Artificial Neural Networks vs. Grey Matter: A RCx Case Study at Matching Cloud-based Fault Detection with Traditional Human Neural Networks

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ABSTRACT

The paper will discuss two unique case studies that compare fault detection and diagnostic (FDD) software with traditional retro-commissioning (RCx) approaches. The projects cover both test implementations of new software and detailed engineering investigations at high-tech campus buildings in Silicon Valley, California.

The case studies summarize the project team's objective experience with an innovative, cloud-based computing, fault detection system. The FDD system is designed to analyze trend data from the building automation system, identify system faults, alert building staff, and report the energy savings from repairing the fault. The fault detection algorithms are composed of sophisticated methodologies including neural network and rule-based engineering approaches.

The installation of the new FDD system was completed in parallel with detailed RCx investigations at separate customer facilities. Both the FDD system and the RCx investigation team analyzed the same trend data to develop sets of recommendations.

The authors will present side-by-side results and objective feedback on the process and installation of the automated FDD system. Not surprisingly, there are overlaps among the faults detected by the automated system and the recommendations made by our engineers. Of those having significant operating cost impacts, measures totaling about $67,000 per year in annual energy savings were independently identified by both the automated system and the RCx team. The Auto FDD system identified savings totaling $17,600 that the RCx team did not identify, and an additional $183,000 in annual savings was identified by the RCx team through other measures that the Auto FDD system did not identify.

Background

In the facility management industry over the last few years there has been growing interest in making more sophisticated use of software, the internet, and more advanced connectivity. Interest in the "green economy" from the financial sector has funneled a tremendous amount of investment capital into software companies developing building controls and energy management, which has spawned a large number of new products and services. These products now encompass a dizzying array of capabilities ranging from portfolio energy management, data visualization, energy use benchmarking, fault detection, optimal building plant controls, and many other areas. Many of these new products overlap in terms of their capabilities, and frequently promise large associated cost and energy savings. For the end user, it may be difficult to separate vendor claims from reality as well as determine effective integration strategies that will produce results.

Last year, kW Engineering's project team was presented with two unique opportunities to perform close-up assessment of one product in one of these sub-categories: an automated fault detection and diagnostic (Auto FDD) tool. The tool uses input data from the facility's building automation system (BAS) to identify and evaluate the cost impacts associated with equipment and controls malfunctions. Our team was invited to examine the recommendations made by the automated system as part of two contemporaneous retro-commissioning (RCx) studies of two similar buildings by our engineers. In both cases our RCx investigation was done around the same time as the automated system was installed and operating. This afforded our team the unique opportunity to compare the findings of the automated system to our results, which were based on current RCx best practices.

This paper will summarize the results of this case study, comparing the results of a traditional RCx investigation, with automated FDD. In it we describe the buildings, the approaches used, and the findings that result from the two methods. Finally, we compare the cost effectiveness of the approaches, both individually and combined, at these two facilities.

The Test Sites

Both test buildings are typical commercial design and occupancy for office buildings in Silicon Valley.

Building #1. Building #1 is an approximately 120,000 sq. ft., four-story building with offices and workstations, a cafeteria, and a small server room. Most of the building is occupied during extended office hours and occupant density is typical for office buildings. The building has relatively high energy-use intensity due to large equipment and computer loads. Lighting in the building is typical for San Francisco Bay Area office construction, with systems retrofit with direct and indirect, T-8 and CFL lighting.

The heating, ventilation and air conditioning (HVAC) systems of the building are variable air volume (VAV) type, with reheat coils in perimeter VAV boxes. The air handlers provide cool supply air via air distribution ductwork and diffusers throughout the building including the labs and server rooms. There are four packaged rooftop air conditioning units (RTUs) serving the building. The RTUs include direct expansion (DX) cooling and no heating. They are equipped with dampers to control the use of outside air (economizer). Each unit has two supply fans with variable frequency drives (VFDs) controlled to maintain a variable duct static pressure set point and an exhaust fan. Heating hot water for the site is provided by two boilers and is supplemented with heat from an onsite combined heat and power (CHP) system.

