Using Automated Diagnostic Tools to Provide Energy Services

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ABSTRACT

Recently, a small number of automated diagnostic tools for building systems have become commercially available. These tools distinguish themselves from analytic software and trouble-shooting tools by automating the actual process of reaching conclusions from empirical data. Their distinction is that they produce easily-used information from raw data. These tools can be contrasted with tools that provide assistance in diagnosis, for example, by plotting data in various ways so performance problems can be detected and diagnosed by a knowledgeable expert. The availability of such expertise is limited and applying it manually takes considerable time. Automation reduces the time required for performance-problem detection and the associated costs.

This paper focuses on the energy service business opportunities made possible by the advent of automated diagnostics for buildings. We start by classifying diagnostic tools by their degree of automation, and then focus on illustrating how automated diagnostic tools can be used, with other modern information technology (such as cellular phones and the Internet), to provide increased value to building owners and occupants. These applications can serve as the basis for new energy service businesses, enhancements to services currently offered, or ways to reduce the cost of offering energy services. The paper provides a number of examples of how automated diagnostic tools can be used and the specific benefits that use can bring. A few examples include: continuous monitoring and diagnosis as part of on-site building operation, remote monitoring, detection and diagnosis of performance problems for many buildings and facilities as a service from a central location, application of automated diagnostics to reduce the cost and improve the thoroughness and value of commissioning services, providing continuous commissioning after initial commissioning, reducing unnecessary service calls for service contractors, and using automated diagnostics to improve maintenance and repair service while reducing costs, reducing risk and maximizing profit for energy providers. This paper examines these use scenarios and shows how automated diagnostics could enhance them or make them possible.

Introduction

In recent years, a small number of automated diagnostic tools has become available commercially (Facility Dynamics Engineering 2000, Field Diagnostics Services 2000, Brambley et al. 1999, Rossi and Braun 1997, Brambley et al. 1998). These tools join a number of other software-based tools that provide analysis specifically in support of diagnosis (Architectural Energy Corporation 2000, Frey 1999) or that can be used during diagnosis of problems with buildings and heating, ventilating, and air-conditioning (HVAC) systems.

These tools provide new business opportunities through their potential for enhancing current service offerings or serving as the basis for entirely new services. This paper describes several of these potential opportunities.

Automated Diagnostics for Buildings and HVAC Systems

What do we mean by automated diagnostics? Webster's (Webster's 1999) defines diagnosis as "The act or process of identifying or determining the nature of a disease by examination" and diagnostic as "Of, relating to, or used in diagnosis." The process of diagnosis is often described in the technical literature on diagnostics for engineered systems as consisting of two primary parts: 1) fault detection and 2) fault classification, followed by a decision regarding whether to correct the fault or not, which is fault evaluation (Rossi and Braun 1997). Fault detection is the process of identifying a deviation from desired or expected behavior. Fault classification is the process of locating where and what kind of fault has occurred in a system or device. Frequently, for purposes of clarity, the process is called "fault detection and diagnosis" to provide some distinction between the process of detecting and the process of diagnosis.

An alternate view describes diagnosis as a stage-wise process of fault detection at greater and greater levels of resolution. At each level, faults are identified based on empirical evidence. The cause of that fault is then investigated by comparing actual behavior to expected or desired behavior (e.g., using rules, qualitative models, engineering-based numerical models, statistical models, gray- or black-box empirical models, etc.) to identify a fault at the next greater level of resolution, which is then called the cause of the initially detected fault. This process can then be repeated ad nauseam until the desired level of cause is identified. The original fault can then be corrected by eliminating the cause at the desired level of resolution. When viewed from the perspective of a causal chain, and the process is taken to a "reasonable" origin, the process is sometimes called "root cause analysis." (Jarrell 1999)

The distinction between these two views and others is not important from a practical perspective. Whether the process is separated into fault detection followed by diagnosis, is viewed as a continuous process of fault detection at greater and greater levels of resolution or further back in the causal chain, is called root-cause analysis, or is lumped together and collectively called diagnosis is mostly semantic and of little importance in practice. For purposes of this paper, we will consider any system that detects a fault and identifies the cause of that fault to one level deeper, or one step further back in the causal chain, as diagnosis or a diagnostic process.

