would significantly cut back this process. This kind of standardization would also simplify operator troubleshooting. In addition to configuration considerations, data access would also be enhanced by standardization. Standardizing data models for HVAC equipment and control devices would enable design and operating data to be accessed automatically by FDDO tools. Standard formats for trend data would also allow third-party FDDO tools (that do not access the data directly from the network) to retrieve trend data more easily.

Finally, the industry would need to promote industry-wide accepted tools for testing the capabilities of FDDO tools (similar in concept to the test scripts used to test BACnet conformance). Currently, ASHRAE TC 7.5 (Smart Building Systems) is sponsoring a research project developing a simulation testbed that will produce faulty and fault-free data for AHUs that can be used by FDDO tool developers to test and refine their tools. This kind of industry-oriented initiative should be encouraged and enhanced.

The natural gas world was once a controlled, heavily regulated environment that was structured and constrained by long-term deals. Now that same industry is market-driven, with unbundled services and value pricing leading consumers' concerns. The electricity market is now facing the same challenges that the gas market did during the 1980's and '90's. In the short term, we will continue to see battles over regulatory restructuring in the power industry. However, the long-term model will be, and must be, a market-driven model.

During this transitional period from a highly regulated market to a free market, enhanced operational efficiency is one way to bridge the gap between supply and demand. Fault detection technology that exists today can accomplish just that. Standards in naming control points, adequate points on control systems, and data collection requirements should be included in the new industry paradigm.

Regulatory Issues

All levels of US Federal, State and Local Government recognize the need to solve the dwindling supply and increasing demand problem. The U.S. Government further acknowledges that, at one time, government regulation was the backbone of the energy industry, providing it with stability. According to the Energy Information Administration (EIA), "Just as electricity's applications and sources change over time, so is the structure of the electric power sector itself evolving. The sector is now moving away from the traditional, highly regulated organizations known for decades as electric utilities and toward an environment marked by lighter regulation and greater competition from and among nonutility power producers. In 2000, nonutility power producers (such as independent power producers and nonutility cogenerators) accounted for 26 percent of total net summer capability, up from 20 percent in 1999." [21] Regulation cannot keep pace with marketplace developments. The government now looks for help from the private sector. The 2003 U.S. Department of Energy (DOE) Strategic Plan says that, "…the role of the Federal Government is to help the private sector develop technologies capable of providing a diverse supply of energy, and to allow the market to decide how much of each energy source is actually used." [22] But participants from the private sector often have conflicting interests that can only be resolved through legislation and regulation at the Federal and State levels.[23]

The most recent expression of public energy policy and legislative/regulatory concerns is the recent energy bill and related documents. The 2005 energy bill, effective January 1, 2006, "provides tax breaks and other incentives to encourage new nuclear plants, cleaner-

21 EIA, "Energy in the United States: 1635-2000, Electricity", EIA website: http://www.eia.doe.gov/emeu/aer/eh/frame.html

22 Department of Energy, Strategic Plan, September 30, 2003, pg.17

23 Sally Hunt, "Making Competition Work in Electricity", pg.78

burning coal facilities, and production of more oil and natural gas. It also offers incentives to produce energy from wind and other renewable sources and to make homes and office buildings more efficient." [24] Specifically, the bill includes tax breaks for builders of new commercial buildings who reduce annual energy consumption by 50% (as compared with the ASHRAE 2001 standard 90.10), providing partial breaks for those who improve efficiency in lighting, the building envelope, and HVAC. But, according to Jim Armstrong of NStar, certifying compliance with this standard is almost impossible, and the tax break is so negligible as to provide little incentive (see complete interview in Appendix, page 52).

At the state level, in California, for instance, Title 24 building codes do not require significant ongoing monitoring of building systems, aside from requiring basic building commissioning "…at least on a component basis… for electrical and mechanical equipment that is prone to improper installation." [25] For example, according to the California 2005 Integrated Energy Policy Report, adopted, November 21, 2005, "While the Title 24 Building Efficiency Standards ensure that new buildings and additions and alterations to existing buildings include energy efficiency in their design, there has been remarkably little regulatory attention to improving the energy efficiency of existing buildings. Although utility energy efficiency programs have generally promoted savings in existing buildings, there is still enormous potential for energy efficiency savings in existing buildings, which turn over very slowly and dominate energy consumption."

The Green Building Initiative, signed in December of 2004, on the other hand, requires State buildings to adhere to a benchmarking program, yet to be finalized (implementation of a customized program is planned in Spring, 2006, with the EnergyStar benchmarking program used until then). This initiative requires the CEC to:

- "Develop and propose by July 2005, a simple building efficiency benchmarking system for all commercial buildings in the state.
- Develop commissioning and retro-commissioning guidelines for commercial buildings.
- Further develop and refine (Title 24) building standards applicable to commercial building sector to result in 20 percent savings by 2015 using standards adopted in 2003 as the baseline" [26]

Incentive Regulation

Incentive regulation has a positive track record in the United States; examples include the deregulation of the natural gas industry and to some degree, that of the electricity industry. According to Mary Beth Tighe of the Federal Energy Regulatory Commission (FERC), incentives have proven to be more effective than penalties (see interview in Appendix,

24 Jim VandeHei and Justin Blum, "Bush Signs Energy Bill, Cheers Steps Toward Self-Sufficiency", Washington Post, August 9, 2005, page A03

25 California Energy Commission, 2005 Building Energy Efficiency Standards, Nonresidential Compliance Manual, CEC-400-2005-006-CMF, page 1-6

26 CEC Green Building Initiative website: http://www.energy.ca.gov/greenbuilding/

page 53). Regulators have encouraged wholesalers and producers to move away from traditional rate design to performance-based rates. This legislation, plus opening the market to competition, has saved the average household $6000 in annual energy costs.[27]

FERC has proposed a standard market design that would develop a marketplace to support a sustainable energy program.[28] Standards for new building design, requirements for building retrofits and adequately "pointed" HVAC controls to support FDDO could and should be part of this regulation, but the current Administration has no interest in broadening the current scope of FERC standards. The Administration's interest lies in the supply side of the problem, rather than in conservation. Consequently, there is no Federal support for reducing resistance to standards or for encouraging data sufficiency in building controls through incentive regulation.

According to the Energy Information Administration, North America is responsible for nearly 29% of the world's electricity consumption. American consumers spent a total of $270 billion on electricity in 2004 (the last year for which figures are available).[29] It would seem that government would be very interested in encouraging conservation though a long-term strategy with a high ROI (return on investment). But mandating change through legislation and regulation is at a virtual standstill.[30] New tactics must be employed to jump-start this process. Case studies that verify energy savings through FDDO need to be published and promoted in a public forum that will capture stakeholder attention. These stakeholders should then be encouraged to lobby for governmental incentives and legislation. Many stakeholders feel that legislation is the most effective incentive to encourage adoption of FDDO systems (see Appendix, page 52, interviews with Dave MacLellan of NStar, Howard McKew of RDK Engineers, Frank Luciani of the U.S. Department of State, Philip Haves of Lawrence Berkeley National Labs, Karen Curran of GSA Region 1, and Ed Rockstroh of Technical Building Services, Inc.).

Public Power

Although there is wide agreement that there should be a more robust transmission grid, resistance from the power industry to developing and implementing standards to create a "real" free market is stronger than ever.[31] Only one sector seems to be more open to new ideas and actually acknowledges with words and actions that their primary objective is to serve the community: Municipal Utilities (munis).[32] There are approximately 2,000 such utilities, which serve an estimated one in seven customers. Their goal is to deliver high quality service combined with low rates. "Public Power is willing to invest in new

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27 Ken Malloy, "To Be or Not To Be" presentation, March, 2002, Center for the Advancement of Energy Markets

28 Bob Shively and John Ferrare, Understanding Today's Electricity Business, Enerdynamics, LLC, 2004, pgs. 147-148

29 Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report.", December, 2005

30 Bob Shively and John Ferrare, Understanding Today's Electricity Business, Enerdynamics, LLC 2004 pgs. 147-148

31 Alan H. Richardson, "On the Right Path", Energy Markets, June, 2005, pg.23

32 Ibid

transmission facilities to relieve congestion and reduce wholesale power costs", [33] according to Alan H. Richardson, president and CEO of the American Public Power Association. This is significant since other power suppliers have created such a strong distinction between new construction needed for reliability versus new construction needed for economic reasons. The municipal utilities realize that the issues cross over and are willing to approach restructuring differently from the industry at large.[34]

Given the munis' innovative attitude, broad public interest, and support from Wall Street, they have the potential of becoming a partner in the standards campaign. They will easily grasp the benefits of implementing standards and the value of data sufficiency. Additionally, the munis are in a position to leverage their power with legislators to pass regulation. The City of Los Angeles (consuming 22,289,149 MWh annually) is the second largest muni in the country. This may be the best candidate to approach for a discussion of standards and data sufficiency.

Summary

Because of the economic and environmental costs of fossil fuels, all sectors of the U.S. Government have recognized the need to promote and increase energy efficiency. FDDO systems would do just that, but there is a need for funding for education about the benefits of FDDO, as well as a need to fund incentives for adoption. The US government should provide these funds (and support other measures to reduce energy consumption) but seems unlikely to without further education about their benefits of FDDO. To that end, we recommend demonstrable study results from unbiased parties, which would be most helpful in making the case for FDDO systems. It is possible that state governments and interest groups, as well as the public power industry, may be more interested in promoting FDDO systems immediately. One approach might be through stressing the vulnerability of the electrical grid. Reductions in the load on the grid will lead to increased overall reliability. Although improved energy efficiency will not alleviate the need for other investments in the grid, it is clear that FDDO and other energy efficiency measures will reduce the necessary amount of investment in the grid.

Our recommendations include incentive regulation to promote the adoption of FDDO technology, investment by energy providers in FDDO adoption, and incorporating FDDO standards into LEED and EnergyStar programs.

33 Ibid

34 Ibid

Industry Standards

Industry standards could play an important role in breaking down barriers to FDDO implementation because they have considerable influence on how buildings are constructed or renovated. There are three immediately obvious types of standards that we believe will have a significant impact on FDDO:

1. Data communication standards for building automation systems will make dynamic data more accessible,
2. Electronic design documentation standards will make it easier to configure FDDO systems, and
3. DDC guide specifications should lead to greater consistency in building automation systems

These standards, if implemented, will speed adoption of FDDO systems by making them faster and thus less expensive to configure and implement.

Building Automation Data Communication Standards

The challenge of obtaining timely, dynamic data from building automation systems is often a significant barrier to the implementation of FDDO projects; one reason for this is the widespread use of proprietary communication protocols. Standard communications protocols, such as BACnet and LonTalk/LonMark, and connectivity standards, such as OPC, are becoming popular in North America and Europe. However, installed systems that use proprietary communications protocols still far outnumber installed systems that use standard protocols. Where standard protocols are used in a building automation system's network, FDDO systems can obtain dynamic data by connecting to the network and querying data from the various devices that comprise the building automation system. This, in turn, allows better control over data collection, allowing it to be more flexible and targeted (enabling, for example, targeted high-frequency data collection when necessary to expose rapid oscillation).

BACnet (ANSI/ASHRAE Standard 135-2004) is an industry standard network protocol for building automation systems that was initially approved in 1995. Several companies offer complete systems that use BACnet as their primary means of communication (so-called "native BACnet systems"), and many other companies offer a gateway allowing their systems to be connected to BACnet systems. BACnet International (formerly known as the BACnet Manufacturers Association) has established a BACnet testing and listing program for products that can communicate using BACnet. Data collected by the market research firm Frost & Sullivan indicate that BACnet has achieved a significant market share in new projects (approx. 23 % as of 2001) and it is predicted to grow to 41% by

2008, outpacing all other protocols and eventually overtaking proprietary deployments.[35] In our experience, some BACnet-based building automation systems installed in buildings do not provide easy access to some dynamic data important for FDDO, but this can generally be avoided if the customer clearly specifies a list of points that must be made visible using standard BACnet objects and properties. The future role of BACnet in FDDO systems exists primarily in larger facilities with more sophisticated systems and expansion needs.

LonTalk is a protocol developed by Echelon Corporation that has made a significant impact in the building automation business. The LonMark Association has developed standards for how LonTalk should be used in a number of applications. Several companies offer complete systems that use LonTalk as their primary means of communication, and many companies offer products that can communicate using LonTalk. A number of systems integrators specialize in putting together building automation systems using products that support LonTalk. If LonTalk-based systems become more common in the future, then FDDO systems should be designed to easily connect to LonTalk networks. Systems that use LonMark certified devices are particularly attractive targets because their use of standard device profiles could simplify FDDO system configuration.