Building #2. Building #2 is about 140,000 square feet. It was remodeled in 2006 and many of the HVAC systems were replaced at that time. The building consists of typical office spaces, including private and open offices, in addition to a number of independently conditioned laboratory spaces. Occupant density is typical for office buildings. As with Building #1, the overall energy use of the building is much higher than typical office buildings due to high equipment and computer loads in the building.

The lighting systems in the building use direct/indirect T8 linear fluorescent light fixtures with a mesh basket over the lamps.

There are eight packaged VAV rooftop units (RTUs), with economizers located on the roof of the building. Each RTU has a VFD on the supply fan that is controlled to maintain a supply duct static pressure setpoint. The exhaust fan on each air handler is turned on whenever the air handler is using outside air in lieu of return air. The air distribution system uses VAV terminal boxes with hot water reheat.

Electrical closets and laboratories have water-source heat pumps located in the plenum above the space in addition to VAV terminal boxes supplying house air. The heat pumps handle the laboratory conditioning loads for each space during unoccupied overnight and weekend hours. Two cooling towers provide condenser water to the water source heat pumps. They are equipped with VFDs on both the fans and condenser water pumps. Two gas-fired hot water boilers supply 160°F heating hot water to the reheat coil distribution system. The hot water is circulated by two pumps.

RCx Approach

A general goal for any RCx project is to bring operation of the building or facility to its optimal point (here taken to be the point of minimum utility bills) by making operational improvements to its existing equipment and control systems. The primary focus of the RCx project is to optimize the existing systems with low cost repairs and/or upgrades.

Objectives

The key objectives of these RCx projects were to:

- Pinpoint deficiencies in existing energy-consuming systems and related controls. Some of these deficiencies pertain to energy savings, while others may have comfort or Indoor Environmental Quality (IEQ) impacts.
- Identify potential optimization strategies for these systems.
- Assist the owner in implementing corrective actions, operational and maintenance (O&M) improvements, and energy efficiency measures (EEMs, or measures) that optimize existing equipment and produce sustainable reductions in energy consumption and demand.
- Verify the implementation of measures and report the achieved savings to the Owner and electrical utility.

RCx Process

To achieve these objectives, our project team conducted comprehensive on-site investigations and analysis to identify deficiencies and potential optimization strategies and to document cost-effective energy saving opportunities. Site work included surveys, investigation and analysis of various mechanical systems for potential energy reduction measures. Investigation and analytical activities included the following:

- Gathering operational and functional performance data to assess equipment operation and identify deficiencies and measures for improvement.
- Gathering data to quantify building operation and deficiencies using the appropriate methods for the facility.
- Short-term monitoring with portable data loggers and the buildings control system.
- Review of existing construction drawings, air and water balance reports, and other pertinent reports.
- Review of maintenance practices and status.

The RCx investigation consists of four phases; Investigation, Implementation, Verification and Training. Detailed activities of each of these phases are shown in Table 1 below.

Table 1. Summary of RCx Approach

Investigation	Implementation	Verification	Training
• Kickoff meeting • Detailed Investigation • Develop energy savings and cost estimates • Develop Project Deficiency and Resolution Log [PDRL] • Issue Incentive Agreement	• Implement EEMs • Track project costs	• Document implemented EEMs • Post-installation verification • Verification Report • Train Customer Staff to ensure persistence	• Train site staff on control upgrades and new sequences • Issue RCx incentive check