Automated and Manual Diagnosis

Probably more important is the distinction between automated and manual diagnosis, but even this distinction is blurred by unclear boundaries. Fully automated might be defined as diagnosis without any human intervention, except to receive the final results of the diagnosis. Such an automated process might obtain empirical data about a physical system (e.g., time, temperatures, pressures, rotational speed, energy consumption, etc.) automatically and output the results of diagnosis in a form that a human can use, such as the printed message "component X has failed and needs to be replaced." In a medical domain, you could imagine a machine that automatically takes your body temperature, blood pressure, throat culture, skin wetness, etc. and prints out a message that you have Influenza type B. On the other hand, manual diagnosis would involve a human collecting and reasoning about a set of symptoms and reaching a conclusion about the state of some system. As an example, consider the auto mechanic of old. The mechanic takes a drive in the car, hears a certain unsteady engine “purr,” hears pinging when a load is applied to the engine during acceleration, feels poor power output during acceleration, and concludes that the engine’s timing is not properly set. No mechanical, electrical, magnetic, or other data collection, analysis, or diagnostic tools, other than human observation of the automobile in operation, were used to diagnosis the problem. Consequently, this is an example of completely manual diagnosis.

Most diagnosis done today uses a combination of manual and automated processes, spanning the entire spectrum in degree of automation. Frequently, some degree of automation is used in collecting data, analyzing data, or preparing presentations of data. The recent advances in the field of diagnostics for building performance and HVAC systems have been related to automating the process of reaching diagnostic conclusions (Rossi and Braun 1997, Katipamula et al. 1999). In this paper, we consider diagnostic tools that automate this process as the most advanced and most appropriate to call “automated diagnostics;” yet in discussing business opportunities we also include business propositions that rely on less complete automation of the diagnostic process.

Why Automate Diagnosis?

A key difference between manual and automated monitoring and diagnosis is in cost and quality of fault detection and diagnosis. Computer technology is relatively inexpensive. For the last two decades, the cost per unit of computer power has roughly obeyed Moore’s Law with power doubling approximately every 18 months. Data storage capacity changes have improved even more rapidly. Labor, in contrast, is relatively expensive, and appears to get more so with time.

Computers are very good at many things for which humans are not. Some examples include: performing complex numerical and symbolic manipulations rapidly, performing highly repetitive calculations rapidly and reliably, managing large amounts of information, and monitoring the conditions of a process or system continuously. Because computers are good at repetitive processes, they can provide consistency in processes. Where a human inspector might take short cuts occasionally, an automated process will be done the same way every time. An automated monitoring system can also “watch” conditions of a process or system continuously, seconds to second and year after year. As a result, where automatic data acquisition and computer processing power can be substituted for labor-intensive manual processes, costs often decrease significantly, while frequently elevating the responsibility of the personnel involved and ultimately increasing the quality of service.

Humans, on the other hand, are good at eliminating unrealistic options such as possible causes of a fault very quickly. Humans can exercise judgement that is context sensitive, are creative, and can collect a very broad set of information that is often costly to replicate using non-human sensors. Examples of the latter include, but are not limited to, any data that can be collected by visual inspection. The “human sensor” can see physical conditions, can sense distance optically and acoustically, can feel and hear vibrations, can sense acceleration and deceleration, can smell or see many gaseous, liquid and particulate emissions, can feel heat, etc. This “human sensor” suite is portable, with processing on board in the brain. A suite of sensors that replicate just the sensing that humans can provide can be quite costly.