OPC (OLE for Process Control) is a standard for communication based on Microsoft Windows technology (COM/DCOM) that is popular in the factory automation and process control industries. Many popular SCADA workstations support OPC, including Wonderware, Iconics Genesis32 and Intellution. At present, OPC is primarily used as a common interface between operator workstations and network protocol drivers (in most cases running on Windows-based computers), and it has become very popular for this application. Some building automation systems allow access to data through an OPC interface, and in some buildings this may be the best way for FDDO systems to obtain dynamic data. The OPC Foundation is developing a new standard based on XML which may allow OPC to migrate to non-Windows devices. In the future, OPC will provide a standards-based alternative for FDDO data collection, particularly when the automation system uses a proprietary network protocol.

Web services are a promising technology for integration of various types of systems, including building automation systems. Most web services being developed today are based on the Simple Object Access Protocol (SOAP). FDDO systems could make use of appropriate web services interfaces in order to get data from building automation systems, and web services may also make it easier to import other types of data into FDDO systems such as utility meter data and weather data. Currently at least two projects are underway to develop web services standards or guidelines for building automation: oBIX was started within the Continental Automated Buildings Association (CABA), but it is now an OASIS project and will be released for public review, presumably by 2007 (version 0.12 is the

35 Frost & Sullivan, North American Building Automation Protocol Analysis A143-19, 2002, page I-7

latest iteration as of June, 2006). The BACnet committee (ASHRAE SSPC 135) has developed a web services interface for building systems that has completed a first public review. The considerable interest in both of these projects is a reflection of customers' desire for higher levels of integration at lower cost.

In summary, we recommend that buildings owners choose building automation systems that employ standard communication protocols and communication interfaces.

Standards for the Electronic Representation of Building Design and As-Built Data

FDDO systems must be properly configured for a particular building (or piece of equipment) before they can generate useful results. The FDDO system needs to "understand" the building automation system—the equipment, building automation system points, HVAC system topology, and the desired sequences of operation. Today this is a time-consuming process requiring engineers to carefully examine mechanical and control system submittal documents and building automation system configuration data that may be incomplete. Reducing the cost and improving the accuracy of FDDO system configuration should be a long-term goal of the FDDO industry.

According to one NIST study, "Inadequate interoperability increases the cost burden of construction industry stakeholders and results in missed opportunities that could create significant benefits for the construction industry and the public at large."[36] The same study finds that "Interoperability problems in the capital facilities industry stem from the highly fragmented nature of the industry, the industry's continued paper-based business practices, a lack of standardization, and inconsistent technology adoption among stakeholders."[37]

The Industry Foundation Classes (IFCs) have been developed by the International Alliance for Interoperability (IAI), "an alliance of organizations dedicated to bring about a coordinated change for the improvement of productivity and efficiency in the construction and facilities management industry." The IFC provides a generic model for interoperable data among software applications used in designing and constructing buildings. The BS-8 initiative has produced a data model for the HVAC and energy simulation related applications.[38]

The Fully Integrated and Automated Technologies Consortium (FIATECH) is a consortium of large facility owners, engineering firms, construction companies, technology companies and research organizations that are working to "improve how capital projects and facilities are designed, engineered, built and maintained." Several FIATECH products are related to standardizing protocols for the exchange of information

36 Gallaher, Michael P., O'Connor, Alan C., et. al. NIST GCR 04-867 "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" 2004 (foreword, pg. iii)

37 Ibid, (abstract, pg. v)

38 A key contact for IFC is Rob Hitchcock of LBNL

between the many organizations involved in the construction, operation and maintenance of buildings.[39]

ASHRAE Guideline Project Committee 20 (GPC 20) was formed several years ago in order to develop a guideline that would define a common data exchange format for commodity data and HVAC&R information using XML.[40] This was a very big task for any one group to tackle, so it is perhaps not surprising that the group made little tangible progress for some time. Recently GPC 20 has has been working on developing use cases and guidelines for the development of XML schema for the HVAC&R industry. GPC 20 has also been sponsored by ASHRAE TC 1.5 (Computer Applications) to create an ASHRAE-funded research project whose objective is to "...assemble information supporting development of interoperability among software applications used at all stages of the HVAC&R project life-cycle." [41]

NIST has also studied the need for the efficient transfer and updating of as-built and design specs from Capital Projects teams to Facilities Maintenance teams. They estimate that $15.8 billion is wasted each year in the U.S. as a result of this lack of interoperability.[42] Further, the same study finds that, "Of these costs, two-thirds are borne by owners and operators, which incur most of these costs during ongoing facility operation and maintenance (O&M)." [43]

The Facility Information Council (FIC) of the National Institute of Building Sciences (NIBS) has launched a committee to develop a National Building Information Model Standard (NBIMS). NIBS states that "The NBIMS Committee seeks to facilitate life-cycle building process integration by providing a common model for describing facility information, common views of information based on the needs of businesses engaged in all aspects of facility commerce, and common standards for sharing data between businesses and their data processing applications. Use of a common information model is expected to significantly reduce building costs, insurance liability, construction schedules, and operating expense while increasing building performance, safety, building life and occupant efficiency." [44]

NIBS plans to involve multiple private and public sector stakeholders in the development of the standard. "In addition to cooperating with IAI, the new committee has initiated working alliances with the Open Standards Consortium for real Estate (OSCRE), the Open Geospatial Consortium, Inc. (OGC), and the Fully Integrated and Automated

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39 A key contact for FIATECH is Mark Palmer of NIST (Gaithersburg)

40 Titles, Purposes, and Scopes of ASHRAE Standards and Guidelines (March 2, 2006)

41 ASHRAE 1354-TRP, "COMMON DATA DEFINITIONS FOR HVAC&R INDUSTRY APPLICATIONS". The chairman of GPC 20 is Chip Barnaby of Wrightsoft Corp.

42 Gallaher, Michael P., O'Connor, Alan C., et. al. NIST GCR 04-867 "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" 2004

43 Ibid

44 "National Building Information Model Standards Committee Launched: New NIBS Group Will Create U.S. BIM Standard", NIBS press release February 24, 2006

Technologies Consortium (FIATECH). In addition, the American Institute of Architects (AIA), the Construction Specifications Institute (CSI), the Construction Users Roundtable (CURT), the International Code Council (ICC), the Department of Defense (DoD), the Army Corps of Engineers (ACOE), the Naval Facilities Engineering Command (NAVFAC), the US Coast Guard (USCG), and the General Services Administration (GSA) are actively participating in the NBIMS effort." [45] Our expectation is that the implementation of standards such as this one will help to pave the way for FDDO market acceptance.

The FDDO industry will greatly benefit from future standards for electronic representation of information about building systems. However, organizations that are promoting FDDO should participate in the standards development efforts currently underway in order to ensure that the future standards will address the data needs of FDDO systems. Specifically, the cost of configuring FDDO systems would be greatly reduced if as-built data were easily available in a format which was interoperable with their software. Additionally, maintenance and optimization would be greatly streamlined if all relevant information were immediately at hand for analysis.

Guide Specifications for Building Automation Systems

High-quality guide specifications (guidelines covering protocols, procedures, and responsibilities) are effective tools for promoting best practices in the design of building automation systems. Because these specifications take into account the needs of FDDO systems, they could help lower barriers to FDDO implementation in the future. Here are some projects that could have a significant impact:

The U. S. Army Corps of Engineers has developed a guide specification for DDC systems[46] that addresses some issues important for FDDO, although we assume that enabling FDDO was not one of their objectives. The specification includes point lists for specific control applications and sensor accuracy requirements.

GSA's Pacific Rim Region has guide specifications for new building automation systems projects that define network communications, instrumentation, and quality standards.[47] The specifications specifically address instrumentation required for FDDO:

> "The designer must require instrumentation to support both the sequence of operations, and the data acquisition capability to support equipment performance monitoring and building diagnostics analysis. A listing generally establishing minimum instrumentation requirements is included with the specifications. This identifies minimum instrumentation for common types of systems. The designer is responsible for requiring additional instrumentation

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45 Ibid

46 U. S. Army Corps of Engineers, "UFGS-15951A: Division 15 – Mechanical: Section 15951A: Direct Digital Control For HVAC," December 2001.

47 Facility Dynamics Engineering, "GSA Control Guide Specifications," 2002.

as necessary to support the sequence of operations, or to supplement data acquisition capabilities when the nature of the equipment or systems to be installed makes this sensible. "[48]

ASHRAE's Guideline 13, entitled "Specifying Direct Digital Control Systems",[49] provides "recommendations for developing specifications for direct digital control (DDC) systems in heating, ventilating, and air-conditioning (HVAC) control applications", and a sample specification for a DDC system. ASHRAE has formed a committee (SGPC 13) that is actively updating this document. Automated Logic's free CtrlSpecBuilder tool is based on ASHRAE SGPC 13-2000 and allows users to develop HVAC control specifications in compliance with the guideline.[50]

The U. S. Navy's Naval Facilities Engineering Command (NAVFAC) has completed a construction guide specification for DDC systems that is based on ASHRAE Standard 135 (BACnet). Cimetrics has reviewed the document and provided feedback directly to the authors. We hope that the final specification will result in the installation of more building automation systems in military facilities that can be easily connected to FDDO systems.[51]

LBNL is working on a project funded by the CEC and PIER-DOE to develop "A Specifications Guide for Performance Monitoring Systems". Currently still in draft form (as of June, 2006), the guideline is "…intended to assist commercial and institutional building owners in specifying what is required to obtain the information necessary to initiate and sustain an ongoing commissioning activity."[52] It promises to include performance metrics by class, a sample basic general spec, a sample basic general level spec language based on ASHRAE SGPC 13-2000, and sample point naming conventions, as well as additional resources.

We believe that guide specifications and software tools that assist engineers in creating control specifications will be increasingly popular as control systems become more complex. Looking to the future, organizations with an interest in promoting wider adoption of FDDO should consider working with the authors of these documents and tools in order to ensure that FDDO-friendly specification language is available. Particular specification areas that should be addressed are sensors, network protocols, network-visible points and the point naming convention.

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48 GSA Region 9 Master HVAC Controls Specification v2.1--Preface and Implementation Guidance to the Design Engineer, created by Facility Dynamics Engineering in 2002

49 ASHRAE, "ASHRAE Guideline 13-2000 -- Specifying Direct Digital Control Systems," 2000.

50 https://www.ctrlspecbuilder.com/sb/welcome.nsf

51 Contact: Bruce Caldwell, Naval Facilities Engineering Service Center, Port Hueneme, California.

52 Gillespie, Haves, Hitchcock, et al., Spec Guide Draft 007, "A Specifications Guide for Performance Monitoring Systems", Ernest Orlando Lawrence Berkeley National Laboratory, March 1, 2006

Recommendations

Recommendations include outreach and education to building owners, accurate FDDO testing tools, and industry standardization including point naming conventions, sequencing conventions, data models, communication protocols, and construction/as built documentation storage and communication standards. Incentives such as rebates, operator training, education, and incorporation of FDDO services into building standards (such as LEED) will help popularize the technology. Recommendations can be summarized as follows:

1. Invest in standards
    a. Network protocols and interfaces
    b. Minimum point counts for data sufficiency
    c. Point naming
    d. Documentation
        i. Construction design and as-built plans
        ii. Mechanical systems
2. Market priming
    a. Rebates
    b. Incentives
    c. Utility pilot programs
    d. Improving FDDO tools
3. End user education
4. Third party validation of results
5. LEED and Energy Star regulations and recommendations

Each recommendation is discussed in greater detail below.

Invest in Standards

A lack of standardization in multiple arenas directly affecting the FDDO industry has resulted in technical and market barriers to the adoption of the technology. Standards generally have proven effective in cost reduction. For example, according to the California 2005 Integrated Energy Policy report, adopted, November 21, 2005, "California's building and appliance standards are the state's most cost-effective efficiency measures. Since the first round of standards was adopted in 1975, the state has saved 6,000 MW in peak demand and expects to save 10,000 MW by 2010."

Network Protocols and Interfaces

There are multiple communication protocols in competition to become the standard in the BAS industry. One protocol will eventually rise to the top and garner the most market share, becoming the de facto standard. Until this happens, the market will remain competitive, with multiple protocols jockeying for position. Cimetrics has been deeply involved in the development of BACnet and feels that its adoption would best accommodate a variety of applications.

Minimum Point Counts for Data Sufficiency

FDDO systems cannot operate without the ability to gather useful data. We are hopeful that, as buildings are upgraded to DDC, wireless sensor prices are reduced, data become available to validate cost savings through improved indoor air quality, and building owners are educated about the life cycle costs of buildings, the data sufficiency problem may be solved. It may be difficult, for example, to reduce natural gas usage without sufficient boiler sensors to effectively monitor the system. The great likelihood is that without legislation mandating a standard for sensor placement, change will be slow. Discussions already underway in California (see Philip Haves second interview, page 55) are a good sign that sensor sufficiency is being considered as part of building codes. Standard codes should be considered throughout the country as energy efficiency and greenhouse gas emission reductions become increasingly urgent matters.