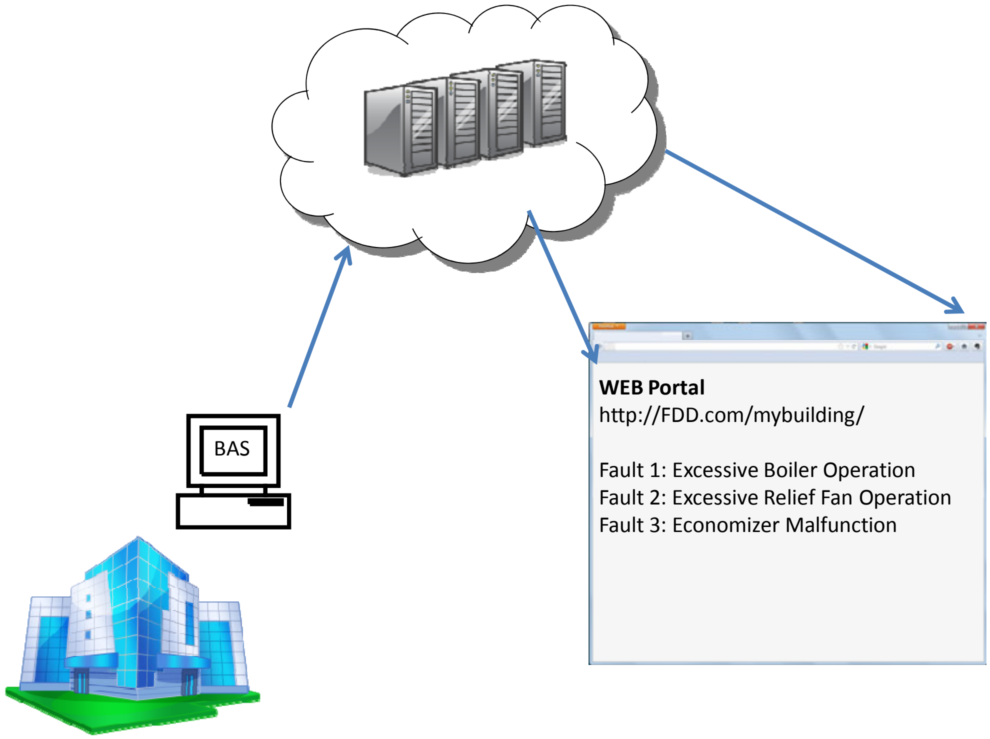
Automated Fault Detection Approach

There are a number of approaches to automated fault detection for building systems. Some systems are integrated into the controls of individual devices. The National Institute of Standards and Technology (NIST) has developed a set of algorithms for detecting faults in air-handling units (AHUs) and variable-air-volume (VAV) boxes that has been integrated into some control units (Schein 2003). Handheld or in-field FDD units can be carried by maintenance personnel to their sites and set up on individual systems (Wiggins 2012). FDD can also be offered as a software-as-a-service (SaaS), as in our test sites. In these applications the real variables from monitoring at the site can be pushed to a cloud computing platform in real-time for processing off site.

FDD via SaaS offers several potential advantages over embedded or handheld FDD systems. These systems offer continuous feedback on system operation, enabling not only diagnosis, but also tracking to ensure the persistence of corrections. Also, a remote FDD system can make use of more computing "horsepower" that can typically be utilized in a diagnostic system that is built-in to controls hardware. It can also constantly update algorithms as new and better FDD methods are adopted.

The automated fault detection and diagnostic software system in use at our two sites used an architecture shown in Figure 1.

Figure 1. Basic Automated Fault Detection and Diagnostic Architecture



Trend data for the sites BAS is constantly pushed to the vendors cloud computing platform offsite. The automated FDD system then analyzes the data and identifies fault conditions that need to be investigated by site personnel. It creates an individual fault item for each condition based on rule-based algorithms, tags it with a diagnostic label, and estimates the energy use and cost associated with the condition. The user then logs on to the system using any web browser, and a secure login. The user can then review the faults, prioritize them, assign the task to other member of the FDD group for follow up, and take corrective actions.

The automated FDD system makes use of a number of approaches to fault detection. Adaptive approaches for "learning" control algorithms, such as artificial neural networks, were initially behind some of the fault detection methods. However, the vendor has since changed to other approaches and many of the fault detection algorithms currently rely on more simple and apparently reliable, rule-based approaches.