Humans and computers bring different capabilities to the process of diagnosing; so, selecting the right combination of automated and manual processes is one of the keys to successfully using automation. In diagnosis, as in other activities, there is probably an optimal combination of automated and manual processes that is system- and problem-specific. In addition, the optimal combination changes over time as new technologies become available and costs change. The key to using automation effectively is to gain the advantages of automation that are cost-effective as time progresses. Currently, there appear to be abundant opportunities to apply automation to detecting and diagnosing performance problems in buildings that affect energy consumption, indoor environmental conditions, and operating costs. The sections that follow give some examples of how automated diagnostics can be used to enhance building services provided as a business.

Business Propositions Based on Automated Diagnostics

The purpose of this section is to share a range of selected business propositions that emerge from the availability of automated diagnostic tools. Some innovative HVAC service companies and energy service providers already are testing some of these propositions. Our purpose is to share ideas, identify benefits, and hopefully contribute to stimulating sufficient interest that we begin to see services based on these models becoming available in the next few years.

Continuous Monitoring And Diagnosis As Part Of On-Site Building Operation

Probably one of the most evident applications for automated diagnostics is to assist building operators keep building equipment "tuned" and operating properly. An automated diagnostic tool connected to a building automation system (BAS) can continuously provide monitoring and diagnosis of mechanical equipment and system performance. The diagnostic tool could provide alarms when problems are detected. These alarms could be prioritized with the type of communication with operations staff depending on the priority of the problem. Minor problems might be logged and provided in a daily or weekly hard printout that operators review periodically. Critical problems, such as failure of a bank of compressors in a refrigerated warehouse might be communicated by placing a highly-visible alert on a computer screen or communicated via an automated phone call to an operations supervisor at home via cell phone, pager, or wired modem, during off hours. Alternatively, building operation staff can periodically during their shifts check for alarms on a computer monitor. When alarms appear, the diagnostic system's results can be examined more completely to identify the problem more specifically, identify the causes of the problem, and to assess the importance of the problems.

Several benefits result from automated diagnostics used in this manner:

- Problems are detected and corrected that otherwise could go undetected for long periods of time.
- Depending on the depth of diagnosis provided by automated diagnosticians, repair and maintenance can be directed better toward solving root causes of problems rather than just treating symptoms.
- Operations and maintenance staff using the system will more consistently handle problems.
- Inexperienced operations staff are guided to the causes of problems more quickly.

- Over time, inexperienced operations staff learn by correlating their observations of equipment with the diagnoses, while making fewer mistakes.

Automated Diagnostics for Building Start-Up and Commissioning

Building start-up and commissioning involve inspections and testing of building equipment to ensure that it operates as intended and is "tuned" to minimize energy consumption and provide acceptable indoor environmental conditions cost-effectively (PECI 1998). Diagnostic tools that take data and automatically determine whether equipment and systems are operating as intended can streamline parts of the commissioning process. When used as a commissioning tool, data can be collected over a few-week time period using data loggers or the logging capabilities of an existing BAS. These data can then be transferred to a diagnostic tool that processes the data and diagnoses any problems found. The results can then be displayed for the period for which data have been collected. Where manual data collection, analysis, and interpretation can be replaced by automated processes, several benefits are possible:

- Less time required to perform commissioning tasks.
- Lower costs as a result of smaller labor requirements.
- Implementation of consistent procedures during commissioning for those activities automated.
- Elimination of data entry errors for cases where the automated diagnostician automatically collects data.
- Data archives can be automatically created from the diagnostician's database.

Lower costs for commissioning could lead to either commissioning for lower total cost or enhanced, more complete, services for similar costs. All the benefits of use of automated diagnostics during on-site building operation accrue. For example, if automated diagnostic tools are installed in the building at the outset of commissioning activities on site, they could be left in place after commissioning and used by the building operators. Provided that operations staff correct problems identified by the diagnostic tools, the tools then become an agent for promoting continuous commissioning as part of ordinary building operation, preserving savings and making commissioning much more cost-effective.

