User and Market Factors that Influence Diagnostic Tool Development

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Introduction

Fault Detection and Diagnostics (FDD) is a technology that has a great potential for improving performance and reducing energy consumed in commercial buildings, and is rapidly becoming feasible for the buildings sector. FDD has the potential to dramatically improve the quality of operation of buildings. Scientists have developed algorithms for FDD, and are making plans for field-testing and demonstration of these methods in real buildings. These efforts will provide a sound technical basis for FDD product offerings. However, progress on technical issues is only one step towards implementing FDD in the market. FDD cannot be expected to have a major impact on buildings unless the real needs of users are addressed. Many questions will have to be asked and answered regarding the users of FDD systems, the usability of the product, the market for FDD, and the nature of possible FDD offerings.

Recently researchers have been developing algorithms intended to be applied to building system diagnostics. The United States Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), and Honeywell Inc. have jointly developed a Fault Detection and Diagnostic tool, the Whole Building Diagnostician (WBD—see *Dodier and Kreider 1999,* and *Katipamula et al 1999)*. This is currently a prototype FDD tool. However, before we can have confidence that this prototype FDD system will yield products that will be successful in the marketplace and have an impact on the buildings sector, a thorough understanding of the following points is necessary: needs of the user and intended purchaser, intent of the FDD system, value to customers, actions customers are expected to take upon fault detection, required reliability of the system, means of notification, intended users, product cost, and market for the product.

In this paper we present analysis of the factors that should be considered to ensure market acceptance. This includes a discussion of some of the general issues that should be addressed, and documentation of a study that was performed to learn about marketability directly from the target users. The WBD tool was the focus of much of this analysis, but many of the results are more generally useful for other FDD developers, and anyone trying to influence the development of FDD tools.

Description of Whole Building Diagnostician (WBD)

The Whole Building Diagnostician (WBD) consists of two modules that help to keep buildings operating properly. It has a whole building energy (WBE) tracking module that compares the actual and expected consumption of energy and alerts the user when there is a mismatch between the two. The outdoor air economizer (OAE) module, detects and diagnoses problems in the outdoor air fraction. The data for these modules can be obtained from a variety of sources, e.g., the building's Energy Management System (EMS), data loggers, or archives. The data are processed every hour, automatically.

Whole Building Energy (WBE) Module

WBE uses a neural net model of building performance to calculate an expected energy consumption each day. The inputs to this neural net are hourly energy consumption (electricity, gas or steam, whole building or end use: whatever data are available for the building) along with whatever other data streams are available

and expected to influence energy consumption (outdoor air temperatures, humidity, occupancy, process…). (The neural net model was developed by the University of Colorado, and is discussed in *Dodier and Kreider, 1999*). WBE displays a graph with the time in days on the X-axis and the energy consumption index (ECI) on the Y-axis, where the energy consumption index is the ratio of the actual energy consumed to the expected energy consumption (see the top of Figure 1). Whenever the ratio deviates from 1, the building's energy consumption is deviating from the expected—either over- or under-consuming with respect to the model. The user may select any point on the graph and obtain information regarding the anticipated cost/savings associated with the situation (see the bottom of Figure 1). The energy cost is calculated based on energy pricing information that is entered by the user when the system is configured.

Outdoor Air Economizer (OAE) Module

The OAE is a module to detect and diagnose problems with the air-side of an HVAC system. It is a rule-based model of system operation. (The model was developed by Pacific Northwest National Laboratory, and is discussed in *Katipamula et al 1999*). Its data are presented as a color map depicting each hour of the day for the selected time range (see the top of Figure 2). The color map is designed to allow quick identification of problem states. Selection of a cell in the color map allows the user to view a description of the problem state together with diagnostic information (see the bottom of Figure 2). For each potential diagnosis, the user may also see troubleshooting recommendations.

Marketability Considerations

Early in the design stages of the development diagnostic tools such as WBD, a range of marketability issues should at least be acknowledeged, even if is not feasible to explicitly address each. These issues were identified and described in *Heinemeier, 1998,* and there a framework was established for assessing marketability early in the development process. The marketability issues are summarized below. As an example of their use, they are applied to the WBD diagnostic modules in Tables 1 and 2.

Intent of System

- *Fault detection vs. diagnosis*: Does the tool detect problems or go on to identify underlying causes?
- *Commissioning vs. ongoing operations*: Is the tool intended to be used in a commissioning capacity, to search out problems early in a system's performance, or is it to be used to detect emerging problems?

Value of System

- *Single or multiple faults*: Is it a single-purpose tool aimed at a particular fault, or a general fault detection mechanism?
- *System encountering problem*: What system or equipment in a building is affected by the type of problems detected? Is this system common in the facilities of the intended users?
- *Probability of problem*: How often does the detected problem occur (in what percentage of buildings, how often throughout the year in a given building?)?
- *Consequences of problem*: Are the problems significant for customers, or merely annoyances?
- *Easier detection alternatives*: Can the problems be detected in a simpler or less expensive manner?