Installation of Automated System

At both sites the installation of the automated FDD systems took longer than expected and caused delays in the RCx execution. In general this can be attributed to the new nature of this technology, and the relative few installations complete at the time of the installation (4^{th} quarter 2010 and 2^{nd} quarter of 2011 for sites 1 and 2 respectively). More specifically the delays were caused by the inherent difficulty in mapping hundreds of points in an existing BAS system, configuring new hardware to communicate those points outside the network, and working with onsite IT staff to ensure system security. Since the product has matured significantly since that time (a year has passed) we would expect that installation delays would not be as significant as what our teams experienced during those early deployment experiences.

Findings

As one would hope, there was significant overlap between the faults detected by the automated system and our engineers. Almost all of the faults detected by the automated system were also found by our engineers. Our team, however, identified many opportunities for more optimal control strategies that the automated system could not or did not identify. Furthermore, our traditional RCx process was used to trouble-shoot the automated system because it was not correctly identifying some of the measures found by our team.

The automated system did, however identify some faults that would have been difficult to identify during a traditional RCx investigation. The auto FDD system found faults with the operation of individual VAV boxes that are beyond the sampling activities of most RCx investigations.

The automated FDD system could potentially provide assistance with one problem in the RCx industry – that of scale. Some utility program administrators have complained that they have limited human resources to call upon to accomplish RCx in commercial buildings. There is a perceived lack of qualified professionals who have the experience to implement RCx projects. Automated approaches may help get more projects done at more facilities and leverage the available experienced labor pool.

Details on individual measure types identified by the automated system, and our investigation are provided below.

Measures Identified by Automated System

In our test cases, the automated FDD system did a good job identifying when specific components of systems were operating outside the ranges of expected behavior for building controls. Some examples of faults found in these system components are detailed in the following sections.

Economizers. The automated system correctly identified malfunctioning economizers on air handlers at both building sites, resulting in a fault labeled “Lack of Air-Side Economizer on AHU-XX”. The system compared actual air handler control settings to those that would result from an enthalpy economizer control. When the system encountered operation that was inconsistent with enthalpy economizer control, it identified those hours, and calculated the expected energy savings associated with returning the system to enthalpy economizer control.

While enthalpy control may be considered “ideal” performance for most sites, in the San Francisco Bay area there are actually more hours available for free cooling using a simple dry-bulb economizer. There is no real humidity penalty in our climate and the simpler control method is less prone to failure (Taylor 2010). For these reasons, our RCx team recommended a dry-bulb economizer for the buildings, which would result more energy savings, and more reliable operation.

The energy savings estimated by the AutoFDD system were underestimated for two main reasons:

1) the automated FDD system did not account for re-heat savings associated economizers that do not properly control outside air during cold ambient conditions.
2) the automated FDD system relied upon design (i.e. constant) supply air enthalpy. When the actual temperature setpoint is reset based on load, such as at our sites, the system did not account for actual supply air enthalpy in its calculations.

To improve the accuracy of the savings, our project team's calculations considered the active supply air temperature setpoint (from monitored data) and included savings associated with reheat.

Excess exhaust fan use. The Auto FDD system was instrumental in identifying problems with exhaust fan controls in both of our test sites. Both facilities had similar rooftop air handlers and controls that produced the same fault. The system reported that "Relief fan should only be on when bldg static (0.02) is > setpt (0.03)". The fault diagnostic was essentially correct in that it identified that the relief fan was on when the building static pressure was below setpoint.

The fault description, however, was cryptic and would have made repairing the fault difficult. The relief fan was actually following the sequence of operation provided by the manufacturer. The OEM control sequence simply turned on the relief fan any time the outside air damper was open more than 20%. A building engineer who checked into the fault may have concluded that since the equipment was correctly following the controls as established by the manufacturer, then the equipment was running as intended, and the "fault" was in error.

