

A Utility-Sponsored Incentive Program for Monitoring-Based Commissioning of Existing Buildings Using FDD Toolsets

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Synopsis

There is general consensus that retro-commissioning offers significant potential for cost-effective optimization of HVAC systems. While energy-focused retro-commissioning programs have produced significant savings, results from a recent industry study suggest that savings may degrade within a few years.

Enovity's Monitoring-Based Persistence Commissioning (MBPCx) Program for existing buildings is a utility-sponsored program targeting energy efficiency measures in large commercial buildings through building tune-ups and control systems optimization, with a persistence component delivered through continuous or extended monitoring of building performance. MBPCx is currently offered as a pilot incentive program under PG&E's 2006-2008 Energy Efficiency offerings. It is anticipated that the program will be continued and expanded for the 2009-2011 program cycle as well.

Enovity's MBPCx Program features the use of monitoring-based fault detection and diagnostic (FDD) software tools at customer sites to identify additional deficiencies not always found during the traditional retro-commissioning process, to monitor system performance, to report when a sequence is changed or over-ridden, and to generate reports regularly to identify new or recurring system faults. With FDD reporting, operators can identify and correct problems quickly, maintaining energy savings and operational benefits. FDD tools may also facilitate measure verification, an important component of utility-funded energy incentive programs.

This paper will outline Enovity's work on the MBPCx Program development and implementation, and will discuss program goals and process, tools employed, challenges encountered, and lessons learned to date. We will also report on preliminary results from one or more program sites.

About the Authors

Greg Cunningham, AIA, LEED® AP, is co-principal of Enovity, Inc., a San Francisco-based commissioning and energy engineering firm that also provides operations, maintenance and repair (OM&R) services to the Federal Government. The firm's retro-commissioning projects include Enovity's Monitoring-Based Persistence Commissioning Program (MBPCx), recent work for the State of California's DGS Retro-commissioning Program, projects for the State of Hawaii's Retro-commissioning Program, monitoring-based commissioning at GSA Federal Facilities throughout Region 9 and for U.C. Santa Cruz, and more than 50 buildings for various utility-funded retro-commissioning programs. Enovity's new construction commissioning projects include the new US GSA Office Building in Downtown San Francisco, major expansions of the Oakland and Sacramento International Airports, and more than fifty individual buildings and school campuses. Mr. Cunningham has more than 28 years of experience related to building energy performance, evaluation and verification. He serves on the Advisory Council to the California Commissioning Collaborative (CCC) and on the Building Commissioning Association's Marketing and Outreach Committee. He is a LEED-Accredited Professional and is a member of the American Institute of Architects. Greg is a graduate of U.C. Berkeley and holds a Master's Degree from Arizona State University in Environmental Planning/Energy Technology.

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Program Background

There has been growing demand for retro-commissioning services targeted to HVAC systems' optimization and energy efficiency over the last five years or more. In California, this is largely due to retro-commissioning savings playing a more prominent role in the state's investor-owned utilities' (IOU) ever-expanding energy efficiency goals and because the process is now seen as cost effective compared to other capital-intensive energy efficiency options. Retro-commissioning offers great potential for optimizing HVAC system performance and realizing verifiable energy and operational savings. Recent IOU-funded retro-commissioning programs have resulted in significant short-term energy savings; the authors have actively contributed to their success. However, while average savings of 7% have been regularly cited, one recent study¹ reported that persistence of energy savings is not reliable; energy savings may diminish after about three years due to a variety of factors that are further described in this paper. Other than training operators and providing good documentation, traditional retro-commissioning programs have generally ignored factors that ensure that the energy and operational benefits will persist long after the program cycle.

A number of factors conspire to degrade energy savings following traditional "once-through" retro-commissioning activities. HVAC systems and their components fail periodically. Operations and maintenance (O&M) staff generally do not have the training, time, resources or educational background to identify insidious equipment failures; these can go undetected for months and sometimes years. Building Automation Systems (BAS) are excellent for providing real-time reporting of alarms for major system faults such as a failed chiller or boiler, excessive static pressure or high space temperature, but cannot easily detect or report on subtle failures such as a frozen economizer damper, a valve that is leaking, a reset sequence that has been overridden, or a sensor that drifts out of calibration. Seldom is the BAS used to optimize performance or troubleshoot insidious problems not readily observable.