Table 1. Whole Building Diagnostician—Whole-Building Energy Module Marketability Issues

Intent of System
Fault detection vs. diagnosis: Detection of any changes in building affecting whole-building and major system energy consumption.
Commissioning vs. ongoing operations: Ongoing operations: training data assumed to be correct operation. Therefore retraining may be advisable if changes that would affect the baseline take place.

Value of System
Single or multiple faults: Single symptom: whole-building and/or major system energy use changes unaccountably. A wide variety faults may cause this.
System encountering problem: Whole building, or any system within building.
Probability of problem: Since most buildings use more energy than they could, the probability of the problem occurring is very high. Not all problems would be detected by the system, however.
Consequences of problem: Energy costs are too high. The importance of this problem will vary from building to building or owner to owner.
Easier detection alternatives: Benchmarks can be used for comparison, but it can be difficult to identify appropriate benchmarks, so they may have limited detection ability.

Action to be Taken
Manual diagnosis: Operator is expected to determine cause of problem. Owner knows the building best, and is in the best position to carry out this diagnosis.
Triage for technician dispatch: None.
Fixing identified problems: Many problems can be fixed with O&M, some broken, misinstalled or misdesigned equipment repairs or changes may be required.
Design feedback: No mechanism is designed for feedback to system or building designer.

Required System Reliability
Probability of false alarm: System detects changes in performance, and the probability of falsely detecting a change will depend on sensitivity that is selected. The reason for the change, however, may not be a building problem (e.g., it might be an expected change in operation), and might be considered a false alarm. When building operation is changed permanently, WBE will establish a new baseline.

Probability of detecting failure: Depends on characteristics of the training dataset. If training follows adequate commissioning, emerging problems will have a high probability of being detected. If problems exist during training data collection, they will not be detected.

Notification
Alarms: Blinking icon, dialog box with message contents.
Wording of alarm message: It is very challenging to convey complex information concisely, and usability tests are needed to assess effectiveness. Messages are nested to allow for user-appropriate complexity.
Identify cost impact of problem: Identifies cost impact.
Acknowledging alarms: Alarms are highlighted until acknowledged, and maintained until deleted.
Adjustable thresholds: Sensitivity "knobs" exist to enable user to easily change detection sensitivity.
Commissioning or ongoing: Ongoing detection, so must be succinct and used by operator.
Corollary information: A great deal of other information available to user.

User
Building operator: Probably the primary user (this will depend on how WBD is packaged during productization). This imposes requirements for ease of use, learning curve, explanation of alarms.
On-site FDD expert: Secondary user.
Remote FDD expert: Secondary user.

System Cost
Hardware: Uses existing Building Automation System and existing sensors, and up to 3 additional sensors (including whole-building electric meter).
Software: Software cost, includes database and communications between Building Automation System and FDD.
Services: Minimal configuration will be required, thus no services will be necessary.
In-house effort: Minimal in-house effort required for configuration, and for operation.
Installation and configuration: Minimal configuration will be required. Wizards will help usability.
Data sources: All data collected by a typical Building Automation System.
Training and documentation: On-line help, very minimal training for operation; some support for configuration.

Market
Market sectors: All commercial buildings.
Building size: Small, medium or large buildings.
Existing vs. made market: Extension of existing controls and service market.
How will FDD be provided: Yet to be determined.

