Implementing Advanced Diagnostics in Fleets of Commercial HVAC Equipment

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Introduction

Fault detection and diagnostics technology has the potential to make a positive impact on the cost of operating buildings. That is, to lower utility bills, service and maintenance costs and extend equipment life. Buildings use a significant amount of the energy used in the United States and around the world, and heating, cooling and lighting buildings consume most of the power used in buildings. The roles fault detection and diagnostics play includes finding, analyzing, documenting, and communicating the existence of a fault, degradation or operational anomaly.

Field Diagnostics Services, Inc (Field Diagnostics) has developed three basic types of fault detection and diagnostic technologies.

- The SA Mobile™ application and the optional HVAC Service Assistant™ tool provides in-field diagnostics and is used by technicians to collect and analyze refrigeration cycle data as well as to collect responses to questionnaires used for a variety of purposes including maintenance inspection task reporting. This data is transferred over the internet and reporting is provided from the data to 1) find opportunities with a high potential for energy and non-energy cost savings 2) Improve equipment performance and 3) manage the quality of the service and maintenance work.
- On-board diagnostics is an emerging technology that Field Diagnostics is developing in cooperation with HVAC manufacturers, also known as Original Equipment Manufacturers (OEM's). In addition to the savings mentioned above, this technology has the potential to alert people of operational anomalies prior to loss of comfort or catastrophic equipment failure, either of which can have costly negative impacts on personnel productivity or commerce.

Customers don't spend money in overly hot or cold indoor conditions. It is also useful to support and validate service delivery quality.

- Portfolio-level diagnostics uses available data sources including utility bills, smart interval meters, building and energy management systems (BMS/EMS) and NOAA weather data. This analysis can be especially useful to customers with hundreds or thousands of sites because in those types of organizations it is easy for opportunities to be hidden in the large volume of data. It detects, analyzes, documents and communicates the existence of opportunities to save energy and to reduce service costs. These opportunities include continuous lighting operation, sites with abnormally high energy use, and sites and zones that cannot maintain set point under a variety of conditions including heat waves and cold snaps.

Types of Fault Detection and Diagnostic (FDD) technology being used today

<u>In-field Fault Detection and Diagnostics</u>

In-field fault detection and diagnostics refers to computer-based tools and devices that are used by technicians on a job for short periods of time. These devices aggregate and analyze a single data set, or data log for short periods of time ranging from hours or weeks. These devices may also collect additional quantitative and qualitative data useful in managing HVAC maintenance programs, including utility incentive programs.

<u>On-board Fault Detection and Diagnostics</u>

On-board FDD for HVAC units are permanently installed systems that analyze data from sensors or controller signals over a long period of time. There have been attempts to commercialize retrofit/add-on versions of on-board FDD in the past that met with limited success usually because of their cost to purchase and install. OEM-installed FDD is now receiving the most focus and commercialization will occur. OEM-installed FDD is a more attractive option because of many concerns best addressed by the scalability, efficiency and credibility of the information. OEM FDD is just starting to be seen in the marketplace with very limited capacities at the time of this writing (early 2014). It is widely expected that OEM-installed FDD products will increase in both availability and capability in the near future. This development is generally being driven by the reduction in the cost of the components and by developments in code requirements, especially in California.

<u>Portfolio-level Fault Detection and diagnostics</u>

Portfolio-level FDD currently uses data sources that are not specifically HVAC hardware related. This includes utility bill analysis, service cost analysis as well as trending and analyzing run time and other data available from building and energy management systems (BMS/EMS).

Field Diagnostics products

Field Diagnostics has been developing and delivering FDD products and services that make field data collection easier, more accurate and more analyzable for nearly twenty years. Its primary commercial market focus is end users with hundreds or thousands of rooftop package units and commercial split systems. This includes national retail chains, restaurants and banks along with their service providers. It also provides FDD products and services for utility quality maintenance (QM) incentive programs around the US. In addition to proven technology, Field Diagnostics recruits customers and service providers for those programs, provides management and training to both and supports utility program implementers.