Point Naming

While some large facility owners already have their own point naming conventions (see second interview with Todd Lash, page 60), in Cimetrics' experience, most facilities suffer from point names which are not useful, and many have no point names at all. This inconsistency creates a challenge for anyone other than the installing contractor. Systems which are intended to be interoperable may not be simply due to a lack of point naming, an expensive and time-consuming issue to remediate. We recommend a nationally adopted point naming convention. Please see the final section, "BAS Point Naming Convention Specification" (page 66) for our suggested convention.

Documentation

Construction documentation is notoriously inaccurate and difficult to work with. In a largely paper-based industry (from the building owner/facility manager's perspective), changes and as-built data are rarely captured. In configuring an FDDO system, mechanical system specs and locations and HVAC system specs are critical. If correct sensor locations and all other critical data could be communicated and stored electronically, it would greatly reduce FDDO configuration costs, making these systems more attractive. In addition, electronic construction documents could be useful in life safety operations (see second interview with Mary Beth Tighe, page 53) and general maintenance. We recommend a standard be established for the easy electronic dissemination and maintenance of as-built construction data.

Market Priming

Essential to the success of FDDO technologies is a market which demands and supports them. Many stakeholders concur that marketplace development is critical to the adoption of FDDO (see interviews with Jim Armstrong, Mary Beth Tighe, Pete Roman, Peter Douglas, Todd Lash, Dave Craven, page 52). In order to prime the market, we recommend incentives and rebates which will help to make the front-end installation of these systems as attractive as the back-end energy savings.

Rebates and Incentives

Rebates to defray initial costs of FDDO tools will encourage stakeholders to overcome their reluctance to try new technologies. Other initiatives could include using regulations to promote FDDO use, such as integrating FDDO tools into LEED requirements for certain types of buildings. For example, the US Green Building Council is a market driver for sustainable buildings, but their goals for energy efficiency will be short-lived if they do not deal with the ongoing operational problems that FDDO tools can identify.

We believe that incentive programs (rebates) are necessary to encourage building owners to make an initial investment in building controls until enough studies exist proving their efficacy in every type of building, in every part of the U.S. It is also important, however, to ensure the longer term future of this technology: that good building controls are installed and continue to be properly maintained. Long-term, performance-based incentives ensure that the initial incentive money will ultimately be well spent. Like control systems, FDDO systems have the potential for energy savings, but both require attention to realize their potential—attention at many stages, including proper installation, configuration and use. Incentives should initially focus on a vertical that is carefully chosen for high potential benefits for FDDO.

Utility Pilot Programs

The Utility Pilot Program approach has been common in the market introduction of energy saving devices (such as solar panels, high-efficiency lighting, etc.). In order to move the market beyond the early adopter stage, utilities can offer incentives for FDDO pilot trials and offer financing for configuration. This will help to mature the market, moving it beyond the early adopters by making FDDO deployment more attractive. In Cimetrics' experience, conservative customers have been convinced almost unanimously of the value of Infometrics through pilot studies.

Improve FDDO Tools

As described in the overview of existing FDDO tools, there are many which require further development to be commercially viable. We feel that an investment must be made in perfecting the usability and clarity of the existing tools, as well as in pushing development further to create new tools.

End User Education

Before the market can grow, more building owners must be made aware that FDDO systems are available that can reduce energy consumption and increase efficiency. We believe that consulting engineers, contractors, building controls suppliers, and architects can be helpful in disseminating information to potential users. Efforts to reach out to these constituencies, as well as directly to building owners, should be made. Resources such as the EPA's EnergyStar program and the USGBC's LEED program may be helpful in this regard. Utilities could also reach out to large users to educate them. Training to improve operator ability to identify operational problems will increase appreciation for the value of automated FDDO. Building-owners' focus groups, more case studies, and broad surveys will raise building owner awareness of the prevalence of operational problems and the associated costs. Additionally, building on the growth of Demand Response, FDDO systems can be implemented as complementary offerings which offer greater savings and additional benefits.

Third Party Validation of Results

More work needs to be done in proving the effectiveness of FDDO diagnostic tools. A large number of installations over a long time period may be necessary before sufficient data can be gathered to establish the value of these tools. This may not be a technical barrier, but customers perceive it as such; they want evidence of the tools' efficacy. So far, only general case studies have been conducted to establish this effectiveness for the industry. Additionally, so-called "soft" (operational) savings must be quantified through more studies.

LEED and EnergyStar Regulations and Recommendations

LEED (Leadership in Energy and Environmental Design), administered by the U.S. Green Building Council (USGBC), and EnergyStar, run by the Environmental Protection Agency (EPA) and the Department of Energy (DOE) are the primary energy efficiency initiatives currently in operation.

EnergyStar's offering in building energy efficiency can be best characterized as a benchmarking tool. The tool tracks utility bills and compares them with those of other buildings. More geared to identifying savings than to identifying ways in which to save, we feel that EnergyStar as it stands now is of limited utility in promoting FDDO.

The LEED rating system is based on the identification and implementation of energy-saving measures in buildings. Currently most popular in certifying new buildings, LEED also has an Existing Buildings certification standard (LEED-EB). The standard addresses multiple measures for minimizing energy use and greenhouse gas emissions, awarding points for adoption of each measure. Our feeling is that the USGBC is a potentially productive partner in promoting FDDO, through both the LEED-EB and the LEED-NC (for New Commercial Construction and Major Renovation Projects) standards.

Appendix

Interviews with Stakeholders

Interviews are summarized by Cimetrics staff and any transcription errors are the sole responsibility of Cimetrics.

David MacLellan, NSTAR

Interview with David MacLellan, Program Manager, Energy Efficiency Services. Original interview held January 13, 2004.

After hearing an explanation of the project, Mr. MacLellan's first reaction was that this is a great idea, but that the industry may oppose standardization. He felt that the building (construction/design) and control industries would not move forward with this easily or "gracefully". Figuring things out in a building is the bread and butter of consulting engineers; standardization would significantly limit their opportunities.

Mr. MacLellan agreed on all the benefits to society FDDO offers: improved air quality, lower operating costs in public buildings and greater stability in energy commodities. However, he is concerned about how to measure results, both long and short term. He agrees that we need additional instrumentation to be specified for new and retrofitted buildings so remote monitoring can be implemented, but notes that this is costly.

Mr. MacLellan believes that standardization, open protocols in control systems and certification of buildings not only for safety but also for energy (including instrumentation) should be legislated.

In a subsequent e-mail, Mr. MacLellan said that NSTAR would have a great deal of difficulty trying to spend ratepayers' money without any direct savings attributed to the project. There would be a "number of obstacles".

Jim Armstrong, NSTAR

Interview with Jim Armstrong- CPE, CEM, Program Manager Technical Energy Efficiency Services. Original interview held March 14, 2006.

Mr. Armstrong asserted that there is a need for standardization in many arenas related to the FDDO industry. He felt that many engineers who design building systems are not in touch with how buildings actually run and are not subject to sufficient oversight. According to Armstrong, they certify that systems are built per their design specs, but may design systems which are inefficient or not according to code. He felt that because of this lack of oversight, employing building codes to encourage adoption of FDDO systems would not be useful. He did note that ASHRAE 2004 code standards are being released, but that they are a reference guide rather than a requirement, again easily overlooked or violated. Interestingly, he felt that a minimum point requirement would soon be unnecessary because control systems are being sold by module rather than by point (by all controls manufacturers, including Siemens and Johnson Controls).

Armstrong said that the best way to encourage broader acceptance of FDDO systems is through the marketplace, by creating a great product, subjecting it to independent testing, and getting the word out about its success. He said that rebates don't work, and that customers are incensed by imposed regulations. He believed a "show me the money" approach was the only one that works. In regard to incentives, Anderson asserted that LEED's scope is too broad and not optimally targeted or weighted, not allowing enough credit for energy and emissions reductions. In his mind, EnergyStar benchmarking is really an educational tool, but their soon to be released EnergyStar AB will consider more details about building equipment. He also said that the 2006 Energy Bill credits for surpassing ASHRAE standards are nominal and difficult to certify.

In regard to BAS protocols, he said that no one can predict right now which one will grow to dominate the market. He mentioned that LonWorks, BACnet, and Modbus are the primary contenders right now, but also mentioned that Zigbee, a wireless protocol, seems to be gaining traction. He did feel that it will be important that one protocol become the standard, and expected this to happen.

Armstrong felt that studies quantifying cost savings associated with "soft benefits" such as increases in productivity due to better indoor air quality and savings through proper maintenance would be critical to increasing FDDO market acceptance. He also saw that in many cases, the disconnect between groups in charge of initial construction and those in charge of ongoing operations leads to unnecessary costs over the life of a building. He asserted that saving up front costs through "value engineering" often means additional maintenance costs in the long run.

NStar is engaging in a few endeavors related to the FDDO field. They have started a pilot retro commissioning program, focusing on low cost/no cost improvements. They are also using a Honeywell Service Tool on rooftop units to assess operation and have found a 30-40% reduction in energy usage through its use. Additionally, they are engaging in ongoing education of customers regarding energy reduction. Armstrong saw the value of FDDO systems and of the establishment of standards in related industries.

Howard McKew, RDK Engineers

Interview with Howard McKew, PE, CPE, Vice President, RDK Engineers

Interview held December 15, 2003.

Mr. McKew is a Vice President at RDK with many years of engineering and building operations experience. While the project is of great interest to him, and he sees high value to his customers, the project would have low priority in his organization for several reasons.

1. 75% of the time, engineers are not writing the spec for buildings.
2. Most consulting engineers are not qualified to develop the appropriate standards.

3. Engineering companies are not the market leaders in initiating change of this type. The customary way of doing business is to wait for the market to broadly implement a new technology or methodology and then follow suit.
4. Writing of specs is less than 2% of their business, without opportunity for recurring revenue. Developing standardization specs would be "viewed as a task, not a project."

Mr. McKew pointed out that commissioning (in the true sense) is not part of the normal start up of a building. The first step to encourage this to change would be:

a. Standardize the commissioning process, i.e. a checklist of key components that are universally accepted on all jobs.

b. Standardize the data sufficiency requirements to ensure that a building can be continuously monitored and thereby optimized.

McKew firmly believes that there needs to be a "back to basics" attitude that combines the sequence of operations and functional performance testing. More often than not, the sequence of operations is not written by an engineer but rather the controls company. This is a major problem in the building industry. Further, the sequence is frequently not provided to the owner nor is it addressed in the submittal.

Frank Luciani, U.S. Department of State

Interview with Frank Luciani, Manager, Energy Program, US State Department.

Original interview held November 12, 2003; follow-up February 27, 2004.

Mr. Luciani is Manager of the Energy Program for the State Department. He is very much a proponent of standards, especially for the government sector. According to Mr. Luciani, however, the current Federal administration is not focused on funding any projects of this nature. Previous administrations were interested and had begun a strategic plan to implement a "Standard Embassy Design." The State Department owns approximately 8,000 buildings overseas. The average building size is 35,000 square feet. Mr. Luciani believes that because the government is so concerned with chemical and biological terrorism in the HVAC systems, funding will become available for standardization in their buildings to help reduce risk and stabilize energy costs.

The issue is not whether or not the State Department believes this is a sound project, but rather the availability of funding for such a project in the short term. If the Energy Bill passes, there may be money to support energy conservation measures.

Mary Beth Tighe, FERC

Interview with Mary Beth Tighe, Energy Industry Analyst (reporting to Mr. Woods), FERC.

Original interview held end of February, 2004; Ms. Tighe reviewed the proposal on March 8, 2004.

Ms. Tighe has a clear understanding of the project and how it would play within the FERC atmosphere. At this time, any funding would be hard to come by. She is close to the proposed Energy Bill and has first-hand knowledge of the fierce competition for the proposed funding.

If the Bill is to pass, it will be a far cry from the original document. R & D money would be significantly cut to accommodate the main and most serious issue—the Electric Grid. In her opinion, the Energy Bill is a political hot potato.

Ms. Tighe's additional comments are as follows:

Can technology solve the problem more easily than establishing standards? (Please note that we have heard this before.) Technology development has more opportunity for funding and the business community is more apt to adopt technology, especially low-cost technology. There is also an attitude in the market place that new technology is "cool". There is a general societal trend in using leading edge technology to solve hard and embedded problems.

Further, in order to have government consider funding, hard numbers are required. A presentation would require case studies, an estimate of savings as a result of optimizing HVAC systems across verticals, the expected reduction of Mwh, the range of savings in O & M, potential reduction in demand, and how such Standards would be deployed.