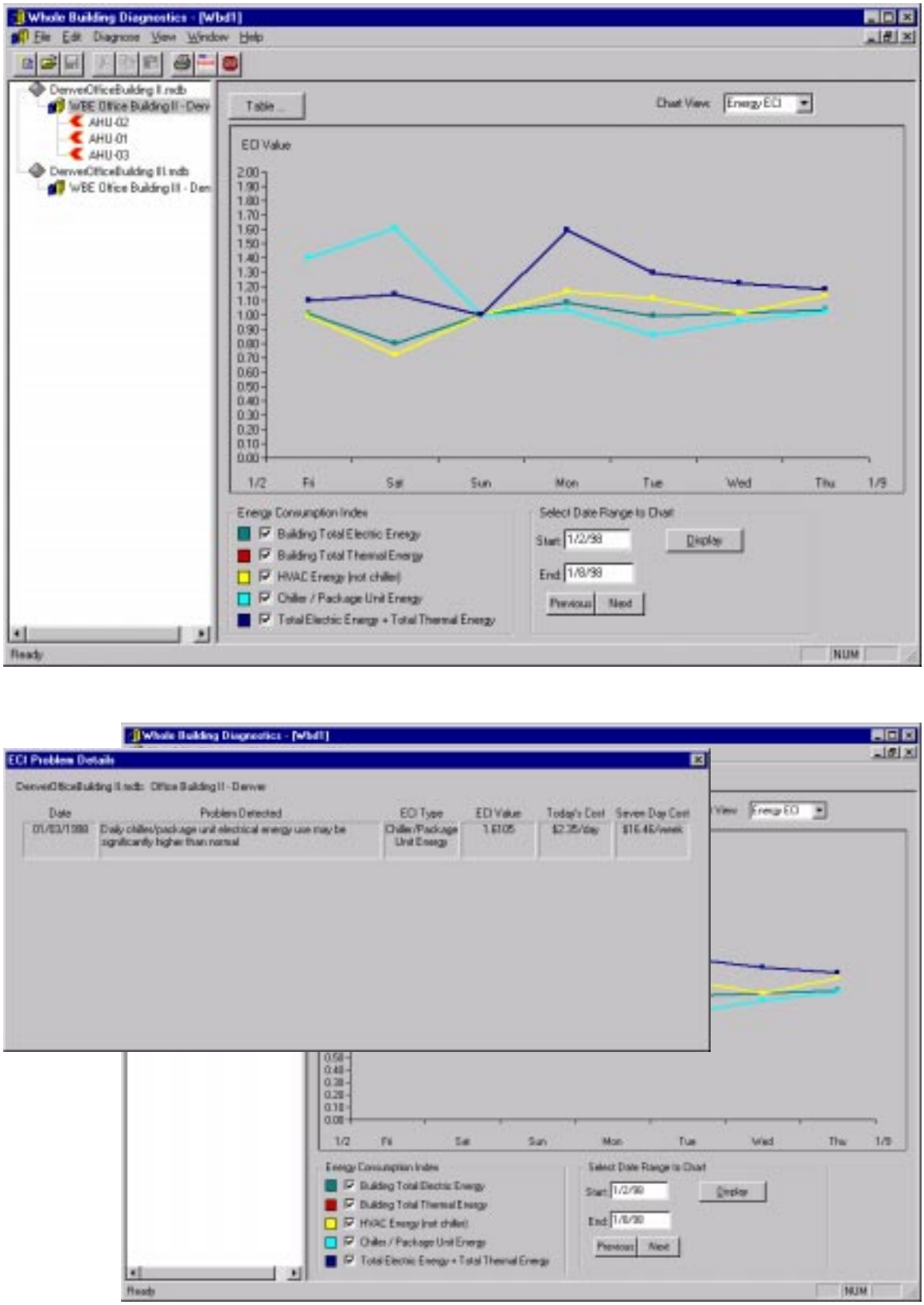


Figure 1. Energy Consumption Index (ECI) graphed over time in Whole Building Energy Module, and additional information presented for a particular day.

Table 2. Whole Building Diagnostician—Outdoor air/Economizer Module Marketability Issues

Intent of System
Fault detection vs. diagnosis: Detection, diagnosis and identification of possible solutions.
Commissioning vs. ongoing operations: Both commissioning and ongoing detection are supported.

Value of System
Single or multiple faults: Many different faults related to air-handling unit and economizer operation, or poor indoor air quality.
System encountering problem: Air-handling unit and economizer operation.
Probability of problem: Problems with air handlers and economizers are very common.
Consequences of problem: Energy costs too high. The importance of this problem will vary from building to building or owner to owner.
Easier detection alternatives: Few have been developed, beyond simple or manual checks.

Action to be Taken
Manual diagnosis: Several possible solutions are presented to user.
Triage for technician dispatch: Inferred from possible diagnoses.
Fixing identified problems: Many problems can be fixed with O&M, some broken or misinstalled equipment repairs or changes may be required.
Design feedback: No mechanism designed for feedback to A/E designer.

Required System Reliability
Probability of false alarm: Primary focus. False alarms are reduced by detecting when there is insufficient information for a certain diagnosis.

Probability of detecting failure*:* Very high—depends on sensitivity selected, and conditions under which the HVAC system operates.

Notification
Alarms: Blinking icon, dialog box with message contents.

Wording of alarm message: It is very challenging to convey complex information concisely, and usability tests are needed to assess effectiveness. Messages are nested to allow for user-appropriate complexity.

Identify cost impact of problem: Identifies cost of impact of problem.
Acknowledging alarms: Alarms are highlighted until acknowledged, and maintained until deleted.
Adjustable thresholds: Sensitivity "knobs" enable user to easily change detection sensitivity.
Commissioning or ongoing: Ongoing discovery and refinement of problem diagnosis, over several days.
Corollary information: A great deal of other information available to user.

User
Building operator: Primary user. This imposes requirements for ease of use, learning curve, explanation of alarms.
On-site FDD expert: Secondary user.
Remote FDD expert: Secondary user.

System Cost
Hardware: Uses existing Building Automation System and existing sensors.
Software: Software cost, includes database and communications between Building Automation System and FDD.
Services: Minimal configuration will be required, thus no services will be necessary
In-house effort: Significant in-house effort required for configuration, but not for operation.
Installation and configuration: Kept as simple as possible with wizards. If configuration will be significant, it could be offered as a service.
Data sources: All data collected by a typical Building Automation System.
Training and documentation: On-line help required, minimal training for operation; significant training and support for configuration.