<u>In-field Fault Detection and Diagnostics</u>

Field Diagnostics developed and produces the HVAC Service Assistant™ tool and SA Mobile™, an application for Smartphones and tablet computers that performs without continuous internet connectivity.

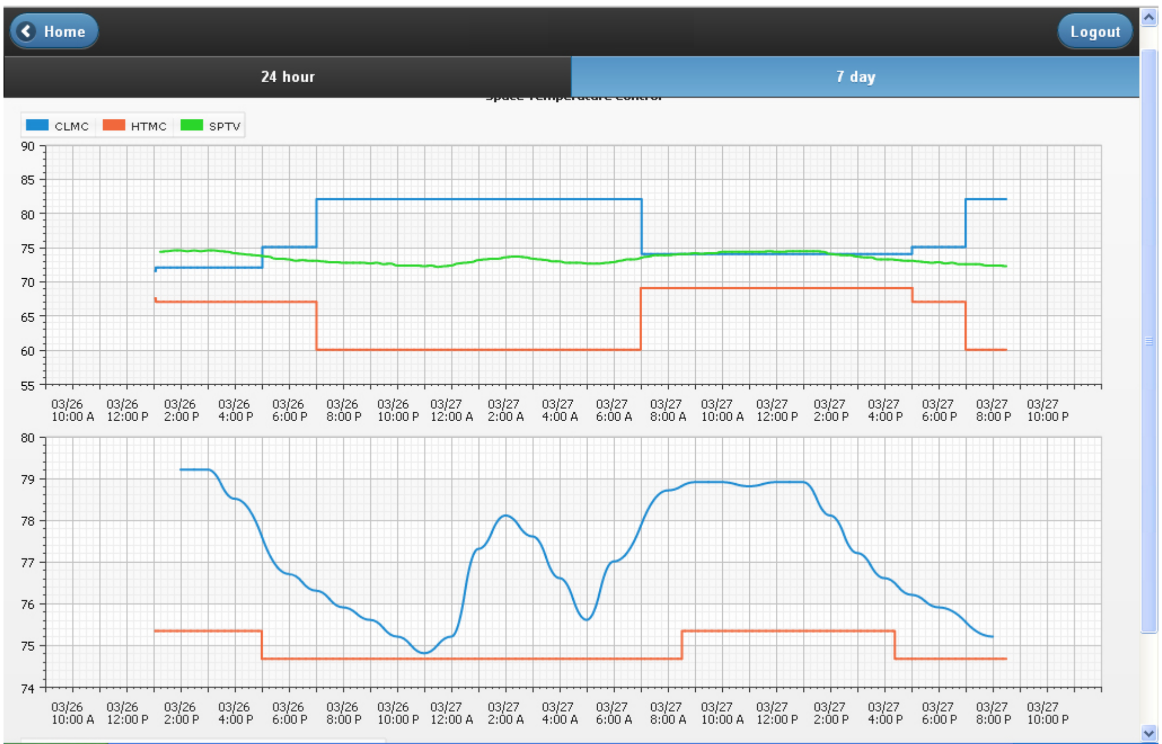
Both platforms assist technicians and others in the chain of responsibility for HVAC performance by collecting the full set of data required for refrigeration cycle performance analysis. That data is then used to produce diagnostic statements based on the difference between current performance of HVAC systems and the how they should be performing. The definition for how systems should be performing is derived from a model that was developed using manufacturers' published performance and other data. It is called this the "Normal model" or "No-fault model". This type of model is used as a reference to analyze all the different potential equipment designs over the range of driving conditions that equipment is tested under. The SA Mobile software also estimates the current relative efficiency and capacity of the system as compared to what it would be with no-fault performance. The faults detected and diagnosed include the most common refrigeration cycle faults that impact system reliability and energy efficiency:

- Excessive and insufficient low side heat transfer
- Excessive and insufficient high side heat transfer (excessive only during low ambient conditions)
- Excessive and insufficient total charge mass
- Excessive and insufficient (liquid line restriction) refrigerant mass flow
- Reduced compressor pumping capacity
- An advisory to test for non-condensables

SA Mobile™ software is also useful for collecting data with questionnaires, as would be required for equipment maintenance programs. Field Diagnostics provides maintenance-tasking questionnaires that are compliant with the ANSI/ASHRAE/ACCA Standard 180 non-residential and the ACCA 4 residential national maintenance standards. This capability is also used by various utility incentive programs around the United States and for maintenance programs used by national and regional facility managers including retail stores, restaurants and banks.