Automated Diagnostics for Retro-Commissioning

As with the startup of new buildings, automated diagnostic tools can benefit the commissioning of existing buildings (retro-commissioning). The use of automated tools for retro-commissioning is similar to that for startup of new buildings. Data can be collected by stand-alone loggers, by a BAS, or the diagnostic tools can be installed on site and left in place to assist building operators preserve the improvements captured during commissioning. Retro-commissioning, however, provides one more opportunity not available for new buildings. Historical data logs can be used to find and diagnose operation problems. Historical data can be processed using the automated diagnostic tool to identify problems that have occurred in the past and been corrected or that still persist. Historical data records can be extremely valuable because they often cover seasons and conditions (and modes of equipment operation) other than current ones. This can eliminate the need to revisit the site during other times of year to complete commissioning, to artificially exercise equipment to simulate performance in other modes of operation, or to forgo tests corresponding to other modes and leave the commissioning incomplete, all of which increase costs or leave the commissioning job incomplete.

As an example of the value of automated diagnostic tools for commissioning, the authors refer to their own experiences. They and their colleagues have found problems in every commercial building in which they have tested an automated diagnostician known as the Whole-Building Diagnostician (Katipamula et al. 1999, Pratt et al. 2000). One of the tools in this diagnostician, which monitors and diagnoses outdoor-air ventilation and economizer operation, has found stuck or inoperable dampers, incorrect operation schedules, poor control, excess ventilation resulting in energy waste, inadequate ventilation potentially resulting in poor indoor- air quality, and failed or poorly located sensors. These problems have been found in about 70% of the air handlers connected to the diagnostician and in every building tested. It is anyone's guess how long these problems have persisted and the cumulative consequences associated with them. One thing is clear, however, these problems went undetected prior to use of this automated diagnostic tool.

In summary, the benefits of automated diagnostics used for retro-commissioning include:

- Less time required to perform commissioning tasks.
- Lower costs as a result of smaller labor requirements.
- Implementation of consistent procedures during retro-commissioning for those activities automated.
- Elimination of data entry errors for cases where the automated diagnostician automatically collects data.
- Discovery of problems difficult to find without automated diagnostics.
- Ability to benefit from historical data logs.
- When left in place to assist operators, automated diagnostic tools can help ensure the persistence of commissioning improvements.

Hand-held Diagnostic Tools for Service Technicians

Automated diagnostics can be packaged as hand-held tools that technicians take on service calls. A good example of such a tool is Field Diagnostic Services' ACRx hand tool (Field Diagnostic Services 2000). This tool uses six (or nine for extended capabilities) on-site measurements of pressures and temperatures to verify proper performance or diagnose performance problems of rooftop HVAC units. Such hand-held tools speed diagnoses on site so technicians can spend less time on the call and start repairs sooner, ensure consistent, high-quality, diagnoses by all service technicians, and store data for uploading to a company database.

Benefits of such tools include:

- More efficient, less-costly service calls.
- Consistent, high-quality, diagnoses by all field personnel by using knowledge embedded in the tool.
- On-the-job training of less experienced technicians by use of the tool.
- More thorough set of calculations than might be performed on-site without a hand-tool.

- Fewer calculation and data entry errors than the non-automated process.

Hand-held automated diagnostic tools can contribute to more competitive (i.e., lower-cost) equipment servicing businesses. Facility owners benefit from lower-energy bills, longer lifetimes for equipment, and better conditioned space, when these tools are used.

Centralized Monitoring and Diagnostic Services

One model for ensuring good building performance is to use automated diagnostic tools at a central technical service site. Such a center might be established by the owner or manager of multiple facilities (e.g., a university campus, a facility management company, a retail store or restaurant chain) or by a service contractor. For both, data would be automatically collected at each building and sent to the technical center, where the data would be automatically processed, problems brought to the attention of staff, the impacts of problems determined, and data archived for future reference. Repair and maintenance staff would then be dispatched with the proper equipment and replacement parts only to those buildings having problems of sufficient impact to warrant correction immediately. Other less-significant problems might be recorded and included in a service call later, when more significant services are required.