Our RCx team recommended a more comprehensive upgrade to the relief control of the building. We provided a plan for overriding the manufacturer's control sequence for the relief fan using the BAS, and installing a variable frequency drive (VFD) on the fan. The fan sequence was then set up to modulate VFD speed to maintain a constant static pressure setpoint in the building.

The energy cost estimates provided by the Auto FDD system were reasonable for this measure. Our team recommended changes to the calculation algorithms to account for two factors. The first was that the system was initially using nominal horsepower, rather than brake horsepower in calculations. The second was that fan energy calculations initially treated the fan power as constant flow, although the fans were modulated with outlet dampers. The algorithms were updated based on our feedback to account for these factors.

Boiler running unneeded. The Auto FDD software identified a fault associated with heating hot water boilers at one of the sites. The system identified excessive boiler usage anytime the boilers were enabled while the hot water return temperature was above the hot water return temperature setpoint. The system provided the description; "Boiler running unnecessarily. Auxiliary hot water return temperature at 159.5° is greater than hot water return temperature setpoint of 130° which is sufficient for heat without boiler." The Auto FDD system seemed to assume a return temperature control strategy, which was not the case in the building.

We found this to be an inaccurate assessment but it did highlight the fact that the onsite cogeneration-boiler system was being severely underutilized. We conducted our own investigation in to the cogeneration-boiler system where we found several control and mechanical design issues that lead to poor system performance of the cogeneration-boiler system.

First, there were no isolation valves installed on either of the two boilers at the site and there was no bypass leg to bypass the boilers when the cogeneration heat exchanger was sufficient to meet load. This meant that hot water flowed through both boilers regardless of how many boilers were needed (even if none). Boilers are very effective air-to-water heat exchangers designed to transfer as much heat as possible from the combustion gases to the water. So when a boiler is not firing, the heat exchange reverses and the boiler's heat exchanger becomes a very effective radiator, heating the air in the combustion chamber while cooling down the water.

We also found that the hot water system was running continuously, the existing outdoor air temperature lockout of 65°F had been overridden, and the pumps were operating inefficiently, routinely operating two pumps during periods of low load and overnight.

The hot water reset controls had also been disabled. The hot water system was controlled to maintain a constant hot water supply temperature of 180°F during occupied hours and 160°F during unoccupied hours. The design documentation for this system recommends a Hot Water Supply Reset from 140°F to 160°F. Operating at hot water supply temperatures this high leads to high hot water return temperatures which significantly limit the effectiveness of the cogeneration heat exchanger.

To address these issues our team recommended the following:

1. Installing isolation valves on each boiler and installing a bypass leg and modulating bypass valve
2. Interlocking the hot water system (pumps, boilers, and CHP loop) to the control of the air handlers
3. Re-enabling the outside air lockout on the boilers
4. Implementing a heating hot water temperature reset during low-load conditions to improve the cogeneration heat exchanger effectiveness (also reducing boiler shell and distribution system losses)
5. Implementing controls to optimize the staging between the cogeneration heat exchanger and boilers and to limit wasted heat lost through disabled boilers

Given the sophistication of the interaction between these system components, it would be very difficult for the automated system to have correctly identified these measures, or correctly approximate the energy savings related to the boiler runtime issues. The cost savings for the condition were greatly overestimated by the auto FDD system, resulting in an estimate for the energy cost penalty that greatly exceeded the annual natural gas bill for the site (including cogeneration).

Measures Missed by Automated System

A number of potential measures were missed by automated system, but identified by our RCx team, some of which with high energy saving-potential (see next section for savings summary). Broadly, these measures could be characterized as scheduling, system-wide approaches (as opposed to component approaches), and measures that are non-HVAC.