These tools, used by technicians to collect and analyze data in the field, also easily transmit the data records to a central server using cellular or Wi-Fi connections. That data may then be processed into a variety of reports including those used for technical quality control and return-on-investment analysis for sophisticated financial buyers. These reports can be configured to show unit, site, district and portfolio analysis and evaluations. The opportunities can be monetized and ranked for easy recognition of the opportunities with the most potential.

The Field Diagnostics Mobile Dashboard™ is an application for Smartphones and tablets that allow the mobile service technician to access data and analysis from the BMS/EMS system while they are on-site. They can see twenty-four hour and seven day trends of each zone's set points, the zone temperature the supply air temperature and the calls for cooling or heat. This provides a useful overview of the performance of each zone. This means that a technician can investigate comfort complaints efficiently and pin point the location and the context of a comfort problem quickly and easily. This greatly increases the probability of an effective repair, leading to lower costs and fewer return trips.



The Mobile Dashboard™ also shows the lighting schedules and the lighting operation. Technicians can proactively resolve excessive lighting runtime problems as well as HVAC and zone performance problems while at a site.

The Field Diagnostics Mobile Dashboard™ is the in-field user interface for portfolio level data collection and analysis.

<u>On-board Fault Detection and Diagnostics</u>

Field Diagnostics has developed a software package and sensor specification for Original Equipment Manufacturers (OEM) that is included in control hardware installed in the factory. This software analyzes the performance of the refrigeration cycle and issues advisories over building managements systems and directly to technicians on the job. The faults detected currently mirror those detected by the Service Assistant™/SA Mobile ™ in-field FDD technology. On-board FDD collects data continuously. This offers the opportunity to detect faults and degradations that are best observed under specific conditions and to detect subtle faults with much a lower risk of "false-positives", meaning detecting an operational anomaly as a fault when no fault exists, by imposing extended persistence qualifiers prior to issuing a fault notice. Additionally, the embedded diagnostic capability provides a larger continuous and more detailed data set for use with portfolio level diagnostics.

Portfolio-level Fault Detection and Diagnostics

Field Diagnostics provides analytics based on "Big Data" to help define energy and non-energy savings opportunities for large multi-site clients. Recommendations are based on utility bill and service cost analysis as well as Building Management System (BMS/EMS) time-series data. Reports include finding the sites with the greatest savings potential and providing specific and actionable recommendations including HVAC capacity loss, excess ventilation and set point abuse, as well as lighting schedule overrides. Higher level analysis is available to document zones and units that have shown the inability to meet their set point requirements during heat waves and cold snaps. This allows facility managers to target these units to avoid comfort problems and potential facility and equipment damage in the future.

As stated above the Field Diagnostics Mobile Dashboard™ is the in-field user interface for portfolio level data collection and analysis. This capability reduces call center traffic and empowers the field service provider to investigate complaints more efficiently and to be proactive in finding and acting upon problems that cause excess energy use while on site.

When thoughtfully implemented and operationalized, portable, on board, and portfolio-level FDD leverage each other to help maximize energy efficiency (lower utility bills), comfort and reliability (ensure productivity and commerce), and to increase the useful life of HVAC systems in order to reduce and delay capital expenditures.

Implementation of Fault Detection and Diagnostic Technology

In-field Diagnostics

Common initial approach

When applying diagnostic tools in the field, there are two approaches customers commonly choose in non-incentivized environments. One is to authorize a pilot program; often five to ten locations chosen based on some criteria related to energy cost or perceived chronic reliability problems. A second common approach is to add the diagnostic capability to a regularly scheduled visit, usually a maintenance inspection. These attempts at implementing diagnostics have the objective of gathering data, assessing opportunities, effectively addressing issues and reporting achieved benefits.