This model concentrates technical expertise at a central site, where the best technical talent could be provided the best tools to improve performance at the largest possible number of buildings. Many unnecessary service calls could be eliminated, and much more uniform quality of service could be provided at all buildings and to all customers. By eliminating unneeded service calls, ensuring that field technicians arrive on site with the proper equipment and parts, and using the best expertise to determine what actions to take, the cost of operating and maintaining facilities or providing services should be reduced.

In summary, the benefits possible from utilizing automated diagnostics as a key component of a centralized service include:

- Best expertise applied to all facilities.
- More consistent, uniform-quality service provided.
- Eliminates unneeded service calls.
- Helps ensure proper tools, equipment, and parts are taken to each site by service technicians.
- Lower costs for higher-quality service.
- Opportunity to prioritize service calls across sites.

Automated Diagnostics On-Board Packaged Units

A next logical step for automated diagnostics is to embed them as part of on-board control systems for packaged HVAC units. Rather than transporting the data via network or modem communication to a central point, diagnosis of performance could be performed automatically at the unit with results or alarms only being transmitted to a central location for easy access by operations or service personnel. Alternatively, diagnostic results can be stored on board and accessed by a service technician using a hand-held or laptop computer during the next service visit. This latter approach is already being tested for some monitored data.

Advantages of this approach include:

- Automated diagnostics become part of "every" packaged unit sold, providing tools on-board that help ensure proper operation.
- Less network bandwidth is needed to transmit data to a central location.
- Service technicians spend less time setting up to collect data.
- Diagnostics could be integrated into a BAS to assist with building equipment operation (see "Continuous Monitoring And Diagnosis As Part Of On-Site Building Operation" above).

Reducing Risk And Maximizing Profit For Energy Service Providers

Performance and shared-savings contracts for energy services present risks to energy service providers in exchange for the potential to profit by providing service at lower costs than the fees collected from customers for performance contracts and to profit by sharing in the savings for shared-savings contracts. In both cases, the successful energy service provider and client benefit from the service provider being able to provide services at lower cost than competing alternatives. Therefore, the service provider must bring benefits of available capital, bulk purchasing, managing risk effectively, and applying superior knowledge, technology and tools to provide services.

Automated diagnostic tools can be used to help manage risk by reducing uncertainty and ensuring that equipment and systems operate as intended and providing superior tools with knowledge embedded in them to provide the highest level of service at the lowest cost. Energy service providers with such tools should achieve profit margins greater than their competition or be able to offer services at lower costs than their competitors while maintaining the same margins.

What's the Energy Connection?

The purpose of using energy in buildings is to provide the occupants with services—communications, entertainment, comfortable conditions, adequate lighting, good-quality air that is safe and healthy, food preservation and preparation capabilities, personal hygiene, etc. It's often forgotten that the energy consumption itself has no intrinsic value; it's the services that energy use provides that occupants desire. However, as consumers, we all want these services at the lowest possible cost compatible with the level and quality of service desired. Automated diagnostics represent a set of tools that can help provide a subset of higher-quality services at lower cost. As a result, they conserve economic as well as natural resources by helping us use them more effectively.

An air handler bringing 80% excess cold 20 F outside air into a building during winter that needs to be heated is wasting considerable heating energy. Likewise, an air handler not using comfortable 58 F outside air for free cooling (economizing) when it is available is probably wasting cooling energy. Automated diagnosticians can help detect and diagnose these sorts of energy-system performance problems that often go undetected today.