The general proficiency of the O&M industry has not kept pace with the growing complexity of BAS over the past 15 years. This generally limited utilization of BAS has resulted in buildings being operated in "safe mode"; that is, the BAS is only used to schedule equipment, decide when equipment should be manually started and stopped, and alert the operator when there is a comfort problem or alarm. Operators rarely have programming-level proficiency in the BAS. Building operators will often make changes to the BAS in an attempt to address an immediate comfort or operational issue, often by overriding a damper or valve from fully closed to open (or vice versa), or resetting a setpoint outside of an acceptable or designed range. These changes may result in short-term fixes but alter the system so that it is usually no longer operating according to design intent. If not checked, the system can remain in this degraded state for a long period of time.

¹ *A Top-down and Bottom-up Evaluation of Retrocommissioning Persistence in Large Commercial Buildings*; N. J. Bourassa, M.A. Piette, and N. Motegi. Ernest Orlando Lawrence Berkeley National Laboratory. National Conference on Building Commissioning: May 18-20, 2004.

Historically, building owners have focused on keeping building occupants comfortable and minimizing the frequency of comfort complaints, leading energy costs and optimized equipment operation to take a back seat to these basic requirements. Regularly scheduled preventive maintenance should identify some equipment failures such as a frozen damper or leaking valve, but this type of maintenance may only be performed once per year and budgets for non-emergency repairs may be limited. Few building owners understand that a fully functioning building requires regular system optimization checks and regular reporting by their building operational staff; owners may not be aware of the limitations of their O&M staff in this critical area. Owners' budgets often place O&M at or near the bottom of the priority chain, resulting in a "run to failure" mentality.

Many factors contribute to degradation of energy and operational performance following a retro-commissioning event, including the following:

- Changes made to controls without regard to energy efficiency or design intent or the global consequences of the change;
- Degradation and/or failure of equipment components and control devices;
- Inability of O&M staff to continually monitor building performance and correct deficiencies as they arise;
- Attrition of O&M staff trained to ensure persistent energy savings;
- Controls technicians unfamiliar with established energy efficient strategies;
- Changing priorities of the building owner and O&M staff.

Energy-oriented retro-commissioning approaches that focus on measure sustainability beyond a few years have generally been untested on a large scale. The authors' experience has been that retro-commissioning can result in significant short-term energy savings; however, there is still greater energy savings potential through a more detailed and persistence-based approach to HVAC systems investigations.

Enovity's 3rd-Party Program for Monitoring-Based Persistence Commissioning (MBPCx) uses a building's BAS to track the ongoing performance of HVAC systems and facilitates, and ensures the reporting and correction of deviations from optimal performance in a timely manner through the use of a fault detection and diagnostic software (FDD) toolset. Enovity initially developed MBPCx as a customer incentive program in the PG&E territory for the 2006-2008 program cycle. MBPCx offers traditional retro-commissioning services combined with a longer-term monitoring approach. The advantage of this approach over traditional retro-commissioning programs is that it provides a mechanism for ensuring that energy efficiency measures are sustained and that new or recurring equipment problems are identified continuously.

Program Goals and Eligibility

The MBPCx Program was developed initially as a pilot program targeting about 4 million square feet of commercial facilities (office, retail, hotel, hospital, college/university, high tech office/

lab/manufacturing) within the PG&E service territory, with net energy savings goals of 4.32 million kWh and 96,000 therms per year over the 2006-2008 program cycle. The general goals of the Program have been to deliver energy and operational savings to customers and the IOU, and to investigate and refine the process to incorporate the use of FDD toolsets into the retro-commissioning process.

Candidate sites generally have a minimum floor area of 250,000 square feet and energy usage of at least 15 kWh/sq. ft. Buildings also needed to be fully air conditioned, generally with a central plant and requiring a robust, modern BAS. Buildings must be in PG&E's service territory and must pay the CPUC energy surcharge that funds statewide energy programs.