Market
Market sectors: All commercial buildings.
Building size: Medium to large buildings with operators, air handlers, and economizers.
Existing vs. made market: Extension of existing controls and service market.
How will FDD be provided: Yet to be determined.

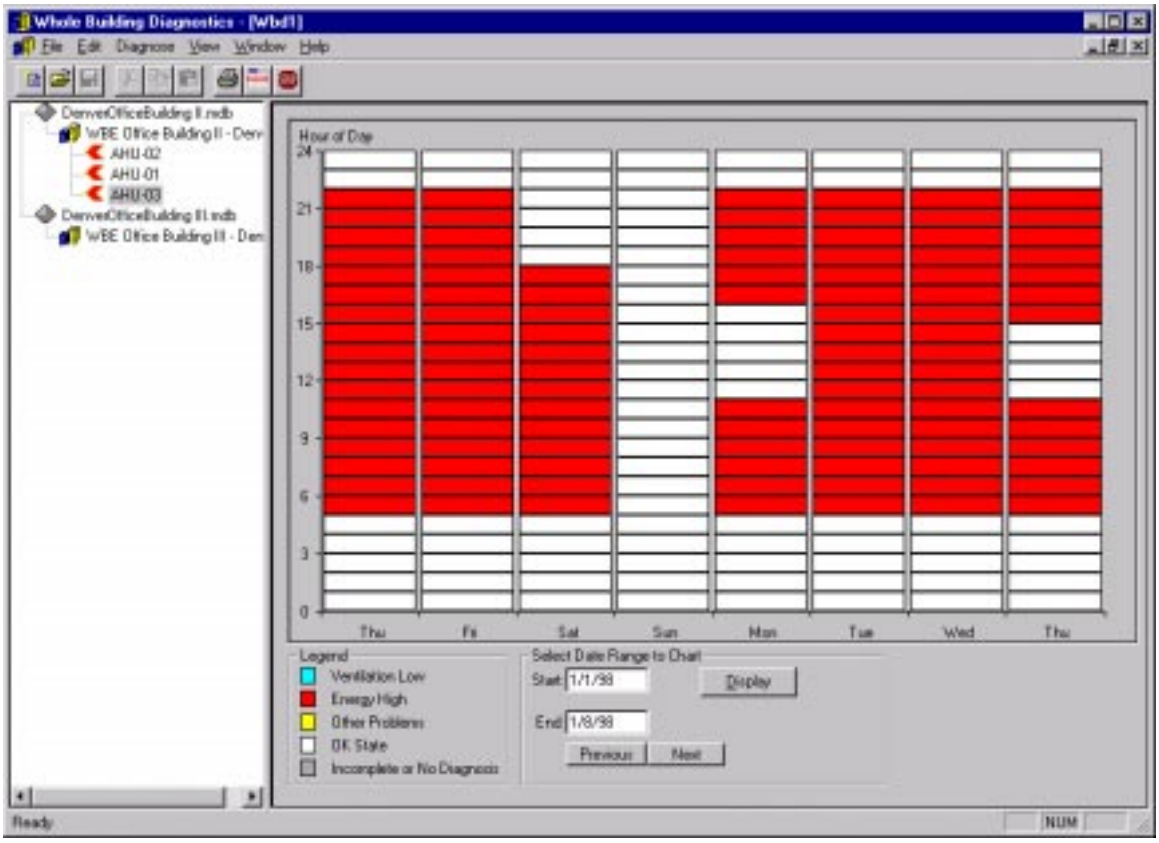
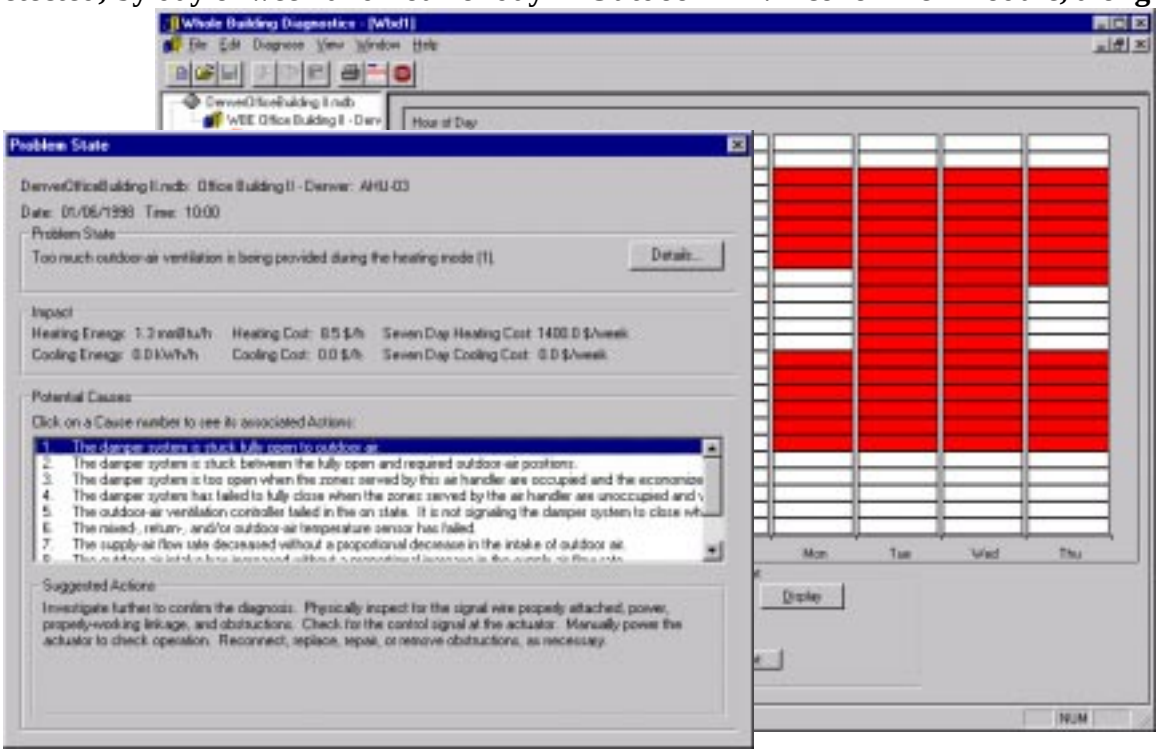