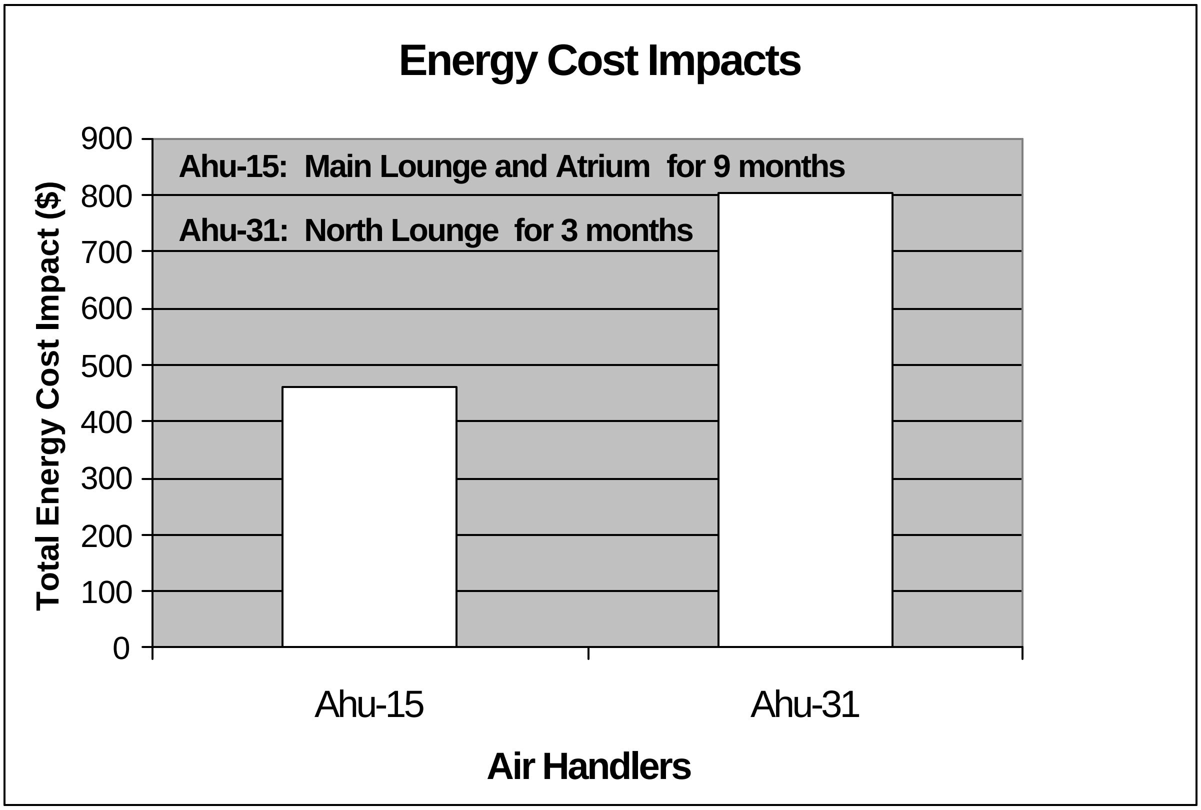

Figure 1 Sample of estimated cost impacts for two air handlers in a large hotel. The outside air dampers for both air handling units were not opening fully, resulting in loss of economizing when available and incurring a cooling-energy penalty

Figure 1 shows two examples of incorrectly operating air-handlers that were identified only by using an automated diagnostic tool. The cost of these problems is modest, but when this is compounded by the number of air handlers in the average commercial building, it becomes quite significant.

Conclusions

Today's computer technology provides us opportunities to use new types of tools to better provide services of all sorts. Automated diagnostics is one such technology, but the buildings and energy community has barely begun to explore use of this technology. Some opportunities to introduce automated diagnostics into energy service and product businesses include:

- Continuous monitoring and diagnosis as part of on-site building operations
- Building start-up and commissioning
- Retro-commissioning
- Hand-held diagnostic tools for service technicians
- Centralized monitoring and diagnostic services
- On-board diagnostics for packaged units
- Reducing risk and increasing profits for energy service providers

These and other products and services will help uncover new opportunities for improving the energy efficiency of buildings through better operation. Results from energy end-use studies, commissioning studies, and early field testing of the few automated diagnostic tools available today point to an incredible opportunity for building occupants, owners, operators, and business providers to benefit by capturing the energy savings and performance benefits of employing automated diagnostic tools.

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