Another implementation approach to in-field diagnostics has been through utility energy efficiency incentive programs. These programs have the goal of reducing energy use and peak demand by making HVAC systems perform better. Because ratepayer or taxpayer funds are employed, as a rule utility programs cannot make use of proprietary technologies. The unintended consequence of this policy is that patented, market-ready FDD products such as Field Diagnostics' can go unused or unsupported by program implementers for years while less effective technologies and approaches in the public domain are supported. Despite this barrier, the use of Field Diagnostics' two in-field FDD platforms have been very useful in gathering data about the general condition of equipment in service and the effectiveness of various approaches to diagnostics. They have supported research into the prevalence, the magnitude and the root cause of inefficient system performance.

Field Diagnostics has participated is many utility incentive programs over the years. While meeting the program requirements, Field Diagnostics has delivered analytics and services that exceed most program requirements. The most notable and significant improvement over standard issue publicly-funded programs delivered by Field Diagnostics' approach has been the documentation of both 1) proof that faults have been eliminated by the work done, and 2) the performance gains made by those improvements in terms that make sense to customers The Field Diagnostics approach has been to analyze each refrigeration cycle and apply the services needed to achieve a "Safe and reasonable" diagnosis and at least a 90% efficiency estimate at each unit, based on the Service Assistant™/SA Mobile™ assessment. This methodology is gaining acceptance in the incentive program world and is moving the utility incentive program industry to adopt specifications more along the lines of the Field Diagnostics approach.

Implementation challenges

HVAC provides several kinds of challenges to facility managers. These include comfort complaints from internal and external clients, perceived and actual high service and energy costs, capitol planning and the complicated decision-making around selecting candidates for replacement, and service provider selection and management. The metrics used to make choices and to judge success are often subjective or poorly focused because of a relative lack of dependable data. There is a need for a simplified and scalable process for interpreting the data that is available. Those in the position to make HVAC maintenance, service and replacement decisions many times are not technical or analytical experts and usually have a different skill set than their "professional energy manager" colleagues where maintenance usually is not considered an energy management measure.

Sometimes, effective implementation of advanced diagnostic techniques are challenged from the onset because objectives are poorly defined, or because the approach requires service providers to behave in ways that unnecessarily increase costs or reduce the value of the outcome.

Some common in-field diagnostic implementation strategies that lead to disappointing results include:

1. Assuming that service providers are already skilled in the new technology and do not require more than a few hours of training.
2. Using an incumbent service provider that is unsuited or not interested in advanced technology or change itself.
3. Selecting a small group of sites based on some criteria other than evidence of a savings opportunity that is capture-able through maintenance. These may include selecting sites near their office or sites where the HVAC equipment is beyond reasonable repair.
4. Setting expectations that each unit at a selected site will be working "perfectly" when the work is complete, this means expending valuable resources on units that are performing adequately, merely because they exist at the same site as poor performers and therefore are under added scrutiny during the project.

Lessons learned

HVAC equipment's current performance, relative to design expectations is highly variable because of a range of factors. These include the equipment's age, how well it is maintained, how much it runs and, how well the system it is a part of was originally designed and constructed. Some fleets of equipment are well maintained while others less so. Experience has shown that the best maintained equipment may have as few as 10% of the fleet performing poorly. However there are some fleets where essentially every unit has serious performance problems. On average, in a normally maintained fleet of HVAC units, about a quarter to a third of the units will represent 80%-90% of the energy savings and bill reduction opportunity. Finding and documenting the units that are performing poorly, prior to applying a basket of services is a good initial approach. Auditing the entire fleet and producing an accurate current inventory with enough data to detect and rank opportunities is a definite best practice.