One of the most frequent recommendations of RCx studies is to correctly schedule equipment, using the BAS or other means (Mills et al, 2004). Since the measure typically has almost no cost associated with it, it is also frequently the most cost effective recommendation. Automated approaches have no way to check for correct scheduling at the facility and so this measure can only be found by a careful review of building occupancy and verifying that the controls in the building operate equipment at a minimum schedule to provide for the health and comfort of building occupants. In some cases, it may be necessary to add or modify existing equipment so that large systems are not brought on to meet the needs of small, specialized zones in the building. In our two sample sites, we found opportunities for scheduling air handling equipment, and for properly commissioning zone controls so that control setpoints were loosened when the space was unoccupied.

Another frequent recommendation in RCx studies of existing buildings is to provide optimal control of air handler supply air temperature setpoints, and duct static pressure setpoints. These approaches are well documented in existing literature (Taylor, 2003 e.g.) and will not be repeated here. Our team typically includes optimal temperature and static pressure reset approaches in our approach to RCx of VAV systems, and these approaches were recommended for both sites in this investigation.

The automated FDD system only looks at the building control points that are part of the BAS at the site. Typically these systems address HVAC only. At Site #1 we found significant control opportunities in lighting and kitchen systems that could not be identified with the Auto FDD system.

Summary of Savings

The table below shows the measures identified through the Auto FDD system and through our project teams RCx investigation, and the annualized energy cost savings identified with each. The cost savings presented here are our project team's estimates, not the savings reported by the Auto FDD software because; 1) we identified many inaccuracies with the Auto FDD systems estimates, and 2) the estimates from the Auto FDD system were not annualized, but based on historical performance over the period where the fault was observed.

We should recognize that we're comparing "apples and oranges" in this table. The product of an RCx investigation is much different from the automated fault log from an automated system. The RCx investigation results in a report to the client that details observations made and specifies precisely what is needed to be done to realize savings. The automated system instead provides the user with an online list of faults to be addressed, as well as fault history that continues to update on a daily basis over the course of the year. The Auto FDD system can't identify the needed corrective action. Thus it can detect, but not diagnose root cause – a well known issue with FDD systems.

Table 2. Itemized List of Measures and Estimated Cost Savings

	Auto FDD Found?	RCx Found?	Estimated Savings
Site 1			
Excessive Boiler Operation	✓	✓	$ 6,400
Excessive Relief Fan Operation	✓		$ 5,400
Economizer Malfunction	✓	✓	$ 23,800
Supply Air Temp and Static Pressure Resets		✓	$ 14,700
AHU Scheduling		✓	$ 9,800
Lighting Controls		✓	$ 16,300
Kitchen Ventilation and Misc		✓	$ 20,700
Auto FDD Total			$ 35,600
RCx Total			$ 91,700
Total Site 1			$ 97,100
Site 2			
Economizer Malfunction	✓	✓	$ 19,300
Excessive Relief Fan Operation	✓		$ 12,200
Supply Air Temp and Static Pressure Resets		✓	$ 103,400
Zone-level Scheduling		✓	$ 35,900
Auto FDD Total			$ 31,500
RCx Total			$ 158,600
Total Site 2			$ 170,800

Source: kW Engineering. All savings estimates peer-reviewed and supported by M&V.