Second Interview: March 10, 2006

Note: Ms. Tighe's title has changed to Group Manager, Division of Tariff and Market Development, West

Ms. Tighe felt that the (now passed) 2006 Energy Bill was focused on promoting nuclear and clean coal energies and that energy efficiency programs and focus on renewable energy sources had been reduced. Her sense, from having worked on HVAC system design in the past, was that customers were very interested in energy savings, but also in the "soft" savings such as operations and maintenance, complaint reductions, and increased productivity. She still felt that research quantifying these savings would be useful in promoting FDDO systems.

She has seen over and over that incentives work better than penalties, finding that penalties scare away potential early adopters.

In regard to standards, she still felt that the product should establish the market rather than government intervention (which might decrease flexibility in product development). Having said that, she did support open architecture rather than proprietary languages in BAS as well as the idea of a consistent software platform for construction documentation.

She said that this idea was "very interesting" and that this type of approach to construction documents would also be quite useful for fire departments, police, etc. in building safety.

Pete Roman, Eaton Cutler-Hammer

Interview with Pete Roman, Corporate Marketing Manager, Eaton Cutler-Hammer.

Original interview held March 10, 2004.

Roman is a long-term employee of Cutler-Hammer. His title does not reflect the scope of his responsibilities. Mr. Roman reports directly to second in command of global manufacturing and marketing. His comments are based on his experience in both areas.

Roman feels that this standardization project would meet with strong resistance from the manufacturing industry. In his opinion, standardization reduces the competitive edge. He believes that the custom engineering of a proposal for a site gives a company the opportunity to be creative, win business and exceed profitability goals within its organization. If standards were imposed, it would be "same ol' same ol'". The only people who would be positioned well at a site are third parties and those companies who are already embedded at the customer. Overall, competition would be significantly reduced. Mr. Roman's final comment was that the effect of standardization on manufacturing would be "benign at best and negative at worst."

However, Roman's comments wearing his service and customer satisfaction hat are quite different. He is 100% behind open protocol. The customer needs to be able to connect and use any technology that improves efficiency, positively affects the business process and increases savings. That being said, Roman believes that advanced technology is the requirement, not standards. He noted an important fact; although the energy bill has not been passed, the federal government has passed requirements for "in the box" radio frequency devices. Wireless communication, painted sensors, and mules are all part of what the government sees as the future. Cutler-Hammer has made a strategic decision to move forward with the emphasis being on advanced (and in some cases even deposable) technology to improve their business process and customer satisfaction. Roman and his company think that technology developed is easier to focus on than a standards project for the following reasons:

- It is an area that is funded by outside sources,
- The internal case for resources will be listened to and have priority,
- The results will be greater and achieved more quickly.

After the R & D is completed, Roman thinks that low cost, easy solutions will be implemented with very little resistance from the marketplace.

Philip Haves, Lawrence Berkeley National Laboratory (LBNL)

Interview with Philip Haves, Leader of the Commercial Building Systems Group, LBNL.

Interview held March 23, 2004. Peng Xu of LBNL also participated.

The commercial building systems group at LBNL is heavily involved in research on building diagnostics. Their funding comes primarily from the CEC and the DOE. Haves favors a model-based approach to building diagnostics that makes use of information about the design of the HVAC system to define expected performance in the commissioning phase.

On the regulatory side, Haves said that California's Title 24 is moving in the direction of addressing building operations. The version of the Title 24 regulations planned for release in 2008 is expected to include additional acceptance testing requirements.

LBNL researchers have been involved in the GEMnet project underway in GSA Region 9. GEMnet has a standard point list for controls. See interview with Mark Levi, GSA Region IX.

LBNL is leading a project to develop a specification guide for performance monitoring in commercial buildings. The goal is to provide better information building operations, both for operators and for automated diagnostic tools.

Haves mentioned the International Alliance for Interoperability's work to develop a data model, known as the Industry Foundation Classes, to support interoperability between software tools for building design and operation. Peng Xu worked on the HVAC models.

Mr. Haves was very supportive of the benefits of standards in order to facilitate building diagnostics. He would like a "road map" that would lead to more funding for FDDO projects.

Second interview: March 15, 2006

LBNL is currently working on a draft report to the DOE and the CEC entitled "Commercialization Path for Automated Diagnostics: Summary of Survey Results". The report documents interviews with a variety of stakeholders, including vendors and ESCOs, that noted the difficulty of extracting data from control systems, the need for standardization in communication protocols and more broadly, and the need to demonstrate results of FDD to create market pull.

New measures being considered for California Title 24 standards for 2008 include some BAS fault diagnostic technologies. A specification guide for performance monitoring for has been prepared and part of it is being considered for inclusion in the 2008 Title 24 standard, as well as the ASHRAE Guideline 13 for Specifying DDC Systems. According to Haves, there is interest in establishing a standard for communicating EMS trends for use by 3rd party software.

To encourage adoption of FDDO, Mr. Haves believes that a combination of market development, legislation, and research yielding demonstrable evidence of the efficacy of

FDDO systems will be necessary. He feels it is important that the research component must include multiple types of buildings in multiple climates and parts of the U.S., providing sector-based cost/benefit data.

Karen Curran, GSA Region 1

Interview with Karen Curran, CEM, Energy Management Specialist, GSA Region 1.

Interview held April 5, 2004.

Curran's comments were similar to those made by other government personnel we interviewed: Standards are a great idea, but there is no funding to overcome the barriers.

Curran explained that currently the GSA does have minimum standard requirements for the control companies in both new construction situations and retrofits but the details incorporated in an RFP are weak. The broad scope in the document simply says, for example, that the system must be able to maintain occupancy comfort, for example. It never addresses what the entire sequence of operations should be or the number of points that should be included. They expect the contractor to handle that. Although the GSA is constantly reviewing energy expense and reporting on it, there is considerable push back on any upgrades. Unlike what the State Department once had, this is no standard building spec for like property.

The GSA has implemented a customer satisfaction survey at all properties and each Region is measured on the results of that survey. Curran agrees that the occupants' satisfaction would be much higher if the standards and on-going commissioning were implemented. And, of course, early implementation would yield the best results for all parties. However, she thinks that the resistance, especially from contractors and owners, will be the high first cost. They may agree that it is the right thing to do but at what price? When funding becomes more readily available from the Federal government, she would suggest a grant that supports a study on new construction done the "right way" and prove that the savings are there in a very straightforward way. She believes that is the only way government will change its behavior.

Ed Rockstroh, Technical Building Services, Inc.

Interview with Ed Rockstroh, General Manager, Technical Building Services, Inc.

Interview held May 3, 2004.

Technical Building Services is a Systems Integrator. Rockstroh's general opinion is that standardization and REQUIRED remote monitoring should be implemented, but the industry has an enormous resistance to it. Controls companies have a lot at stake by using open protocols and standards. The development of models that indicate the minimum point requirements is "years' worth of work" and monitoring compliance would be nearly impossible.

Rockstroh thinks that the funding to launch such an endeavor must come from a government grant and that the government grants need to fund pilots that would prove dollar savings. He estimates that first cost would increase to $500 to $700 per additional point. Plus, the additional skill level required to spec the correct model for each piece of equipment would increase cost significantly. Mr. Rockstroh gave the example of air handlers. Each AHU would need a particular model depending on its intended functionality. The design engineer must be very clear on its operation so the correct number of points is installed. The complexity of a project increases the cost. In his experience, all owners are interested in ROI on hard numbers that have already been proven. O & M are soft savings and never play well in convincing an owner that additional costs will save him money in the long run. Rockstroh has found that some owners are interested in "doing the right thing," but as weeks pass and lower level staff speaks to the decision maker, interest dissipates. The classic response becomes "cut the cost back".

Rockstroh has also found that compliance to standards and recommendations in this economy is poor. With government funding (from DOE, for example) and improved economic conditions, end users may develop an interest. But industry players (such as equipment manufacturers and controls companies) will continue to offer strong resistance.

In spite of all this, Rockstroh says he does believe that improved controls will increase value. Managers need more accurate data in order to make better decisions.

Peter Douglas, NYSERDA

Interview with Peter Douglas, Program Manager, Buildings Research, NYSERDA.

Interview held May 11, 2004.

Standard point naming and required points to be monitored will, most likely, decrease energy consumption, but to what extent? Douglas believes that an EMS system significantly decreases energy consumption and improves efficiency. Standardization of point names and requiring a minimum number of points on particular pieces of equipment is a "sub-set of EMS as a class." (The class he is referring to is technology.) Although data sufficiency is important, it is not of high importance. The ROI on savings is not worth the level of effort to reduce the number of barriers.

Douglas believes that this is not an arena the government should be involved in. The industry itself should set the standards because it has the skill to do so, whereas the government does not. Mr. Douglas feels that this is not the national or state government's job. By setting standards through legislation or regulation, government is "going too deep into the industry" and "overstepping its authority."

In terms of remote monitoring, Douglas believes that the data collection and analysis should be done by a vendor, not by in-house staff. He believes that in-house personnel do not have the talent to analyze the data and take necessary actions. He is also of the opinion that at many sites, the low-level manager does not have the skill to take action even on recommendations provided by outside firms; therefore, the remote monitoring company should take control of the building.

Mark Levi, GSA Region 9

Interview with Mark Levi, Energy Manager, GSA Region 9.

Interview held May 11, 2004.

GSA Region 9 has an active program for implementing building diagnostics. They are already collecting data from a number of building automation systems that use BACnet, and the data are stored in an SQL database. In the future, they plan to use PACRAT to analyze that data that they have collected. They hope that PACRAT will be able to be interfaced to a maintenance management system in order to generate work orders for maintenance contractors.

Levi's view is that the most serious problem impeding the GSA Region 9 from using FDDO is how (poorly) building controls are installed and configured. When controls are implemented poorly, everything else is undermined. QA is a big issue. The lack of engineering skills in controls contractors is also a problem. Commissioning helps to address the quality of controls installation.

In order to improve the design of building automation systems, GSA Region 9 licensed guide specifications [6] from Facility Dynamics Engineering, developers of the PACRAT software. The specifications are designed to enable FDDO in a number of ways, including the requirement to use a standard network protocol (BACnet or LonTalk) and standard instrumentation lists.

Levi believes that one high-leverage activity that would be of great benefit would be the creation of an "open source" guide specification for building controls. There is a free web-based tool for creating HVAC controls specifications (http://www.ctrlspecbuilder.com/), but Levi considers it to be "immediately suspect" because the tool was developed by a vendor (Automated Logic).

When asked about changes to Title 24 in order to enable building diagnostics, Levi said that there was significant potential leverage there, but he said that Title 24 enhancements would not solve the problem of the quality of installation of control systems.

GSA Region 9 would be interested in participating in funded pilot/research projects related to FDDO. Mr. Levi says that they already have a lot of data that might be useful in such a project.

Second Interview: August 5, 2005

GSA Region 9 is using PACRAT on a few buildings. It looks useful. Not many people know how to set it up, except for Facility Dynamics Engineering. GSA Region 9 has had some problems getting steady long-term trends—loss of data affects the results. Mr. Levi believes that they need to do retro-commissioning before PACRAT can be used.

They are using VPAC (developed by NIST) on a couple of floors. It has potential. It can generate real-time alarms.

Levi is worried about system bandwidth in older systems. Overall, FDD has a lot of potential but it is "thin" at present. GSA Region 9 would like to deploy the technology everywhere eventually.

Concerning point names: Mr. Levi believes that standard names are not critical as long as names are understandable. There is a naming standard in their current guide specification. They have a convention for the assignment of BACnet network numbers and device IDs that is being used on new projects. Data management is an issue in general—building controls installers do not pay attention to it. There are often discrepancies between point names and OWS screen graphics.

Question about California's Title 24—how can we use it to require the use of diagnostics? Answer—it is not clear how. Specify error conditions that should be detected by the control system? California is out front. However, need to allow time for adoption. Levi favors performance-based specs and requirements.

Major construction projects in GSA Region 9 will include "whole building commissioning", but will it be sufficiently focused on controls?

Mr. Levi is interested in comparing various FDD tools and services.

Todd Lash, Siemens Building Technologies

Interview with Todd Lash, Product Manager, Siemens Building Technologies

Lash's first reaction was that standard point naming and improved data sufficiency are good ideas, but they are not going to happen.

Siemens and, most likely all controls companies, would benefit from standard point naming since their installed costs would be reduced. However, customers often have a required point naming convention of their own. This is especially true in the pharmaceutical industry and in hi-tech firms. Siemens would, perhaps, reap more benefits from standard naming because they own their distribution channel. Other controls companies do not; they simply produce product that is distributed to re-sellers. Managing the distribution channels you own is one thing; managing channels you do not is difficult.

Lash felt that the public sector, e.g. public schools, would be a good place to establish data sufficiency requirements and standard point naming because there is opportunity for a cookie cutter approach. The drawback is the cost of establishing the model in a vertical that never pays full price.