Establishing achievable goals for the implementation and then designing an approach that takes into account the condition of the equipment, the budget available for investment in performance improvement and the capabilities of the people and systems involved in implementing the solution greatly increases the probability of success. There are many variables that make defining a cookie-cutter solution that will work everywhere difficult. However there are some characteristics of a successful plan including:

1. Define the group of units that are performing poorly and have the better opportunities for measurable improvement and return on investment.
2. Target that group in a way that focuses most of the effort on the units with the performance problems. Some examples might be a plan where only the units identified as poor performers are addressed, or a plan where the performance of all the units at a site are averaged and the sites are ranked and a common basket of services are applied to all units at the sites with the most savings opportunity.
3. Understand that customers have budgets and package solutions that do not exceed them. By ranking the units or sites and focusing on the larger opportunities, the budget can be managed to produce the best return with the available investment and the project can pause when the budget is exhausted.
4. Be clear with the service provider about the goals of the program, how success is being measured and how to communicate unexpected information early in the process. Bring the service provider into the planning process and get agreement to the plan from the whole team.
5. Be flexible when unanticipated obstacles arise. Very often the best answer is to temporarily bypass a problematic site or unit and then re-engage it when the issue is resolved. Some examples of this may include sites with access problems or sites or units that need repairs outside the scope of the program like compressor or fan motor replacement.
6. Train the people that are doing the work. This includes training on the use of the

technology, effective testing procedures and equipment performance prior to the audit and then training on effective cleaning and adjustment procedures when remediation work has commenced. Write clear step-by-step instructions and make them available on a single laminated page for use in the field. Do not assume that any technician, regardless of how much experience they have will know what the expectations are and what the definition of success is for a job.

7. Have a plan for reporting results and an expectation that there will be a formal meeting where final results are delivered to the people that will make the judgments about the effectiveness of the program. Work to get explicit agreement about the resources expended and the benefits produced.

Benefits produced

There are a range of benefits that could be expected from the implementation of in-field diagnostic technology in a HVAC maintenance program. These include:

1. A current and accurate equipment inventory
2. Data about the condition and performance of each unit that can be processed into effective reporting:
   a. Exception reports showing unfulfilled maintenance requirements
   b. List of units that are inoperable and what is required to return them to service
   c. Ranked list of opportunities to save energy
   d. Ranked list of opportunities to resolve problems that lead to service interruptions and premature compressor failures
   e. Ranked list of replacement candidates based of a pre-determined selection formula

<u>On-board diagnostics</u>

Common initial approach

On-board diagnostic capabilities in HVAC equipment is on the cusp of commercialization primarily because, despite barriers, the potential benefits of this technology are high. A university study concluded that automated FDD reduces service costs due to reduced maintenance inspection (tasks), fault prevention, lower cost fault detection and diagnostics, better scheduling of multiple service activities and better scheduling to the low season.

Operating cost savings consist of utility cost and equipment life savings.[1]

Implementation strategies are still being worked out. The current theory is that the diagnostic messaging will be communicated in several ways. Units that exist on a building network will carry the diagnostic messaging, presumably integrated into the BMS/EMS front-end. However, the great majority of HVAC units are "stand alone" meaning no such network connection exists. It is envisioned that these units will integrate with indicators expected to be included on the thermostat interface to alert the building occupants of detected issues. Additionally it is assumed that there will be a way to inform the technician at the unit either through a display in the unit or through a user interface brought to the job. The thought is that it may be a specialized tool that will plug into an access point provided or a general purpose device, like a Smartphone or tablet computer that will communicate wirelessly. Ultimately, the expansion of the wireless Internet is likely to make communication with each unit simple.

It is currently assumed that diagnostic messaging from OEM diagnostic modules will be managed by each OEM's proprietary system. It seems likely based on the history of technology development that an open system will ultimately be the choice of most manufacturers and consumers.

There have been attempts to retrofit diagnostic capabilities into existing HVAC units. The cost of the equipment and especially the installation cost made them unattractive when combined with the immature communication infrastructure and absence of a common system to manage the diagnostic outputs. However, a retrofit solution may make sense for larger units with complicated controls and applications with persistent performance problems.