Program Process

Enovity identified about 30 potential buildings from PG&E's customer database, PG&E Account Manager referrals, and the firm's client base. From this larger list, approximately 20 buildings appeared to meet the basic building criteria for the Program. Buildings were initially pre-screened over the phone and if they met Program requirements, a one-day Screening Audit was performed. A Customer Access Agreement was executed giving Enovity staff access to the building and its operators; however, this agreement did not commit the customer to any specific measure implementation. During the audit, a general review of building systems was performed, the capabilities of the BAS were reviewed and documented, and general building operation and utility billing history were investigated through staff interviews and on-site data collection. The O&M staff's level of understanding of the building systems and the BAS also played a role in considering the building for participation, as did their perceived level of enthusiasm in participating in the Program. A major focus of the audit and subsequent evaluation was to identify potential low-cost energy measures that could lead to a minimum of 5% energy savings. A total of 15 buildings totaling 7.4 million square feet were eventually pre-screened for the Program. From the pre-qualified list of 15 buildings, three were rejected due to a variety of factors. Ultimately 12 buildings were selected for further Program participation. These include a mix of public and private sector facilities and feature office buildings, courthouses, a research laboratory and several hotels.

MBPCx pairs a traditional retro-commissioning approach with the use of fault detection and diagnostic software. Onsite retro-commissioning is performed by Enovity engineers and is based on a process-oriented, detailed investigation activity tailored to the specific building systems. HVAC systems and components, BAS controls, hot water generation, lighting controls and other energy-using systems are included in the detailed site investigation. While the rigor of onsite testing may vary within the industry, the traditional retro-commissioning process is generally well-documented and involves component and systems tests and measurements, stand-alone monitoring, BAS point validations, sequence of operations functional tests, BAS trend analysis, and documentation and reporting activities. Baseline energy usage is also documented, and specific energy metrics are collected for subsequent post-measure evaluation.

The Program goals were to identify a site-specific mix of energy efficiency measures (EEMs) that generally have a payback period of less than two years. Combined measure paybacks could

be reduced to 1-1/2 years or less with Program incentives. Following the detailed investigation, a Detailed Investigation Phase report was produced that described building systems, energy usage, data and results, recommendations and a preliminary implementation plan. Upon owner consensus, a Customer Commitment Agreement would be executed to commit the owner to completing the work and to reserve incentive funds for the customer.

Fault Detection and Diagnostic Approach

There is a growing list of fault detection and diagnostic (FDD) toolsets now offered in the industry. While most are proprietary and may not yet be available for use by a third party, and also may carry a licensing fee, each of the tools listed below has unique benefits and BAS integration/connectivity requirements for collecting data, and unique processes for analyzing and reporting faults. Enovity performed a survey of tools as part of this Program and already had more than two years of experience with some of the tools prior to implementing this Program. While it is not a comprehensive list, Table 1 shows some of the FDD tools available today.

Key to successful deployment of these tools is an understanding of the method for data collection and handoff from the BAS to the system/server where the fault diagnostic analysis and data reports are generated. For example, some FDD tools utilize embedded BAS software routines while others utilize a remote collection/upload methodology.

Table 1: FDD Tools

FDD Tool	Equipment Analyzed	Method	Analysis	Company/ Organization
PACRAT	AHUs, Hydronic Systems, Chillers	Historical trend data uploaded to company server	Analysis done at company server	Facility Dynamics Engineering
VPACC	VAV Boxes	Imbedded programming in BAS/VAV box controllers	Output to BAS	NIST
APAR	AHUs	Imbedded programming in BAS/AHU controller	Output to BAS	NIST
Enforma	AHUs, Chillers	Communicates via Niagara AX/ JACE	Analysis done at company server	AEC
Infometrics	AHUs, Chillers	Communicates via caching router	Analysis done at company server	Cimetrics

After reviewing toolsets offerings, Enovity decided on two tools for the Pilot Program, PACRAT and VPACC. Enovity also considered the use of the NIST APAR programming toolset for buildings where the BAS has less than robust capabilities and may employ this tool at future

sites. Toolset use considerations included available program features, time on the market, reporting capabilities, time and effort required to overcome the steep learning curve, features and limitations of the building systems in the program, and Enovity's prior experience and level of comfort with some of the toolsets. For example, Enovity staff already had experience with both of the chosen toolsets and with the APAR tool through its O&M service contract at the Phillip Burton Federal building in San Francisco, where FDD toolsets had been tested and integrated into the building computerized maintenance management system (CMMS) by Enovity engineers and Enovity O&M staff.

PACRAT - Performance and Continuous Recommissioning Analysis Tool

PACRAT is a comprehensive automated diagnostic tool for HVAC systems performance and is already established in the market. PACRAT can be set up to automatically collect trend data from the BAS. The built-in diagnostic tools identify system deficiencies from historical data, generating reports of system deficiencies and associated energy and operational cost savings at regular user-defined intervals. In the case of the Program, there was an initial PACRAT run evaluation after setup of the tool and a follow-up evaluation after three months.