Figure 2. Faults detected, by day of week and hour of day in Outdoor Air / Economizer Module, along



with Impact, Potential Causes and Suggested Actions, for a given hour.

Action to be Taken

- *Manual diagnosis*: Would a user be required to take additional action to detect the root cause of the problem, or to verify the diagnosis?
- *Triage for technician dispatch*: Can the tool help a user to identify what service provider to call or what tools to bring to the site?
- *Fixing identified problems*: What can the user do when the fault is identified? If there is no feasible remedy, there is little value to the user in detecting the fault.
- *Design feedback*: Does the tool provide feedback to designers, so that this type of problem can be prevented in the future?

Required System Reliability

- *Probability of false alarm*: What is the liklihood that the tool will indicate a fault when there really is no fault? (This had better be low).
- *Probability of detecting failure*: What is the liklihood that the tool will indicate a fault when it exists? (This had better be high—equally important).

Notification

- *Alarms*: What mechanism is used to alert the user to the presence of the fault?
- *Wording of alarm message*: What is the appropriate level of detail to give to a user in annunciating a fault?
- *Identify cost impact of problem*: Can the tool assist the user in prioritizing responses by identifying the cost impact of ignoring the problem?
- *Acknowledging alarms*: What must a user do to acknowledge an alarm? This should not be overly burdensome, yet it must reflect the severity of the problem.
- *Adjustable thresholds*: Can the sensitivity of the fault detection be altered by the user, so that a manageable number of faults are reported?
- *Commissioning or ongoing*: Is the mechanism for reporting the alarm appropriate to the way the tool is used: either as an interruption to other activities or a tool used actively to detect problems?
- *Corollary information*: Is information beyond the existence of the fault available, to allow the user to learn more about the situation?

User

- *Building operator*: Is the building operator the intended user? This will require a tool with short learning curve and very carefully crafted user interface.
- *On-site FDD expert*: Is an FDD expert the intended user? This may allow for a steeper learning curve.
- *Remote FDD expert*: Is a remote FDD expert the intended user? This may allow for a steeper learning curve, but may require access to information about the system being diagnosed.

System Cost

- *Hardware*: What existing sensors can be used, and what additional sensors will have to be added? Will computers or wiring have to be added?
- *Software*: Is there a significant cost for the FDD software itself, or any related software?
- *Services*: Are services required to use or install the tool?
- *In-house effort*: How much in-house effort will be required for using or installing? This is often overlooked.
- *Installation and configuration*: Is installation and configuration a time-consuming activity? Who can carry it out?

- *Data sources*: What other data sources are needed (eg weather, utility information)?
- *Training and documentation*: How much training and documentation is needed to ensure effective use?

Market
- *Market sectors*: Is this tool applicable to all commercial buildings, or only to a subset of building types.
- *Building size*: Can this be used effectively in small, medium, and large buildings?
- *Existing vs. made market*: Does this tool replace something that is already well accepted, or will the need for it have to be communicated to potential customers?
- *How will FDD be provided*: Is the tool provided as an algorithm embedded in a piece of equipment or Building Automation System? Is it a standalone application (if so, how does it get its data?)? Is it provided as a service?

Focus Group Design

In order to begin to assess some of the user and purchaser related marketability issues, we conducted a set of focus groups to address the following questions, regarding diagnostics in general, and the WBD tool in particular:
- Are members of the target audience interested in the concept and the implementation of the product?
- How should the product be marketed?