Siemens has reviewed the standards issue many times. In addition to the difficulties already stated, there is the problem of their legacy systems. Their existing customer base has no interest in footing the bill for such an expensive conversion venture.

Lash agrees that data sufficiency would have a significant impact on energy consumption and air quality. Commodity volatility would be reduced because the owner would better understand the usage pattern, and therefore, make informed decisions on purchasing and adjustments on usage. The bigger and better benefit, in his opinion, is the controllability of the system so the facility could participate in Demand Response programs. This would be an enormous societal benefit.

Lash believes that government should not play a stronger role than it already does through programs such as Energy Star. He knows of no Federal regulations or legislation currently addressing issue. He does not believe that the Federal government would be interested, at least in the short run.

Second interview: August 9, 2005

Mr. Lash feels that government mandates are the only way that the end user will be interested in standardization and the data sufficiency issue. He says that Siemens experiences the end-user continuing to insist on using their own point-naming convention, not that of the controls company. Customers will not pay for any conversion costs from the existing convention to a broad standard, nor are they interested in increased costs for standardization on new projects. Again, Lash believes that the government must push the end user through legislation and thus force the controls companies to comply.

He does point out that large end users have their own point naming convention, so they understand the value of a standard. He also notes that end users and controls companies are “unwilling to invest in something with an unknown return.” Technologies that track the benefits of such endeavors are just emerging; therefore, the risk is unable to be quantified in their view.

Mr. Lash does feel that these new technologies will advance a standard point naming convention and data sufficiency requirements. Mr. Lash admits that some companies have adopted standard point ID’s that are used in determining operational inefficiencies in buildings. The points collected from the building’s BAS are “mapped” to these ID’s and then used in the diagnostic process. This process has not yet been scaled.

David Craven, Andover Controls

Interview with David Craven, Director of OEM Sales, Andover Controls.

Andover is of the opinion that the systems in question are too diverse/complex to attack using diagnostics. Every project would have to be custom designed.

Andover manufactures programmable controllers, which makes the problem much more difficult. Fixed function controllers would be much easier; on those products something might be possible.

A significant number of customers do want diagnostics. One example of what they want is add-on software to existing Andover systems which would look at unit health (not system health). Andover developed a special software package for FDA compliance sold to pharmaceutical companies, and it has been quite successful. ROI is an issue for other customers.

Andover has tried several times to adopt a standard nomenclature, but it has been difficult to make it stick. Customers have their own preferences about names. Andover sells instrumentation, and dealers buy a lot. Dealers are receptive to standard programming.

Craven's view is that diagnostics should start at the unit level, and that equipment manufacturers could lead the way in providing diagnostic packages for their products.

Summary of TIAX Article

The article described below preceded the November, 2005 TIAX report for the DOE entitled "Energy Impact of Commerical Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential".

Kurt Roth, PhD and Karen Benedek of TIAX wrote an article in Energy User News[53] regarding the need for increased information about buildings and their systems in order to improve system functionality and reduce costs. They focus on the commercial office space, which uses approximately 15% of all energy in the United States. In spite of the volume of energy this space consumes, they continuously engineer standardization and full commissioning out of new construction. Owners often "flip" buildings and they will not pay for anything that does not significantly enhance property value. First cost is the most significant barrier in this vertical. It is also important to note that, generally the cost of energy is only 1% of their overall operating budget including salaries of workers who use the building.

75% of new control systems are installed in existing buildings. New control systems that can measurably improve the attractiveness of leased space or enhance occupancy comfort and productivity have the greatest chance of becoming a budgeted item.

TIAX claims they have conducted a study proving that labor and maintenance costs are reduced by as much as 50% if buildings' points are tied together through standardization. The study further states that 70% of the installed system costs are wiring, other electrical work and commissioning. TIAX believes that any measure that reduces the cost of commissioning would be an incentive to install adequate controls in a building, commission it, and step and repeat.

Interoperability is an elusive concept to REIT owners, so decisions about controls are relegated to the facility managers. Their main function is "fire fighting". They often do not have time to review material or to access it for quality. The classic behavior in this vertical is NOT to allow, from a budgetary view, integrated building systems. The building owner and building management paradigm impedes deployment of standards. For new construction, the goal is complete the building as inexpensively and quickly as possible. There is a clear bias against innovative approaches because they continue to believe that there is no connection to tenant comfort or the bottom line.

There is a general lack of knowledge about the benefits of systems. Further documentation is needed to support positive economics to the REITS.

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[49] Roth, Kurt W. and Karen Benedek, "Commercial Building Controls: Barriers & Opportunities," Energy User News (web site), 1/26/2004.

Table 19: Comparison of Current FDDO Tools

Vendor/Tool	Advantages	Disadvantages
PNNL/WBD	• Uses commonly available sensors • Well developed graphical interface that effectively conveys information to users • Capable of identifying many common faults in HVAC equipment and controls • Provides estimates of the energy cost associated with identified faults • Has successfully interfaced with products made by several building control systems manufacturers • OAE is a relatively mature tool with the capability to accommodate different economizer strategies without reconfiguration; the WBD is considerably less mature	• It is not clear how faulty data is identified and removed during the training phase for the WBE; without such filtering, energy estimates would be influenced by faulty operation • Uses hourly averages; this makes it difficult to identify unstable control loops • Despite having addressed communication interface challenges, configuration time is significant • AEC's PIER Report P500-03-096-rev2-final.pdf, page 46 has some interesting conclusions: "The time and cost of diagnostic-tool installation is a significant component to implementing diagnostic technologies. Labor costs to set up tools like the WBD (~1 week) will likely exceed the purchase cost of commercialized software."
NIST/APAR and VPACC	• Uses commonly available sensors • Capable of identifying many common faults in HVAC equipment and controls • The underlying diagnostic inference engines are easy to understand, making technology transfer less challenging • Both tools have been embedded in products of at least one manufacturer (Automated Logic) and tied into the controller alarm function • Configuration time is reduced considerably if tools are embedded in control products	• Testing has been limited in terms of the number of installations and the number of system types considered • Thresholds are set using heuristics • APAR prototype user interface is less refined than that of PACRAT and the WBD; control companies that adopt all or parts of these tools would need to develop their own user interfaces
LBNL/Model-Based Approach	• Uses commonly available sensors • Capable of identifying many common faults in HVAC equipment and controls • Model-based approach allows degradation faults such as valve leakage and coil fouling to be identified at any time; approaches that do not use models can only detect these problems at specific operating conditions • Models are based on physical laws, therefore their parameters have physical meaning and the models are less susceptible to extrapolation problems associated with operation outside the operating conditions used to tune the models	• Testing has been limited in terms of the number of installations and the number of system types considered • Requires design data to "tune" the models – this data can be difficult to obtain or locate • Method is more sophisticated than most and, as such, development is somewhat slower and technology transfer will be more difficult
AEC/ENFORMA	• Stores raw data, plus performance metrics and diagnostic results in central database • Strong data filtering capabilities • Works with real-time data • Strong visualization tool	• Time-consuming configuration: requires specially formatted headers to specify data collection frequency and time range • Assumes sequential data; does not import timestamps • Requires data analysis by outside expert-primarily a visualization tool

Vendor/Tool	Advantages	Disadvantages
		• Not currently designed to connect directly to BAS • Short-term data collection
Cimetrics/Infometrics	• Capable of collecting data from a wide range of modern building automation systems • Has demonstrated ability to collect and transmit large number of trend logs in 15 minute intervals (and at higher frequency as necessary) without overloading communications network	• Only sold as a service • Monthly reporting rather than immediate, on-demand information access
Facility Dynamics/PACRAT	• Uses commonly available sensors • Well developed graphical interface that effectively conveys information to users • Capable of identifying many common faults in HVAC equipment and controls • Provides estimates of the energy cost associated with identified faults • Communication interfaces allow access to trend data from products of many manufacturers of building control systems • Relatively mature tool	• Relies on trend data collected by other systems • Despite communication interfaces, configuration time is significant • Uses only batch files, no real-time data capabilities
JCI/FPI	• In conjunction with JCI performance contract, uses maintenance management software to structure maintenance plans and optimize building systems • Performance guarantee ensures that work is performed per system information obtained	• Not in widespread use- no independent testing has been performed • Link with performance guarantee makes a “closed loop”; maintenance contractor performs diagnostics, no 3rd party validation
Field Diagnostic Services/Service Assistant™	• Can implement some pre-programmed “expert logic”, perform checks, alarm and sense faults • Combines handheld PDA and pressure/temperature gauges in a single tool to automate field data collection • Calculates “Efficiency Index” which includes projected savings and maintenance prioritization • Associated web-based reports available	• Not a proactive system degradation diagnostic tool • Controller-based • Must be used by technician on-site
Honeywell/Atrium	• As a suite of services, facilitates vendor tracking and evaluation • Honeywell Global Service Response Center handles alarm response and dispatch functions • User can remotely implement load shedding and demand limiting strategies through the Atrium web site	• Difficult configuration • Inability to connect to disparate systems
IDS/EW	• Integrates with FAMIS software and HEGIS systems • Immediately available information • Data representation and reporting interface clear and well automated • Collects a large amount of data • Organizes and archives data in a convenient visual format	• Requires on-site staff to perform skilled diagnosis and analysis • Significant configuration process • No capability for automatic fault recognition • Not yet finished (as of 3/06) • Requires a great deal of operator intervention to organize data

Building Automation System (BAS) Point Naming Convention Specification

Introduction

This specification describes a convention for the naming of Building Automation System (BAS) points to facilitate the mapping of those points to a remote system for automated analysis. The remote system is often described as a Networked Building System (NBS) and is referred to as such throughout the remainder of this document. It is assumed that the NBS will gather data via a BACnet interface to the BAS. As such, this specification is specific to native BACnet systems or other systems that expose their points via a BACnet gateway.

The naming convention was developed by Cimetrics Inc. (http://www.cimetrics.com/) and remains proprietary to that entity.

BAS Point Definition and NBS Point Mapping

Glossary

- *BAS Point Name*: The name assigned to a BAS point for workstation screen display, logging, use in calculations, etc. It is assumed that the BAS operator understands the meaning of the name.
- *NBS Point Name:* The name assigned to a BAS point for remote automated analysis. The meaning of the name is understood by the NBS.
- *BAS Point Definition:* The activity where the network address of a point is assigned a BAS point name.
- *NBS Point Mapping:* The activity where the network address of a point is assigned a NBS point name.

Key Points

- Ideally, the BAS point name and the NBS point name are identical. If they are identical, NBS point mapping is trivial and can be fully automated.
- BACnet implementations are not identical. Some manufacturers will not be able to support a BAS point name that follows the NBS point naming convention due to restrictions on name lengths, allowed characters, etc. Also, BAS operators may not consider NBS point names suitable for workstation screen display, logging, use in calculations, etc. Therefore, this convention applies to NBS point names and optionally applies to BAS point names.
- If a BAS point name does not match the convention for a NBS point name, the NBS point name must be contained in documentation for each BAS point. The BACnet definition of a point includes

documentation fields. The number and capacity of the fields depends on the implementation. If the BACnet documentation fields can contain the NBS point name, then the point will effectively have both a network visible BAS point name and a network visible NBS point name. If the BACnet documentation fields cannot contain the NBS point name, then separate documentation is required.

Without NBS point names, NBS point mapping reduces to a labor-intensive manual process. The high cost of this manual process is ultimately borne by the Building Owner. Therefore, it is the intent of this specification that all points are provided with NBS point names in accordance with the convention described herein. In those cases where the BACnet definition of the point cannot contain the NBS point name, the contractor shall provide a point mapping table (see the table titled “Columns Contained in Point Mapping Table”) which includes the names and addresses of the BAS points mapped to NBS point names based on this specification.

Point and Device Naming

All BACnet objects include a mandatory object name, and most objects include an optional description text string. The BACnet Device object includes an optional description text string and an optional location text string. When available, these text strings shall be used by the controls contractor to contain the NBS point name.

If the BACnet properties are not available or they cannot contain the required information due to field size limitations or other constraints, then a point-mapping table shall be submitted by the contractor. The point-mapping table shall include both the full BACnet address (i.e., Device Name, Object Type and Object Instance) of the point and the complete NBS point name based on the convention. The point mapping table shall also include any additional point specific information that is available electronically from the contractor’s system, such as the BAS point name, engineering units, location of point within the building, identification tags that correspond to notations on the submittal or mechanical drawings, etc.

The initial mapping table shall be submitted for approval. After the initial mapping table is approved, it shall be updated and submitted on a weekly basis throughout the commissioning process. The ongoing submittal will be for information only and will not be returned unless exceptions are noted. If exceptions are noted, the mapping table will be returned to the contractor for revision and resubmission. Upon completion of the project, the final mapping table shall be submitted for approval.