PACRAT was designed to perform four basic functions: Automated Diagnostics, Energy Use and M&V Validation, Historical Building Performance Documentation, and Data Visualization. PACRAT diagnoses system problems (anomalies), poor performance and energy waste from equipment. It also provides energy and costs saving numbers in a standard report.

PACRAT provides a variety of system diagnostics and system characterizations for air handlers, hydronic systems and chillers. Failed or miscalibrated sensors, leaking valves, wrong schedules, outside air evaluation, chiller sequencing, low delta-T, space loads, and chiller efficiencies are a few of the several analyses that PACRAT performs. There are also user-customizable parameters that can be set to further evaluate a particular set of variables on a piece of equipment.

PACRAT utilizes historical BAS trends which are set up to automatically be transferred to the company's server for analysis. Set-up time to configure the system is primarily used to map the BAS points to the correct analysis module in PACRAT so that the analysis is meaningful.

VPACC - VAV Box Performance Assessment Control Charts

VPACC is an FDD tool that uses the idea of "control charts" as a cumulative sum chart. As the cumulative sum error between a process variable and its expected value goes more positive based on input from the VAV box control program, the VPACC program indicates a box that is not controlling.² Four errors are used in the typical VPACC installation:

² Additional information on the technical aspects of NIST VPACC can be found in ASHRAE Transactions, Volume 109, Part 2 (2003 ASHRAE Annual Meeting), "Application of Control Charts for Detecting Faults in Variable-Air-Volume Boxes," J. Schein & J. House.

- airflow rate error
- absolute value of the airflow rate error
- temperature error
- reheat coil differential temperature error

The core program code for VPACC is relatively simple and can be imbedded into the VAV box controller storing only a few values in memory. The BAS control points required by VPACC are zone temperature, cooling setpoint, heating setpoint, airflow rate setpoint, actual airflow rate, discharge air temperature, and occupancy. If the VAV box does not have entering air temperature, supply air temperature from the BAS can be used.

Several versions of the VPACC code are available from NIST or other sources for a variety of BAS installations and VAV box controllers. These “pseudo” code samples can be modified for the specific BAS installed at a given site.

Unique Program Challenges

Of the unique Program challenges, first and foremost is the importance of identifying appropriate buildings that meet the prerequisites. While there are many large commercial buildings that could benefit from traditional retro-commissioning, only a subset feature a modern DDC-based BAS that is capable of meeting the robust trending and storage requirements for retrieving building operational performance data. It is critical that a careful evaluation of BAS features against FDD toolset requirements is performed as early as possible in the process.

As with any FDD tool, PACRAT features and requirements are unique, and the types of data that it can easily manage are somewhat limited. Nearly all modern BAS collect and format trend files using different protocols, and the translators currently available in PACRAT have not been developed for every industry solution. However, PACRAT has modules or wizards that are applicable for several popular BAS formats. Enovity eventually identified specific BAS for which PACRAT is best suited.

Another issue that should be carefully considered during the scoping audit is the robustness of the BAS point list. Most FDD toolsets will require specific data points for a given piece of equipment to ensure that the tool’s analysis results will be accurate. Such an example would be a mixed air sensor in an air handler that is used by PACRAT to calculate and analyze outside air and economizer functions, whether or not the sensor was required in the design statement of objectives (SOO). If the sensor is not available, either one would have to be installed or a data logger would be put in place over the course of monitoring. These costs need to be considered in the overall cost of installing the FDD toolset.

Ensuring the availability and timing of funding sources for implementing recommended measures is a major challenge common to all retro-commissioning programs. While the MBPCx Program includes incentives for EEMs that are identified during the course of retro-commissioning, these incentives are tied to energy savings; there is no direct mechanism to pay for the licensing or costs of the FDD tools to remain installed after the program ends so that

continued systems performance is monitored. Finally, there is no guarantee that the FDD tool will identify sufficient energy savings to pay for itself over a longer installation period.

Program Progress and Results to Date

The Program was fully subscribed as early as eight months into the Program cycle. To date, at just over one year into the two-year cycle, Enovity has fully completed six of the 12 detailed investigations that have been targeted, with the remaining six nearly complete. Detailed investigation phase recommendations represent a cumulative total of 4.9 million kWh and 150,000 therms of annual energy savings identified for the 12 targeted building sites. Implementation has significantly progressed at two sites, with 2.5 million in annual kWh savings and over 100,000 therms in annual savings realized by the utility and building owners to date.