Implementation challenges

At the current state of development, the most significant barrier to implementation is the lack of availability of OEM-enabled HVAC units in the marketplace. This is likely to be addressed in the next few years. Product delivery is expected to start in 2014.

When product is available, it is easy to predict that early adopters will embrace the technology, and assuming the rollout is managed effectively, and that the infrastructure to manage the diagnostic messaging is forthcoming, wider adoption will follow.

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[1] Li, H., and J.E. Braun. 2007. Economic Evaluation of Benefits Associated with Automated Fault Detection and Diagnosis in Rooftop Air Conditioners. *ASHRAE publication LB-07-023*

When that happens, resistance to change and risk aversion are likely to be factors hindering wide scale adoption, while code requirements and perhaps other encouragements and incentives will drive wider adoption.

Portfolio level diagnostics

Common initial approach

When implementing a "Big Data" analytics strategy, it is easy to see a large variety of opportunities and attempt to "boil the ocean", for example to attempt to integrate several data sources and provide analytics to produce a comprehensive management system for energy opportunities across their portfolio. Such a goal might seem right to ambitious facilities and energy managers, but in reality, setting such an unrealistic goal is likely to lead to frustration and disappointment.

Experience has shown that you can spend a lot of money and time, and discover far more opportunities than the facilities management and mobile workforce systems in place can possibly react to. Successful portfolio analytics implementation programs start by trying to do some simple useful things and then build on small successes incrementally.

One example of a measured approach might include determining the top ten sites in terms of energy use measured in kWh per square foot from analyzing the utility bill and lease data. Then, using the time series data from the BMS/EMS systems, try to determine if the problem is a lighting control problem or a HVAC performance problem. With this information, a technician can be dispatched to investigate further and hopefully find a cause of the problem that can be repaired. The following month, perhaps five more sites could be added to the list. After several months, if things are going well, an impact on energy use will start to be evident in the utility bill analysis. After several more months, some sites may be declared "fixed" and removed from the list. Some sites will probably be "stubborn" and require specialized investigation to determine the cause of the abnormal energy use.

Another example might be to use the BMS/EMS data to detect units and zones that are not performing well. There may be several levels of severity to consider. For example, in order to keep the number of opportunities to a minimum, the goal might be to find zones that the data shows have not maintained the set point only during heat waves and cold snaps in the past. The aim would be to reduce the rush of comfort complaints during extreme weather conditions. After that has been addressed, the goal may switch to finding zones that are currently not maintaining comfort. That will be a larger list and may take a substantial amount of time to clear and have a variety of root causes. A very sensitive version of this concept would be to find the zones that are maintaining the set point but where the units are running nearly continuously to accomplish this.

Another example of a simple approach that pays well in terms of energy saving and cost reductions would be to find the sites where the interior or the exterior lights remain on continuously. Depending on the specifics of the organization and the facilities, addressing this might be as simple as making phone calls to the sites and asking that the hand/off/auto switches be returned to “auto”. This works sometimes. However, there are times when the reason for the override becomes clear and a schedule change is required to make the override unnecessary. There will be other times when the people at the site just disagree with the level of lighting during reduced lighting periods. There will be sites where there are equipment failures that must be addressed to get the system back under control.

An example of a relatively sophisticated analysis that can make a huge impact on energy use if acted upon is analyzing the relationship between the outside air temperature, the return air temperature or zone temperature and the supply temperature when the fan is running without heating or cooling. This analysis is used to quantify the amount of air in the supply that came from the outside. Resolving over-ventilation is one of the highest-impact energy savings opportunities available in buildings today. In some cases, something as easy and inexpensive as adjusting a programming variable, like the changeover set point, is something that can be done once and has an impact on the entire portfolio.

Some organizations prefer systems or processes that are self-implementing and self-managing. An example of this would be to provide information about energy use and HVAC performance and lighting operation to site managers or to mobile workforce technicians and creating an incentive for improvement. Incentives are tricky however and it may take several iterations before an incentive scheme is found that produces the desired behavior.