The controls contractor shall assign the correct BACnetEngineeringUnits to the “Units” property of each BACnet object. It is extremely important that the correct units be supplied. Take pressure measurements for example: Pressure in HVAC systems is often measured in inches of water, feet of water, pounds per square inch or inches of mercury. Also, pressure can be measured as absolute¸ gauge, or differential. The BACnetEngineeringUnits for tons of refrigeration is “tons-refrigeration”. If, for any reason, BACnetEngineeringUnits cannot be assigned to the "Units" property of a BACnet object, they shall be included in a mapping table.

Point Naming Convention

In an effort to provide a great deal of flexibility, the point naming convention is not rigid or deterministic. Different people will arrive at different names for a given point depending upon whether a location or an equipment-based view dominates the naming process. As a result, the completed list of point names will require automation assisted analysis and possible modification prior to insertion into the NBS.

The complete NBS point name is assembled using predefined reserved words and indices. A predefined reserved word shall be used if an appropriate one is available. The contractor shall add a reserved word if an appropriate predefined reserved word is not available. A list of predefined reserved words can be found at the end of this specification. The controls contractor shall submit a complete description of any reserved words that are added.

Point Naming Convention Details and Examples

Example #1:

Point Description: A point name is required for the Chilled Water Supply Temperature (CHWST) of Chiller 1 at the Whitehouse.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	WHITEHOUSE
CHLR_C_WC	1

The indexes were created based on the point description.

POINT NAME	POINT INDEX
CHWST	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-WHITEHOUSE/PLANT/CHLR_C_WC-1/CHWST

Note that the type index WHITEHOUSE is separated from the type name BLDG by a hyphen. Again note that type index 1 is separated from type name CHLR_C_WC (water cooled centrifugal chiller) by a hyphen. Note that point name CHWST does not have an index, as there is only one CHWST sensor. Note that one name-index pair is separated from the next element of the complete name by a forward slash. PLANT is the category name. Note that a complete point name includes one or more type names (each with an optional index) plus a point name plus an optional index. Exception: A category name appears after the first type name and type index pair.

Example #2:

Point Description: A point name is required for the cooling coil discharge air temperature of Air Handling Unit 1 (AHU_CHW, chilled water type) at the Whitehouse.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	WHITEHOUSE
AHU_CHW	1
SA	(NONE)
CC_CHW	(NONE)

The indexes were created based on the point description.

POINT NAME	POINT INDEX
DAT	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-WHITEHOUSE/AIR_DIST/AHU_CHW-1/SA/CC_CHW/DAT

Note the inclusion of type name SA in the point name. It indicates that the cooling coil (CC_CHW, chilled water type) is located in the supply air stream. This naming level is necessary, because some air-handling units have multiple supply air streams (i.e., SA-1, SA-2, etc.) Note that an index is not necessary in this case because there is only one supply air stream. AIR_DIST is the category name.

Example #3:

Point Description: A point name is required for the power consumption rate measured by Electric Meter 1 (METER_E) at the Whitehouse.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	WHITEHOUSE
ELEC	(NONE)
METER_E	MAIN

The indexes were created based on the point description.

POINT NAME	POINT INDEX
PWR_ELEC	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-WHITEHOUSE/UTILS/ELEC/METER_E-MAIN/PWR_ELEC

UTILS is the category name.

Example #4:

Point Description: A point name is required for the 3rd room temperature (zone temperature) sensor in the Science Center's lecture hall (located on the second floor, FL-2).

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	SCIENCE_CENTER
FL	2
Z	LECTURE_HALL

The indexes were created based on the point description.

POINT NAME	POINT INDEX
Z_T	3

Below is the complete NBS point name assembled from the above elements:

BLDG-SCIENCE_CENTER/SPACES/FL-2/Z-LECTURE_HALL/Z_T-3

Note that unlike the previous examples, there is a point index (i.e., 3). This is required because there are several room temperature sensors in the lecture hall. SPACES is the category name.

Example #5:

Point Description: A point name is required for the room temperature in Dorm A, Room 22.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	DORM_A
FL	2
ROOM	22

The indexes were created based on the point description.

POINT NAME	POINT INDEX
Z_T	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-DORM_A/SPACES/FL-2/Z-22/Z_T

Example #6:

Point Description: A point name is required for the main chilled water supply flow rate in FAB A.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	FAB_A
CHW	SUPPLY_MAIN

The indexes were created based on the point description.

POINT NAME	POINT INDEX
CHWF	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-FAB_A/PLANT/CHW-SUPPLY_MAIN/CHWF

Example #7:

Point Description: A point name is required for the control signal to the cooling tower's three-way bypass valve in FAB A.

The names in the below tables were selected from the list of predefined reserved words.

TYPE NAME	TYPE INDEX
BLDG	FAB_A
CW	CT_BYPASS
CV_M	(NONE)

The indexes were created based on the point description.

POINT NAME	POINT INDEX
SIG	(NONE)

Below is the complete NBS point name assembled from the above elements:

BLDG-FAB_A/PLANT/CW-CT_BYPASS/CV_M/SIG

Point Name Pattern

From the above examples it can be seen that points have been named in accordance with the following pattern:

“BLDG” + ‘-‘ + building_index + ‘/’ + category + ‘/’ + type_name + ‘-‘ + optional_type_index + ‘/’ + point_name + ‘-‘ + optional_point_index

Note, as stated previously, a complete point name includes one or more type names (each with an optional index) plus a point name plus an optional index. Exception: A category name appears after the first type name and type index pair (which is constrained to “BLDG” + ‘-‘ + building_index). The category name is limited to one of the following:

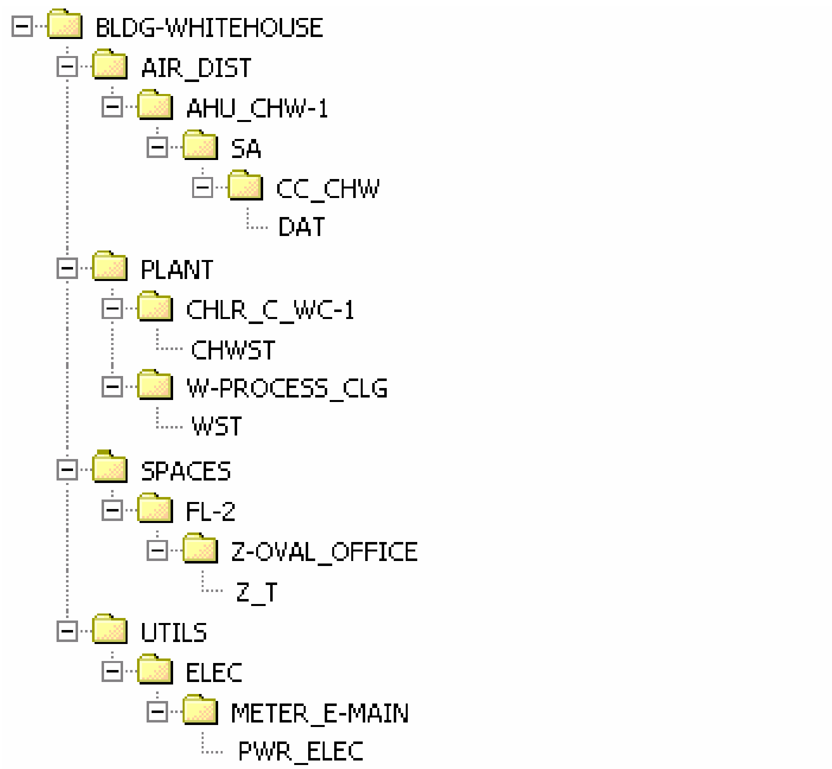
- AIR_DIST
- PLANT
- PROCESS
- SPACES
- UTILS

Indexes may be text, numeric or alpha numeric. Indexes may begin with integers; type names and point names shall not. Type names, point names and indexes shall include underscores instead of spaces.

Indexes may use lower or mixed case for appearance, but they will typically be converted to upper case upon insertion into the NBS. (i.e., upon insertion into the NBS, an index with lower or mixed case will be identical to an index that is all uppercase)

Point Name Tree

It may be helpful to think of the building's points residing on a tree as in the below example:



The tree illustrates an includes/has-a relationship. For example, the building (BLDG-WHITEHOUSE) has an air distribution system (AIR_DIST) which includes chilled water air handling unit one (AHU_CHW-1) which has a supply air stream (SA) which has a cooling coil (CC_CHW) which has a downstream air temperature sensor (DAT).

Points should be named so as to retain relationship information.

BLDG-WHITEHOUSE HAS AN AIR_DIST
AIR_DIST INCLUDES AHU_CHW-1
AHU_CHW-1 HAS A SA
SA HAS A CC_CHW
CC_CHW HAS A DAT

Hence the name: BLDG-WHITEHOUSE/AIR_DIST/AHU_CHW-1/SA/CC_CHW/DAT

BLDG-WHITEHOUSE HAS A PLANT
PLANT HAS A CHLR_C_WC-1
CHLR_C_WC-1 HAS A CHWST

Hence the name: BLDG-WHITEHOUSE/PLANT/CHLR_C_WC-1/CHWST

BLDG-WHITEHOUSE HAS A PLANT
PLANT HAS A W-PROCESS_CLG
W-PROCESS_CLG HAS A WST

Hence the name: BLDG-WHITEHOUSE/PLANT/W-PROCESS_CLG/WST

BLDG-WHITEHOUSE HAS SPACES
SPACES HAS FL-2
FL-2 HAS A Z-OVAL_OFFICE
Z-OVAL_OFFICE HAS A Z_T

Hence the name: BLDG-WHITEHOUSE/SPACES/FL-2/Z-OVAL_OFFICE/Z_T

BLDG-WHITEHOUSE HAS UTILS
UTILS HAS ELEC
ELEC HAS METER_E-MAIN
METER_E_MAIN HAS PWR_ELEC

Hence the name: BLDG-WHITEHOUSE/UTILS/ELEC/METER_E-MAIN/PWR_ELEC

Notes:

- Air distribution systems have air handling units, but zones have terminal units.
- Air handling units serve zones, but zones have room temperature sensors.

Standard Types

Name	Description
AHU_CHW	Air Handling Unit - Typical Chilled Water
AHU_DX	Air Handling Unit - Typical Direct Expansion
AHU_GENERAL	Air Handling Unit - Arbitrary Design
AHU_HP	Air Handling Unit - Typical Heat Pump, Air Source
AHU_HP_WS	Air Handling Unit - Typical Heat Pump, Water Source
BBH_E	Baseboard - Electric Heat
BBH_HW	Baseboard - Hot Water Heat
BBH_STM	Baseboard - Steam Heat
BLDG	Building
BOILER_HW	Water Boiler
BOILER_STM	Steam Boiler
CAV	Constant Air Volume Terminal Unit
CAV_DD	Constant Air Volume Terminal Unit - Dual Duct
CAV_E	Constant Air Volume Terminal Unit - Electric Heat
CAV_HW	Constant Air Volume Terminal Unit - Hot Water Heat
CC_CHW	Cooling Coil - Chilled Water
CC_DX	Cooling Coil - Refrigerant (i.e., Direct Expansion)
CF	Condenser Fan
CHLR_C_AC	Air Cooled Centrifugal Chiller
CHLR_C_WC	Water Cooled Centrifugal Chiller
CHLR_GA_WC	Water Cooled Gas Fired Absorption Chiller
CHLR_H_WC	Water Cooled Helical Chiller
CHLR_R_AC	Air Cooled Reciprocating Chiller
CHLR_R_WC	Water Cooled Reciprocating Chiller
CHLR_SA_WC	Water Cooled Steam Absorption Chiller
CHP_GEN	Combined Heat and Power Generator
CHW	Chilled Water Circuit
CMP	Compressor
CR	Condensate Return Circuit
CRACU	Computer Room Air Conditioning Unit
CRS	Condensate Return Set
CT	Cooling Tower
CV_B	Control Valve Binary
CV_M	Control Valve Modulating
CW	Condenser Water Circuit
DEAERATOR	Deaerator
DIESEL_GEN	Diesel Generator