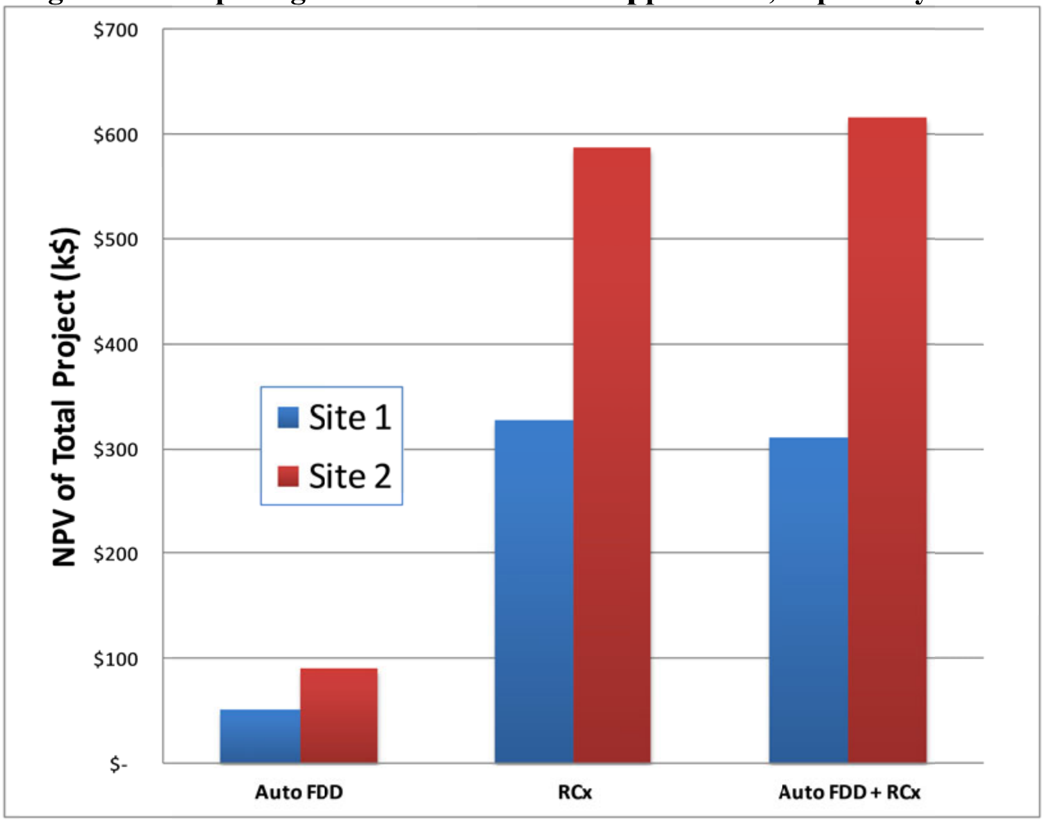
As shown in the table above, the energy savings identified at the site, using both approaches was very significant, though the savings identified through our traditional approach were much greater.

The cost effectiveness of the two approaches is perhaps more important than the raw value of the savings. We addressed this through a life-cycle cost analysis (LCCA) comparing the two approaches. For each approach (Auto FDD and traditional RCx), we found the net present value (NPV) of the identified savings, individually, and then considering the two together. In the case of the Auto FDD system, we applied the annual subscription fee to the lifetime of the measures, and added the installation fee to the initial measure implementation costs. This is slightly "unfair" to the Auto FDD approach because the software could potentially find additional savings over time and would potentially help maintain measure persistence. For the RCx approach, we considered the full investigation cost as added to the implementation cost of the measures. Actually, in this assessment the cost of the RCx investigation was paid by the local utility RCx program. This analysis shows the cost effectiveness in the absence of this incentive.

The economic analysis assumed that control reset measures had a 3 year lifetime, BAS code changes had a 5 year life, and hardware replacements or upgrades had an 8 year lifetime. The discount rate was assumed to be 8%.

The results of the LCC analysis are shown in Figure 2.

Figure 2. Comparing Net Present Value of Approaches, Separately and Combined



Source: kW Engineering. Based on actual project costs, program lifetimes, and 8% discount rate.

The analysis shows that for Site #1, the NPV for the traditional RCx approach was the greatest, and was therefore the most cost effective opportunity. However, the NPV of the combined approach was only slightly lower, and the benefit of monitoring over time would likely make up the difference. In Site #2 the combined overall approach was the most cost effective alternative. In other words, using both approaches in concert was the most cost effective approach for that site. Given the relatively small difference between RCx-only, and the combined Auto FDD + RCx approach at Site #1, it appears that using the combined approach may be the best alternative to identify the most savings, and then make sure those savings persist over time.