Implementation challenges

There are challenges at several levels when implementing an analytics strategy that may have to be overcome to produce good data, accurate analysis and action to resolve the operational problems and achieve measurable results. Some of the challenges may include gathering the data required. Some of the obstacles may include the availability of, or access to data, inconsistent naming conventions and inconsistent data collection strategies. Some of these challenges may be resolved relatively easily. Others will not and will limit the analytical possibilities, at least in parts of the portfolio. These obstacles might include permissions to access data, incapable or uncooperative vendors or in some cases, the required data is simply not being collected, or is not collected in a way that can be accessed at scale.

Having accessed the data that is going to be collected, the data will need to be validated and normalized. The data will need to be tested for validity and invalid data removed. It is helpful to create statistics to help judge the quality of the data for analysis. For instance if 95% of a particular data point is invalid, the usefulness of that data may be limited.

If the sites are distributed geographically, it will be necessary to do weather normalization to compare the sites to one another. It is so common as to be considered a universal fact that the cooling capacity per square foot will range widely across a portfolio and the variation is usually not easily explainable. Normalization for equipment density is required if valid runtime analysis is a goal. Other normalizations include variations in operating hours and the activities carried out in the facility as it may cause wide variations in internal heat gains.

Lessons learned

Experience has shown that overcoming technical challenges are relatively straight forward compared to the challenges introduced by people. Finding opportunities is easier than getting them acted upon. Change management within an organization is an important part of any implementation process involving people. Change management is a field of study in itself.

American John P Kotter (b 1947) is a Harvard Business School professor and leading thinker and author on organizational change management. Kotter's highly regarded books 'Leading Change' (1995) and the follow-up 'The Heart of Change' (2002) describe a helpful model for understanding and managing change. Each stage acknowledges a key principle identified by Kotter relating to people's response and approach to change, in which people see, feel and then change.

Kotter's eight-step change model can be summarized as:

1. Increase urgency - inspire people to move, make objectives real and relevant.
2. Build the guiding team - get the right people in place with the right emotional commitment, and the right mix of skills and levels.
3. Get the vision right - get the team to establish a simple vision and strategy focus on

emotional and creative aspects necessary to drive service and efficiency.

4. Communicate for buy-in - Involve as many people as possible, communicate the essentials, simply, and to appeal and respond to people's needs. De-clutter communications - make technology work for you rather than against.
5. Empower action - Remove obstacles, enable constructive feedback and lots of support from leaders - reward and recognize progress and achievements.
6. Create short-term wins - Set aims that are easy to achieve - in bite-size chunks. Manageable numbers of initiatives. Finish current stages before starting new ones.
7. Don't let up - Foster and encourage determination and persistence - ongoing change - encourage ongoing progress reporting - highlight achieved and future milestones.
8. Make change stick - Reinforce the value of successful change via recruitment, promotion, new change leaders. Weave change into culture.

Kotter's eight step model is explained more fully on his website ww.kotterinternational.com.[2]

Adding analytics to an organization's process is very often not just change, but also a design-as-you-build project. It is not always clear in the beginning which analytical insights will be found to be useful and usable to the team. Attempting small but useful changes over a period of time greatly reduces resistance and increases the probability of success. Contrary to the conventional wisdom, the hardest part of implementing a performance improvement strategy is not getting started, it is getting beyond just getting started and getting the first measureable success. Everything gets easier when people see something working and producing a tangible benefit.

Portfolio level analytics works best as part of an overall analytical strategy that includes in-field diagnostic technology and a management system that drives results. In such a system, portfolio-level diagnostics provides evidence that an opportunity exists at a particular site and sometimes points to a particular system as a suspect. In-field diagnostic technology and data capture may be needed to acquire more granular information to identify specific actions or to capture data about what was found and what was done to resolve the problem. Capturing resolution data can be valuable to inform future investigations and for reporting.

Reporting results to decision makers is essential to getting agreement that benefits are

[2] Excerpted from http://www.businessballs.com/changemanagement.htm

being captured. Getting agreement about the costs and benefits derived from the effort is often required to maintain funding for the project. In a very real way, if success is not reported, it does not exist.