Although the answers to these questions were of interest primarily in making the decision of whether and how to market the software, the answers should also be of interest to others developing similar tools. In order to answer these questions, a series of focus groups were conducted. These focus groups were quite successful in assessing overall interest in the concept, and obtaining information to improve the product and improve its marketability. *Richardson et al. 1998* is a full presentation of the focus groups. This paper describes the focus group process, as well as the findings.

The goal of the focus groups was to obtain information on the market acceptability of fault detection and diagnostics, and specifically of the WBD product, from members of the target audience. The aim of focus group research is to obtain qualitative information from reliable informants. With a limited size focus group study such as this, it cannot be expected that the group will provide statistically significant quantitative information. Instead, the goal is to learn what types of issues the participants find to be important, and how they react to certain concepts. It is also important to note that this was not a usability study, which would have gone into more detail on the functionality of the particular application.

Ideal Participants
It was decided that there were three distinct groups who should be included in the study:
- service providers,
- potential product purchasers, and
- potential product users.

We planned to hold one focus group with each of these audiences. Group dynamics dictated the optimum size for each group to be between six and eight participants. When there are fewer participants, it is likely that viewpoints exist that are unrepresented by the participants. When there are more participants, it is difficult to obtain input from everyone present.

To select participants for the groups, the profile of an ideal potential customer was identified. The characteristics are described below. These characteristics were put in the form of a list of questions to be

asked of potential participants, which became the "participant screener" that was developed jointly by all project team members, and approved by the project sponsors.

- Product User or Purchaser: To be included in one of the potential product customer groups, the respondent had to be either a potential user or a potential purchaser of the product. Potential purchasers were described as building managers; potential users were described as building operators/engineers.
- Square Footage Respondent is Responsible For: Since it was not clear whether WBD should be marketed to large or small facilities, it was decided to invite participants who were responsible for buildings with a range of square footage.
- Multiple Buildings vs. Single Buildings: Since it was not clear whether WBD should be marketed to single- or multi-building facilities, it was decided to invite participants with a both types of buildings.
- Nature of Business: No key market had been identified for WBD, so participants from a range of business sectors were sought.
- Public vs. Private Sector: It was not known whether there were differences between public- and private-sector facilities, relevant to WBD marketability, so it was decided to invite participants from both sectors.
- Energy Management Systems (EMSs): WBD could be marketed to customers with or without EMSs. However, it was decided to focus on customers with EMSs. We sought a mixture of customers: some with controls provided by the project co-sponsor and some with controls provided by competitors.
- Service Contract: Since it had not been determined whether or not WBD should be marketed in conjunction with service contracts, or offered as a standalone product, a mixture of customers with and without service contracts was sought.
- Interest in Concept: Although it skews the results of the focus groups in a positive direction, it was decided that only individuals who demonstrated some interest in the concept would be included. Certainly, to assess the likely overall market share, one would have to include those less interested in the concept. But to really understand the strengths and weaknesses of the concept, only those predisposed to be interested in this type of technology were included.

Discussion Guide

The project team was responsible for drafting a discussion guide to be used during the focus groups. This is a critical task, since the discussion guide was to be followed very closely during the different focus groups, in order to ensure a consistent presentation of information and collection of feedback. The quality of information gained from the focus groups depends directly on the quality of the discussion guide. The project team produced a draft of the guide—along with the focus group moderator—which was then reviewed in detail with the project sponsors, until a document that was acceptable to all parties was prepared. The outline of the discussion guide is as follows:

- Objective—A clear statement of the objective of the focus group, to ensure that everyone involved understands what type of information is sought.
- Introduction—Introduction of the purpose of the focus group, and introduction of participants.
- The Customer's Attitudes about Keeping the HVAC System Operating Properly and Identifying and Addressing Problems—Warming up the participants by beginning to find out what problems they currently have with keeping their buildings running, and how they currently address these problems. This also gets further information about who the participants are and their roles in building operation.

- Awareness/Understanding of the Automated Diagnostics Category—Defining the concept of automated diagnostics.
- Reaction to the Concept—Presentation of the concept statement and discussion of the participants' reaction to it, together with impressions of how helpful diagnostics would be in their work, and how it would be used. The reaction to diagnostics in general, before presentation of the prototype, is important in differentiating between potential customers' response to the concept of diagnostics and the particular implementation of diagnostics in WBD.
- Reaction to the Prototype—Demonstration of the prototype, followed by discussion of the participants' reaction to it. The demonstration was to be very brief, and very controlled. The presentation of the WBD was quite intentionally not a "sales pitch," because a reaction solely to the product itself was desired (as opposed to the salesperson or touting of benefits and applications). Instead it was to be a very brief (10- or 15-minute), factual presentation of capabilities of the WBD, illustrated only using the software itself; no bulleted lists of features or functionality were provided. How the WBD might be used in the buildings and the advantages of having it were not stressed, and how it worked was not discussed except in passing. The differences in reaction to the general concept and the actual prototype were probed. Questionnaires were designed to collect quantitative information on participant reaction, although it was recognized that with such a small sample size, only limited conclusions could be drawn.
- Delivery System—Discussion of the different ways in which the WBD could be provided to customers (service, part of existing building management systems, and standalone software).
- Pricing/Motivation to Buy—Assessment of what price participants would be willing to pay for the tool. It was recognized that meaningful price information is difficult to collect in such a focus group, and only "ballpark" figures could be sought.
- Design/Installation—Discussion of related issues that may be of concern to the participants.
- Wrap-Up—Discussion of how the software could be improved. Although the objective of the focus groups was not to improve the current software, any such information that could be collected would be valuable in any future versions of the software.