DMPR_B	Damper Binary
DMPR_M	Damper Modulating
EA	Exhaust Air Stream
ECON_CTRL	Airside Economizer Control
ELEC	Electricity Supply
F	Air Fan (constant speed, no flow modulation)
F_IGV	Air Fan Inlet Guide Vanes
F_V	Air Fan Variable Speed Drive
FCU_CHW	Fan Coil Unit - Chilled Water
FCU_HW	Fan Coil Unit - Hot Water Heat
FL	Floor
FP_VAV	Fan Powered Terminal Unit
FP_VAV_E	Fan Powered Terminal Unit - Electric Heat
FP_VAV_HW	Fan Powered Terminal Unit - Hot Water Heat
FUEL_CELL	Fuel Cell
FUME	Fume Hood
GAS	Gas Supply
GT_GEN	Gas Turbine Generator
HC_FB	Heating Coil - Face and Bypass
HC_E	Heating Coil - Electric
HC_G	Heating Coil - Gas
HC_HW	Heating Coil - Hot Water
HC_STM	Heating Coil - Steam
HEAT_PIPE	Heat Pipe
HEAT_RECOV	Heat Recovery
HEAT_WHEEL	Heat Wheel
HPS	High Pressure Steam Circuit
HUM_E	Duct Humidifier - Electric
HUM_STM	Duct Humidifier - Steam
HW	Hot Water Circuit
HX_PF	Plate and Frame Heat Exchanger
HX_ST	Shell and Tube Heat Exchanger
HYD_DC	Hydronic Decoupler
LIGHT	Lighting Controller
LOAD_SHED	Load Shed Controller
LPS	Low Pressure Steam Circuit
LRC	Laboratory Room Controller
LSP	Life Safety Point
LSZ	Life Safety Zone
METER_E	Electric Meter
METER_G	Gas Meter
METER_OIL	Oil Meter
METER_STM	Steam Meter
METER_W	Water Meter
MUA	Makeup Air Stream
OA	Outdoor Air Stream
OCC	Occupancy Sensor

OIL	Oil Supply
P	Water Pump (constant speed, no flow modulation)
P_FUEL	Fuel Pump
P_FW	Feed Water Pump
P_V	Water Pump Variable Speed Drive
PCW	Process Cooling Water Circuit
PG	Process Gas Circuit
RA	Return Air Stream
ROOM_DHUM	Room Dehumidifier
ROOM_DX	Room Direct Expansion Unit
ROOM_EF	Room Exhaust Fan
ROOM_EF_V	Room Exhaust Fan Variable Speed
ROOM_HC_HW	Room Heating Coil - Hot Water Heat
ROOM_HP	Room Heat Pump
ROOM_HUM	Room Humidifier
RP	Radiant Panel
SA	Supply Air Stream
STM	Steam Circuit
UH	Unit Heater
UPS	Uninterruptible Power Supply
UV_HW	Unit Ventilator - Hot Water Heat
UV_STM	Unit Ventilator - Steam Heat
VAV	Variable Air Volume Terminal Unit
VAV_DD	Variable Air Volume Terminal Unit - Dual Duct
VAV_E	Variable Air Volume Terminal Unit - Electric Heat
VAV_HW	Variable Air Volume Terminal Unit - Hot Water Heat
W	Water Circuit
Z	Zone

Standard Points

Name	Description
ADF	Air Differential Flow
ADF_SP	Air Differential Flow Setpoint
ADP	Air Differential Pressure
ADP_TOTAL_DESIGN	Air Differential Pressure Total Design
ALM	Alarm
ALM_INFO	Alarm Information
ALM_REFRIGERANT	Alarm Refrigerant
AUT_RESET_ALM	Auto Reset Alarm
BASIN_LEVEL_HL_ALM	Basin Level High Limit Alarm
BASIN_LEVEL_LL_ALM	Basin Level Low Limit Alarm
BASIN_T	Basin Temperature
BASIN_T_FREEZE_SP	Basin Temperature Freeze Setpoint
BHP_MAX_DESIGN	Brake Horsepower Maximum Design
BST	Boiler Stack Temperature
CHLR_DEMAND_HL	Chiller Demand High Limit
CHLR_STAT	Chiller Global Status
CHWDP	Chilled Water System Differential Pressure
CHWDP_DESIGN	Chilled Water System Differential Pressure Design
CHWDP_SP	Chilled Water System Differential Pressure Setpoint
CHWDT	Chilled Water Differential Temperature
CHWDT_DESIGN	Chilled Water Differential Temperature Design
CHWDT_SP	Chilled Water Differential Temperature Setpoint
CHWF	Chilled Water Flow Rate
CHWF_DESIGN	Chilled Water Flow Rate Design
CHWF_STAT	Chilled Water Flow Status
CHWRP	Chilled Water Return Pressure
CHWRT	Chilled Water Return Temperature
CHWRT_DESIGN	Chilled Water Return Temperature Design
CHWRT_SP	Chilled Water Return Temperature Setpoint
CHWSP	Chilled Water Supply Pressure
CHWST	Chilled Water Supply Temperature
CHWST_DESIGN	Chilled Water Supply Temperature Design
CHWST_HL	Chilled Water Supply Temperature High Limit
CHWST_HL_ALM	Chilled Water Supply Temperature High Limit Alarm

CHWST_LL	Chilled Water Supply Temperature Low Limit
CHWST_LL_ALM	Chilled Water Supply Temperature Low Limit Alarm
CHWST_SP	Chilled Water Supply Temperature Setpoint
CLG_ENABLE	Cooling Enable
CLG_LOCKOUT_OAT_SP	Cooling Lockout Temperature Setpoint based on Outside Air Temperature
CLG_INPUT	Cooling Input
CLG_MODE	Cooling Mode
CLG_OUTPUT	Cooling Output
CLG_OUTPUT_DESIGN	Cooling Output Design
CLG_OUTPUT_DESIGN_KBTUH	Cooling Output Design kBTUh
CLG_OUTPUT_NOMINAL	Nominal Cooling Output
CLG_OUTPUT_SENSIBLE_DESIGN	Sensible Cooling Output Design
CMD	Command
CO2	CO2 Level
CO2_ALM	CO2 Alarm
CO2_HL_ALM	CO2 High Limit Alarm
CO2_LL_ALM	CO2 Low Limit Alarm
CO2_MAX_SP	CO2 Level Maximum Setpoint
CO2_MIN_SP	CO2 Level Minimum Setpoint
COMP_BEARING_T	Compressor Bearing Temperature
COMP_CUR_DRAW_PH	Compressor Current Draw by Phase
COMP_DISCH_REFRIG_T	Compressor Discharge Refrigerant Temperature
COMP_FREQUENCY	Compressor Frequency
COMP_PF	Compressor Power Factor
COMP_RUN_TIME	Compressor Run-Time
COMP_SPEED	Compressor Speed
COMP_STARTS	Compressor Number of Starts
COMP_VOLTAGE_PH	Compressor Voltage by Phase
COMP_WIND_T	Compressor Winding Temperature
COND_APPROACH_T	Condenser Approach Temperature
COND_DP	Condenser Water Side Differential Pressure
COND_REFRIG_P	Condenser Refrigerant Pressure
COND_REFRIG_P_HL	Condenser Refrigerant Pressure High Limit
COND_REFRIG_P_HL_ALM	Condenser Refrigerant Pressure High Limit Alarm
COND_REFRIG_T	Condenser Refrigerant Temperature
CONDUCTIVITY	Electrical Conductivity
CUR_DRAW	Current Draw
CURRENT	Current
CURRENT_ACTIVE_MIN	Current Activity Minimum
CWF	Condenser Water Flow Rate

CWF_DESIGN	Condenser Water Flow Rate Design
CWRP	Condenser Water Return Pressure
CWRT	Condenser Water Return Temperature
CWRT_DESIGN	Condenser Water Return Temperature Design
CWRT_SP	Condenser Water Return Temperature Setpoint
CWSP	Condenser Water Supply Pressure
CWST	Condenser Water Supply Temperature (temperature downstream of cooling tower)
CWST_DESIGN	Condenser Water Supply Temperature Design
CWST_SP	Condenser Water Supply Temperature Setpoint
DADP	Discharge Air Dewpoint Temperature
DADP_SP	Discharge Air Dewpoint Temperature Setpoint
DAF	Discharge Air Flow Rate
DAF_CLG_DESIGN	Discharge Air Flow Rate for Cooling Design
DAF_DESIGN	Discharge Air Flow Rate Design
DAF_HCFM	Discharge Air Flow Rate / 100
DAF_HL_DESIGN	Discharge Air Flow High Limit Design
DAF_HTG_DESIGN	Discharge Air Flow Rate for Heating Design
DAF_KCFM	Discharge Air Flow Rate / 1000
DAF_LL_DESIGN	Discharge Air Flow Low Limit Design
DAF_MAX	Discharge Air Flow Rate Maximum
DAF_MAX_CLG	Discharge Air Flow Rate Maximum for Cooling
DAF_MAX_CLG_DESIGN	Discharge Air Flow Rate Maximum for Cooling Design
DAF_MAX_CLG_OCC	Discharge Air Flow Rate Maximum for Cooling Occupied
DAF_MAX_CLG_UNOCC	Discharge Air Flow Rate Maximum for Cooling Unoccupied
DAF_MAX_DESIGN	Discharge Air Flow Rate Maximum Design
DAF_MAX_HTG	Discharge Air Flow Rate Maximum for Heating
DAF_MAX_HTG_DESIGN	Discharge Air Flow Rate Maximum for Heating Design
DAF_MAX_HTG_OCC	Discharge Air Flow Rate Maximum for Heating Occupied
DAF_MAX_HTG_UNOCC	Discharge Air Flow Rate Maximum for Heating Unoccupied

DAF_MIN	Discharge Air Flow Rate Minimum
DAF_MIN_CLG	Discharge Air Flow Rate Minimum for Cooling
DAF_MIN_CLG_DESIGN	Discharge Air Flow Rate Minimum for Cooling Design
DAF_MIN_DESIGN	Discharge Air Flow Rate Minimum Design
DAF_MIN_HTG	Discharge Air Flow Rate Minimum for Heating
DAF_MIN_HTG_DESIGN	Discharge Air Flow Rate Minimum for Heating Design
DAF_OCC	Discharge Air Flow Rate Occupied
DAF_PCT	Discharge Air Flow Rate Percent
DAF_SP	Discharge Air Flow Rate Setpoint
DAF_SP_OCC	Discharge Air Flow Rate Setpoint Occupied
DAF_SP_PCT	Discharge Air Flow Rate Setpoint Percent
DAF_SP_UNOCC	Discharge Air Flow Rate Setpoint Unoccupied
DAF_TOT	Total Discharge Air Flow
DAF_TOT_KCF	Total Discharge Air Flow / 1000
DAF_UNOCC	Discharge Air Flow Rate Unoccupied
DAH	Discharge Air Enthalpy
DAP	Discharge Air Static Pressure
DAP_SP	Discharge Air Static Pressure Setpoint
DAP_SP_EXTERNAL_DESIGN	Discharge Air Static Pressure Setpoint Design
DAP_VELOCITY	Discharge Air Velocity Pressure
DARH	Discharge Air Relative Humidity
DARH_SP	Discharge Air Relative Humidity Setpoint
DAT	Discharge Air Temperature
DAT_C	Discharge Air Temperature Celsius
DAT_DESIGN	Discharge Air Temperature Design
DAT_FREEZE_LL	Discharge Air Temperature Freeze Protection Low Limit
DAT_HL	Discharge Air Temperature High Limit
DAT_LL	Discharge Air Temperature Low Limit
DAT_HL_ALM	Discharge Air Temperature Low Limit Alarm
DAT_LL_ALM	Discharge Air Temperature Low Limit Alarm
DAT_SP	Discharge Air Temperature Setpoint
DAT_SP_CLG	Discharge Air Temperature Cooling Setpoint

DAT_SP_CLG_OCC	Discharge Air Temperature Cooling Setpoint Occupied
DAT_SP_CLG_UNOCC	Discharge Air Temperature Cooling Setpoint Unoccupied
DAT_SP_HTG	Discharge Air Temperature Heating Setpoint
DAT_SP_HTG_OCC	Discharge Air Temperature Heating Setpoint Occupied
DAT_SP_HTG_UNOCC	Discharge Air Temperature Heating Setpoint Unoccupied
DAWB	Discharge Air Wet-Bulb Temperature
DAY_MODE	Day Mode
DEMAND	Demand
DEMAND_UTIL	Utility Energy Demand
DP	Differential Pressure
DP_SP	Differential Pressure Setpoint
DUCT_AREA	Duct Area
DWDP	Domestic (House) Water Differential Pressure
DWDP_SP	Domestic (House) Water Differential Pressure Setpoint
DWST	Domestic (House) Water Supply Temperature
EAF	Exhaust Air Flow Rate
EAT	Exhaust Air Temperature
ECON_CUTOVER_OAH_SP	Economizer Cutover OA Enthalpy Setpoint
ECON_CUTOVER_OAT_SP	Economizer Cutover OA Temperature Setpoint
ENABLE	Enable
ENABLE_CLG_OAT_SP	Enable Cooling OA Temperature Setpoint
ENABLE_HTG_OAT_SP	Enable Heating OA Temperature Setpoint
ENABLED	Control Enabled
ENERGY_AVG_COST	Energy Average Cost
ENERGY_ELEC	Power Consumption
ENERGY_ELEC_MWH	Power Consumption Megawatt Hours
ENERGY_UTIL	Utility Energy Consumption
EVAP_APPROACH_T	Evaporator Approach Temperature
EVAP_DP	Evaporator Water Side Differential Pressure
EVAP_REFRIG_P	Evaporator Refrigerant Pressure
EVAP_REFRIG_T	Evaporator Refrigerant Temperature
FACE_AREA	Face Area
FACE_VELOCITY	Face Velocity
FILTER_ADP	Filter Air Differential Pressure