Benefits produced

The main benefit of analyzing data at the portfolio level is to, in a systematic way, find, define, document and rank the opportunities, including their potential financial value, so that they may be addressed in a logical way and to measure and report improvements. The opportunities found may be systematic, meaning a change made will have an impact across the portfolio, or they may be site or unit specific issues.

Systematic improvements might involve adjustments to control strategies, or changes to policies like the maintenance protocol. Site-specific improvements include finding units bringing in excessive amounts of outside air because of faulty or poorly designed or installed economizers.

The main benefit sought is usually a reduction in costs. These could be energy costs as in the case of finding the sites with the lighting on continuously, or there could be energy reductions combined with comfort improvements as would result for resolving excessive ventilation cases. It also might be reduced service costs by detecting units with diminished capacity and making that information available at the time when a technician is at the site for another reason and can address the issue without a special truck roll. The largest return on investment comes from finding units that are performing poorly and targeting them for visits by technicians, sometimes equipped with in-field diagnostic technology, with the desired result being finding and resolving operational anomalies that would otherwise lead to premature failures of the compressor or gas heat exchanger.

Proactive maintenance has the best return on investment because compressor and gas heat exchanger failures often precipitate an unplanned unit replacement and the net present value of a few years of additional equipment life is often very high compared to the cost of solving the problem prior to failure. This was made clear by a widely distributed study of the economic value of preventive maintenance by one of the largest property management companies in the world[3]. That study shows that "an investment in preventive maintenance

[3] http://maintenance5.com/Determining-the-Economic-Value-of-Preventive-Maintenance-pdf-e585.html

not only pays for itself but also produces a huge return on investment". The study went on to say "At the portfolio level, the analysis indicated… a ROI of 545 percent. The bulk of the return comes from increasing the useful life of equipment."

Conclusion

Field Diagnostics Services, Inc. has been developing and deploying HVAC diagnostic technology and using it to create energy savings benefits and non-energy benefits for end users and service providers since the mid 1990's. Nearly twenty years of experience has shown that the common expectation that HVAC equipment performs poorly can be true. There has been some hard won wisdom gained in that time, including these ideas:

- While HVAC equipment performance is too often weak, finding and addressing the specific needs of the weak performers is far more cost effective than applying a common basket of services to every unit in a portfolio.
- Old habits die hard. The customer must drive the adoption of diagnostics and more sophisticated servicing techniques. Contractors do what the customer requires and is willing to pay for; technicians do what the contractors require for them to keep their jobs.
- Contractors will be profitable or they will cease to exist. Pressure from customers to reduce maintenance costs inevitably reduces the time technicians spend with equipment and just as inevitably, HVAC units performing poorly will continue in that state longer and fail earlier. Many fixed price contracts make any activity that doesn't directly impact comfort an uncompensated expense to the service provider. By allowing for extra payments for compressor replacements and no payments for activities that reduce premature compressor failures, customers create an incentive for service providers to neglect their equipment and actively reduce their service life. This is a particularly counter-productive strategy for the end user.
- Technicians need to be trained to use diagnostic technology and they also need to be trained and encouraged to do the tasks that produce good running units. It is not logical to assume that a technician will work harder to solve a problem that does not impact them personally without encouragement and support, and even the requirement from their employer.
- The customer must see and feel the benefits of diagnostics in terms of increased occupant satisfaction and reduced operating costs in order to invest in quality maintenance and better servicing techniques. Data driven reporting is key to customer adoption.
- There are opportunities to find additional savings with very attractive returns on the investment in data analysis by finding easy to understand and easy to repair operational anomalies like the

continuous operation of lighting by analyzing utility bills and BMS/EMS time series data.

- There are further savings opportunities provided by more sophisticated analysis of zone temperature performance and runtime analysis.
- Providing access to existing lighting operation, zone temperature and set point data and zone temperature performance to the mobile service technician empowers the technician to be proactive, resolve problems, and produce energy savings with very limited additional cost when they are already at a site.

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