The Focus Groups

Potential Participant Pool

Potential customer participants were identified and contacted by a recruiter from a market research firm. The recruiter utilized area business directories for a potential participant pool. The controls company that co-sponsored the study furnished names of their service and monitoring customers for inclusion in the recruiting. Some of each group chose to participate. These participants were invited to participate in the focus groups. For the service provider group, participants were selected for by the District Service Leader for the controls company co-sponsoring the research. He selected participants based on their experience, technical abilities, and communication skills. The group included field technicians, technical resource managers, and service team leads.

After identifying the potential participant pool, the recruiter contacted each of the prospects on the telephone, and went through the questions in the screener to determine their characteristics and assess their interest in the subject technology. If the prospect's answers to any of the questions did not fit the profile, they were thanked for their time, and the call was terminated. If they were deemed to be suitable participants, and contributed to the diversity of participants that was required, they were invited to attend the focus group. This recruiting process was continued until a suitable number of participants were selected, with a few extras in case some did not show up.

Participant Descriptions

Three focus groups were organized to study the three categories of informants defined earlier: one group of service providers and two customer groups.

The first focus group was composed of eight service providers. For customer groups, the intent was to include building engineers/operators in a "User" group (Customer Group A), and building managers in a "Purchaser" group (Customer Group B). However, it was found that these categories of individuals overlapped significantly. Participant self-descriptions indicated that each of these groups represented a mixture of personnel with direct operations responsibilities and managerial responsibilities, in some cases both of these roles were represented within the same individual. Therefore, the distinction between these two groups was meaningless. In light of this, and the generally common themes expressed by the two customer groups, findings from the two customer groups will be discussed together in this report. Both groups had seven participants. Tables 3 through 5 provide descriptive information regarding the focus group participants.

Table 3. Service Provider Participant Descriptions

Group and Participant	Job Title / Principal Responsibilities	Facility Type / Size	Sector	Service Contract
SP 1	Technical Resource Manager	No information	N/A	N/A
SP 2	Technical Resource Manager Responsible for public schools; manages HVAC systems as an on-site manager	Large metropolitan school district	N/A	N/A
SP 3	Systems Service Engineer Responsible for public schools; construction and services	Large metropolitan school district	N/A	N/A
SP 4	Automation Team Lead Supervisor for automation	No information	N/A	N/A
SP 5	Senior Field Service Technician Works on automation systems	No information	N/A	N/A
SP 6	Service Team Lead Mechanical HVAC maintenance	-	N/A	N/A
SP 7	Technical Resource Manager Responsible for corporate office buildings	1 large office complex and 1 mid-size research facility	N/A	N/A
SP 8	Senior Service Technician Responsible for service in a metropolitan area	No information	N/A	N/A

Table 4. Customer Group A Participant Descriptions

Group and Participant	Job Title / Principal Responsibilities	Facility Type / Size	Sector	Service Contract
C 1	Head of Facilities Manages a 3-building complex; heads a team of 5 engineers that take care of the complex. All services except electrical and mechanical are contracted out; primarily works automation, chillers, etc.	Property management and Leasing Over 200,000 sq. ft.; multiple buildings	Private	Yes
C 2	Assistant Chief Engineer Responsible for daily scheduling; mostly mechanical; takes care of 95% of pump works, motor replacement etc; works with lots of automation	Property management Over 200,000 sq ft; multiple buildings	Private	No
C 3	Facilities Supervisor and Chief Boiler Operator Responsible for HVAC systems and college construction; also works as the 'Chief Boiler Operator'; oversees boilers and tasks on grounds	College 150,000 to 200,000 sq ft; multiple buildings	Private	No
C 4	Director of Plant Operations In-charge of maintenance of the whole hospital and grounds, and safety and security	Hospital Over 200,000 sq ft; single building	Private	No
C 5	Manager of Operations Oversees most day-to-day operations	Hospital Over 200,000 sq ft; multiple buildings	Private	No
C 6	In-Charge of Buildings and Utilities	Hospital Over 200,000 sq. ft.; multiple buildings	Public	Yes
C 7	Operations manager In-charge of buildings and grounds; has a staff comprised of engineers, housekeeping personnel, security staff, and maintenance technicians; 25 years experience	Shopping Mall Over 200,000 sq. ft.; single building	Private	No