Retro-commissioning measures identified through detailed onsite investigations include equipment scheduling; resetting of schedules for condenser water, hot water and chilled water systems; lighting controls repair; chiller VFD; variable speed primary pumping; control sequence optimization; control system upgrades; economizer and outside air functions; and simultaneous heating and cooling control issues.

Additional measures identified through FDD tools deployment include failed sensors; zone temperatures out of specification at specific times or hours; leaking heating and cooling valves; and setpoint deviations. Several smaller issues with VAV boxes have been found with the VPACC tool and were corrected during preliminary evaluations of the data. FDD data review, reporting and measure evaluations to identify additional measures are progressing to the end of the program period, which sunsets in December of 2008.

It is the authors' hope that some or all of the sites will maintain their FDD toolsets following the conclusion of the current Program funding cycle. The MBPCx Program can only pay for the FDD toolset licensing fees during the Program period; the site will be responsible for future license fees.

Program Summary and Lessons Learned

There are several key lessons learned during the implementation of this Program. It is critical that only appropriately qualified buildings be targeted for FDD toolset deployment. While there are many large commercial buildings that could benefit from traditional retro-commissioning, only a few buildings will have the energy savings potential to support the costs associated with the robust BAS trending and data harvesting activities. Spending additional time during the initial identification process to ensure the BAS can support the specific requirements of the selected toolset is a worthwhile upfront expense.

It is important to ensure early on that the BAS can handle the additional trending requirements of the FDD toolset. Being mindful of the fact that the BAS must function normally while managing large volumes of trends that are collected every five or 15 minutes, the following issues need to be taken into account for the proper ongoing operation of the facility:

- The data transfer rate on the BAS communications trunks;
- The capabilities of the BAS controllers, field devices and the servers;
- The storage capacity of the BAS server.

Using a separate remote storage device can decrease the burden on the BAS server.

If there is sufficient time available, it is not necessary to wait until the detailed investigation phase is complete before deploying the FDD toolset. Early deployment of the FDD tools was considered, but due to the program's short timeframe, it was decided that the detailed investigation and measure identification should be completed first so that the owner had sufficient time to set aside implementation funds and implement recommended projects within the Program period. Enovity is exploring using FDD toolsets earlier in the process so the tool can be used in parallel with the labor-intensive screening effort to maximize the number of measures that can be identified and minimize the time spent onsite.

Having enough adequately trained, qualified and readily available engineers to support this type of effort is a challenge common to the California commissioning industry today. In addition, the technical complexity of managing and executing multiple-site FDD deployments should not be taken lightly. Even a highly experienced controls engineer with a good understanding of HVAC systems, control sequence of operations and IT communication protocols will typically require 2-3 months to come up to speed with any FDD toolset; each toolset offers unique technical challenges to successfully navigate the process in a short timeframe. Finding engineers with these interdisciplinary engineering skills is a current industry challenge. As with all retro-commissioning activities, appropriate budgeting of manpower when employing a relatively new methodology is critical. Allowing for sufficient time to perform the traditional retro-commissioning activities coupled with the FDD tool implementation, while ensuring little or no disruption to the normal BAS operation, is key to success.

There is a very steep learning curve to overcome for most of the FDD toolsets unless the tool is to be installed by the developer. In the case of PACRAT, multiple training sessions were required to familiarize key program engineers with the methodology required for setup and mapping of system trended points and equipment parameters for each site. FDD installation and troubleshooting often required up to two man-weeks before even cursory analysis could begin. Ongoing technical FDD support is necessary, as every installation is unique.

Overall, this pilot program is on schedule to realize the targeted energy savings. Part of this achievement is due to Enovity's ability to implement some measures on behalf of the owner, rather than relying on a lengthy bidding and contracting process. The pilot program has so far been successful in integrating traditional process-driven retro-commissioning with the deployment of persistence reporting tools for longer-term management and sustainability of energy and operational benefits. Lessons learned to date will help guide future efforts in fine-tuning the methodology and optimized utilization of FDD toolsets. Current success may lead to extension and/or expansion of the program for the next IOU program cycle. Further development and utilization of useful persistence tools can only lead to more long-term and verifiable retro-commissioning benefits for the customer and utility.