Conclusions

The automated FDD system helped to identify energy-saving opportunities in both our test sites. Traditional onsite RCx methods found much more potential than the automated FDD system, and missed few faults detected by automated system. The cost of the automated system was lower than the traditional RCx approach, but savings would have been difficult to achieve without the RCx team to interpret the results and outline the steps needed to effectively correct the faults. For this reason we discourage any approach that treats an automated system as a direct replacement for an engineered approach.

The energy cost savings associated with the faults identified by the automated system were significant and corrections to those faults would have been cost effective investments. Cost savings associated with our traditional RCx approach were much greater because our team was able to identify measures that an automated system could not. These measures including scheduling, system-based approaches, and commissioning of non-HVAC end uses.

The auto FDD system takes a component-based approach that works well for individual system components. However, this method precludes a whole-system approach to energy efficiency that is needed to arrive at optimal control sequences. The potential for this system-wide approach may be technically feasible, but it cannot be realized unless the system also does a better job of estimating the energy-use impacts of system components. Without the ability to accurately estimate the end use energy consumption, accurate trade off strategies are not possible.

The Auto FDD approach is cost effective for identifying zone-level issues. This can be a significant benefit because investigation costs can be high in zone-by-zone functional testing is applied using a conventional approach.

The automated FDD approach can't identify scheduling issues. Since the cost of implementing scheduling measures is low, and the savings high, an approach to any building should include these measures.

Savings calculations for the automated FDD we tested were very poor, and the algorithms for calculating savings appeared crude. With a component-based approach, improvements on cost savings estimates are difficult. In reality systems are highly customized, and system intricacies may be hard to capture with an automated system.

Automated system faults were often labeled in ways that were difficult to interpret. Though they did point to issues, it might be hard for site staff to identify real issues from the system.

The automated FDD approach offers a cost effective means for ensuring persistence of measures identified by both (automated and traditional) approaches. Tracking measures and savings potential over time is very valuable to ensuring effective savings, and this potentially addresses a known problem with traditional RCx approaches. The ability to trend and report over time also serves a valuable M&V tool for incentive programs.

From our experience we offer the following lessons learned for end users and software designers:

Lessons for end users:

- Have realistic expectations – automated systems are not a panacea
- Take cost savings estimates with a grain of salt. They may provide reasonable proxy for setting priorities, but Auto FDD is not automated measurement and verification (M&V)
- Make sure your vendor has experience with the specific BAS network architecture at your facility. This will have an impact on time to implement.
- Ensure that trained professionals are tasked with making good use of the output.
- Ensure the approach for your building includes steps so that scheduling measures are not omitted.

Lessons to software/system designers:

- Under-promise and over-deliver. Marketing messages should set reasonable expectations from end users.
- Make sure customers understand that cost savings estimates are to prioritize. Methods are far from automated M&V, though they can inform M&V.
- Provide building owners with FDD messages that are actionable. We saw messages from systems that were cryptic or tangentially related to the real problem in the system. Poor messaging could cause the systems to be perceived as another meaningless alarm to be ignored – a practice that is far too common already with building automation systems.

Pairing an engineering team with the automated FDD system is potentially a good method to identify opportunities, diagnose the problem, implement a solution, and track for persistence. The persistence issue is a critical one, and a known issue with traditional RCx approaches. Automated approaches thus have the potential to track performance over time, and alert building staff when additional intervention is needed, greatly improving the potential for ongoing savings. At our two sites, the combined approach proved the most cost effective alternative overall at one of our sites. While the combined approach was not the most cost-effective alternative at the other site, it was close enough to recommend if one includes other benefits not quantified in our simple analysis, such as persistence.

While the automated system can make effective use of the data, experienced personnel are needed to turn recommendations into solutions for the building. An effective use of resources is to use the automated FDD system as a means of providing ongoing feedback on building operation, providing persistence for recommended measures, and coupled with an engineering team that can make use of those recommendations and implement the solutions on site.

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