FILTER_ADP_ALM	Filter Air Differential Pressure Alarm
FILTER_ADP_HL	Filter Air Differential Pressure High Limit
FILTER_WDP	Filter Water Differential Pressure
FILTER_WDP_ALM	Filter Water Differential Pressure Alarm
FILTER_WDP_HL	Filter Water Differential Pressure High Limit
FWT	Feed Water Temperature
G_F	Gas Flow
G_F_CCFH	Gas Flow CCFH
G_F_TOT	Gas Flow Total
G_F_TOT_CCF	Gas Flow Total CCF
G_P	Gas Pressure
G_P_DESIGN	Gas Pressure Design
HTG_CMD	Heating Command
HTG_ENABLE	Heating Enable
HTG_LOCKOUT_OAT_SP	Heating Lockout Temperature Setpoint based on Outside Air Temperature
HTG_INPUT	Heating Input
HTG_MODE	Heating Mode
HTG_OUTPUT	Heating Output
HTG_OUTPUT_DESIGN	Heating Output Design
HTG_OUTPUT_DESIGN_KBTUH	Heating Output Design/1000
HTG_OUTPUT_DESIGN_KW	Heating Output Design in kW
HTG_OUTPUT_KBTUH	Heating Output/1000
HTG_OUTPUT_PCT_NOMINAL	Heating Output Percent
HWDP	Hot Water Differential Pressure
HWDP_SP	Hot Water Differential Pressure Setpoint
HWF	Hot Water Flow Rate
HWF_DESIGN	Hot Water Flow Rate Design
HWF_STAT	Hot Water Flow Status
HWRT	Hot Water Return Temperature
HWRT_DESIGN	Hot Water Return Temperature Design
HWRT_SP	Hot Water Return Temperature Setpoint
HWST	Hot Water Supply Temperature
HWST_DESIGN	Hot Water Supply Temperature Design
HWST_SP	Hot Water Supply Temperature Setpoint
HX_CS_F	Heat Exchanger Cold Side Flow Rate
HX_CS_IN_T	Heat Exchanger Cold Side Inlet Temperature
HX_CS_OUT_T	Heat Exchanger Cold Side Outlet Temperature

HX_HS_F	Heat Exchanger Hot Side Flow Rate
HX_HS_IN_T	Heat Exchanger Hot Side Inlet Temperature
HX_HS_OUT_T	Heat Exchanger Hot Side Outlet Temperature
IADP	Inlet Air Dewpoint Temperature
IAH	Inlet Air Enthalpy
IARH	Inlet Air Relative Humidity
IAT	Inlet Air Temperature
IAWB	Inlet Air Wet-Bulb Temperature
IN_HAND	In Hand
INPUT_0_10V	Input 0-10V
INPUT_1_5V	Input 1-5V
INPUT_2_10V	Input 2-10V
INPUT_4_20MA	Input 4-20 mA
LOAD_FACTOR_EST	Estimated Load Factor
MAF	Mixed Air Flow Rate
MAN_RESET_ALM	Manual Reset Alarm
MAT	Mixed Air Temperature
MAT_LL	Mixed Air Temperature Low Limit
MAT_LL_ALM	Mixed Air Temperature Low Limit Alarm
MAT_SP	Mixed Air Temperature Setpoint
MODE	Mode
NAMEPLATE_HP	Nameplate Horsepower
OA_FRAC	Outdoor Air Fraction
OA_FRAC_MIN_DESIGN	Outdoor Air Fraction Design Minimum
OADP	Outdoor Air Dewpoint Temperature
OAF	Outdoor Air Flow Rate
OAF_MIN_DESIGN	Outdoor Air Flow Rate Design Minimum
OAH	Outdoor Air Enthalpy
OARH	Outdoor Air Relative Humidity
OAT	Outdoor Air Temperature
OAT_C	Outdoor Air Temperature Celsius
OAWB	Outdoor Air Wetbulb Temperature
OAWB_DESIGN	Outdoor Air Wetbulb Design Temperature
OCC	Occupancy Status
OIL_DP	Oil Differential Pressure
OIL_DP_HL	Oil Differential Pressure High Limit
OIL_DP_HL_ALM	Oil Differential Pressure High Limit Alarm
OIL_DP_LL	Oil Differential Pressure Low Limit
OIL_DP_LL_ALM	Oil Differential Pressure Low Limit Alarm

OIL_F	Oil Flow
OIL_F_TOT	Oil Flow Total
OIL_P	Oil Differential Pressure
OIL_P_HL	Oil Pressure High Limit
OIL_P_HL_ALM	Oil Pressure High Limit Alarm
OIL_P_LL	Oil Pressure Low Limit
OIL_P_LL_ALM	Oil Pressure Low Limit Alarm
OIL_T	Oil Temperature
OIL_TYPE	Oil Type (#2, #4, #6)
OUTPUT_0_10V	Output 0-10V
OUTPUT_1_5V	Output 1-5V
OUTPUT_2_10V	Output 2-10V
OUTPUT_4_20MA	Output 4-20mA
PCT_RL_CUR_DRAW	Percent of Run Load Current Draw
POS	Actuator Position Percent
POS_ACTIVE_MIN	Actuator Position Activity Minimum
POS_FRAC	Actuator Position Fraction
POS_SP	Actuator Position Setpoint
PUMP_DISCH_P	Pump Discharge Pressure
PUMP_DP	Pump Differential Pressure
PUMP_INLET_P	Pump Inlet Pressure
PURGE_30DAYOFF	Purge 30 Day Off
PURGE_30DAYON	Purge 30 Day On
PURGE_RT	Purge Run-Time
PURGE_STAT	Purge Status
PURGE_SUC_T	Purge Suction Temperature
PWR_ELEC	True Power
PWR_ELEC_APPARENT	Apparent Power
PWR_ELEC_MW	True Power Megawatts
PWR_ELEC_NOMINAL	Nominal Power Input
PWR_ELEC_PER_CLG_OUTPUT	Power (input) Per Unit of Cooling
PWR_ELEC_PER_CLG_OUTPUT_DESIGN	Power (input) Per Unit of Cooling Design
PWR_FACTOR	Power Factor
PWR_FACTOR_EST	Estimated Power Factor
RADP	Return Air Dewpoint Temperature
RAF	Return Air Flow Rate
RAF_MAX_DESIGN	Return Air Flow Rate Maximum Design
RAF_KCFM	Return Air Flow Rate / 1000
RAF_SP	Return Air Flow Rate Setpoint
RAH	Return Air Enthalpy
RARH	Return Air Relative Humidity
RARH_SP	Return Air Relative Humidity Setpoint
RAT	Return Air Temperature
RAT_SP	Return Air Temperature Setpoint
RAT_SP_CLG	Return Air Temperature Setpoint Cooling

RAT_SP_HTG	Return Air Temperature Setpoint Heating
RAWB	Return Air Wetbulb Temperature
REFRIG_CON	Refrigerant Condition
REQUIRED_SCHEDULE	Required Schedule
RUNTIME	Run Time
SCHEDULE	Schedule
SETTLED	Control Settled
SETTLING_TIME	Settling Time
SIG	Actuator Signal Percent
SIG_0_10V	Sig 0-10V
SIG_1_5V	Sig 1-5V
SIG_2_10V	Sig 2-10V
SIG_4_20MA	Sig 4-20mA
SIG_FRAC	Actuator Signal Fraction
SIG_HZ	Frequency (Output) Signal Hertz
SIG_HZ_HL	Signal Hertz High Limit
SIG_MIN_OA_SP	Signal Minimum OA Setpoint
SIG_MIN_OA_SP_P	Signal Minimum OA Setpoint Pressure
SIG_P	Signal Pressure
SIG_P_HL	Signal Pressure High Limit
SIG_P_LL	Signal Pressure Low Limit
SINGLE_ZONE	Single Zone
SMOKE_ALM	Smoke Alarm
SMOKE_CTRL_MODE	Smoke Control Mode
SPACES_SERVED	Spaces Served
SPEED_DESIGN_RPM	Speed Design RPM
SPEED	Speed Percent
SPEED_ACTIVE_MIN	Speed Percent Activity Minimum
SPEED_HZ	Speed Hertz
SPEED_HZ_HL	Speed Hertz High Limit
SPEED_MULTI	Speed Selection of Multiple Speed Motor
SPEED_RPM	Speed RPM
SPEED_RPM_HL	Speed RPM High Limit
STAGE	Stage
STAGES	Stages
STAT	Status
STM_F	Steam Flow Rate
STM_F_DESIGN	Steam Flow Rate Design
STM_F_DESIGN_KPPH	Steam Flow Rate Design kpph
STM_F_KPPH	Steam Flow Rate kpph
STM_F_TOT	Steam Flow Total
STM_F_TOT_KLBS	Steam Flow Total k lbs
STM_P	Steam Pressure
STM_P_DESIGN	Steam Pressure Design
STM_P_SP	Steam Pressure Setpoint
STM_T	Steam Temperature

SUPPLY_STREAM	Supply Stream
SUPPLY_VOLTAGE	Supply Voltage
T_RISE_DESIGN	Design Temperature Rise
VANE_POS	Vane Position
VANE_POS_SP	Vane Position Setpoint
VAV_P	VAV System Downstream Static Pressure
VAV_P_SP	VAV System Downstream Static Pressure Setpoint
VFD_T	Variable Frequency Drive Temperature
VOLTAGE	Voltage
VOLTAGE_DESIGN	Voltage Design
WDP	Water Differential Pressure
WDP_DESIGN	Water Differential Pressure Design
WDP_DESIGN_FT	Water Differential Pressure Design Feet
WDP_SP	Water Differential Pressure Setpoint
WF	Water Flow Rate
WF_MAX_DESIGN	Water Flow Rate Maximum Design
WF_TOT	Total Water Flow
WRT	Water Return Temperature
WST	Water Supply Temperature
X_A	Value Analog
X_B	Value Binary
X_S	Value State or Mode
Z_DP	Zone Dewpoint Temperature
Z_DP_SP	Zone Dewpoint Temperature Setpoint
Z_H	Zone Enthalpy
Z_RH	Zone Relative Humidity
Z_RH_SP	Zone Relative Humidity Setpoint
Z_T	Zone Temperature
Z_T_CI_DT	Application Parameter - Zone Temperature Comfort Index Scale
Z_T_CI_HL	Application Parameter - Zone Temperature Comfort Index High Limit
Z_T_CI_LL	Application Parameter - Zone Temperature Comfort Index Low Limit
Z_T_SP	Zone Temperature Setpoint
Z_T_SP_CLG	Zone Temperature Setpoint Cooling
Z_T_SP_CLG_DAY	Zone Temperature Setpoint Cooling Day
Z_T_SP_CLG_NGT	Zone Temperature Setpoint Cooling Night
Z_T_SP_CLG_OCC	Zone Temperature Setpoint Cooling Occupied

Z_T_SP_CLG_UNOCC	Zone Temperature Setpoint Cooling Unoccupied
Z_T_SP_HTG	Zone Temperature Setpoint Heating
Z_T_SP_HTG_DAY	Zone Temperature Setpoint Heating Day
Z_T_SP_HTG_NGT	Zone Temperature Setpoint Heating Night
Z_T_SP_HTG_OCC	Zone Temperature Setpoint Heating Occupied
Z_T_SP_HTG_UNOCC	Zone Temperature Setpoint Heating Unoccupied
Z_T_SP_MAX	Zone Temperature Setpoint Maximum
Z_T_SP_MIN	Zone Temperature Setpoint Minimum
Z_WB	Zone Wetbulb Temperature

Columns Contained in Point Mapping Table[1]	
Column Name	**Example Data**
Units (per ASHRAE Standard 135)*	degrees-Fahrenheit
Device Name*	
Device Instance Number	17
Object Name	Room22Temp
Object Type*	analog-input
Object Instance Number*	6
Description**	BLDG-SCIENCE CENTER.SPACES.ROOM-22.ROOM_TEMP
Property Identifier (if not "present-value")*	
Reference Drawing Tag	Dwg-073
Point Tag on Reference Drawing	6
Point Name Based On Convention*	BLDG-SCIENCE CENTER/SPACES/FL-2/Z-22/Z_T
Comment	

*Required columns

**If the BACnet object description field contains the point name based on the convention, then the point mapping may be discovered electronically.

[1]Microsoft Excel document