Table 5. Customer Group B Participant Descriptions

Group and Participant	Job Title / Principal Responsibilities	Facility Type / Size	Sector	Service Contract
C 8	Chief Engineer	Hospital Over 200,000 sq ft; multiple buildings	Private	No
C 9	Operations Manager/Chief Engineer	Hospital 150,000 to 200,000 sq ft; multiple buildings	Private	No
C 10	Head of Maintenance/Construction	Financial Services & Life/Health Insurance Over 200,000 sq ft; single building	Private	No
C 11	Facilities Manager	University Over 200,000 sq ft; multiple buildings	Private	No
C 12	Property Maintenance Manager Manages a 20-unit apartment complex	Property Management 150,000 to 200,000 sq ft; multiple buildings	Private	No
C 13	Manager of Engineering Services	Hospital 150,000 to 200,000 sq ft; multiple buildings	Public	Yes
C 14	Team Leader / Manager of Operations In-charge of operations and facilities management	Shopping Mall 150,000 to 200,000 sq ft; single building	Private	Yes

Conducting the Focus Groups

Focus groups were conducted at a market research facility in Plymouth, MN on the evenings of September 15-16, 1998. Participants in the Service Provider Group and Customer Group A were paid $75 for their participation. Customer Group B was paid $100 for their participation. No participants knew who was sponsoring the focus groups. Service providers were told that their employer was the sponsoring organization at the end of their session.

The focus groups were all held in a room with a two-way mirror. The groups were observed by project team-members and by project sponsors. All focus groups were moderated by a professional market research facilitator. Video and audio tapes were made of all sessions. All participants were asked to sign a Confidentiality Statement, which assured them that their names would not be used in conjunction with the research, but did alert them that they were being observed and videotaped.

In the course of the focus group, participants were shown a written Concept Statement (see below).

> Now, there is a new automated diagnostics software to help you identify and eliminate energy waste and outdoor air ventilation problems in your building. The software collects data

> from your Building Management System (BMS) or Direct Digital Control (DDC) system and alerts you when it finds problems. It also provides specific causes of the problems and suggests corrective actions.

This statement described diagnostics tools in general, and had been carefully drafted by all project team members and sponsors. The Concept Statement was amended after the first focus group was conducted, to respond to concerns that participants had about "overselling" the concept. Participants were then asked if they were interested in the concept. They were asked detailed questions about how they currently conduct troubleshooting activities, and how they perceived that a diagnostics tool would contribute to their activities. They were given a written questionnaire to assess quantitatively their level of interest, and then they verbally discussed their interest.

One of the WBD developers then presented a demonstration of the WBD tool, and again the participants' level of interest was assessed quantitatively in a written questionnaire, and probed verbally. During and immediately after the demonstration, there was no opportunity for the participants to ask questions. This was intentionally done, so that a well-controlled presentation could be assured and an accurate assessment of could be made of exactly what was presented. This did lead to some misunderstandings concerning the product's capabilities. On the positive side, however, it contributed to an understanding of how the product is perceived and how it should be marketed. After the formal focus group was completed, participants were invited to stay and ask additional questions of the developer, and the participants did have sufficient interest to do so.

In the sections that follow, we describe the findings of the focus groups. In a study such as this, it is not appropriate to attempt to explain the motivations of the participants, or to present recommendations to the product developers. The intent, therefore, is simply to present and summarize the responses of the participants.

Findings

Overall Response

Across all focus groups, participants saw value in the WBD concept particularly with respect to the energy/cost saving potential it offered their facilities. Participants were also interested in the system's potential to provide early fault detection and, further, to inform them about the cause of a problem, thus facilitating early intervention and potentially avoiding system failures. WBD was seen as a tool to help focus preventive maintenance scheduling on the most cost-effective activities.

Despite the general interest and perceived benefits, however, most participants indicated that they would be reluctant to purchase WBD. This reluctance was primarily due to skepticism about the ability of the tool to deliver on its promises. None of these barriers is insurmountable, but all pose technical or marketing challenges if WBD is to be a successful product implemented in a large number of buildings.

The participants can be clustered into four groups according to their expressed level of interest in the WBD.

- A few were quite interested and expected to have to pay a considerable amount of money to purchase such a system. This group tended to point out the need for training, good user's manuals, upgrades, and future extensions of the tool to more systems. This group expressed some reluctance to be the first to adopt an unproven technology, however.

- A somewhat larger group also expressed interest, but only a willingness to enter into shared savings contracts for the WBD, effectively shifting the risk in the new technology to the provider. For this group, in particular, interest was reduced by the lack of empirical evidence of cost savings from real buildings.
- Another such group were interested in the WBD, but emphasized their desire to see the WBD provided as a basic, integrated part of their control system. In fact, this is how the developers envision the WBD being delivered by controls firms—as an added value feature more than a separate product.
- A few participants indicated they were not interested in the WBD, generally citing skepticism that it would work or claiming that their DDC systems already provided such capabilities.

The critical need for demonstrations in establishing a track record and value for this new technology was highlighted by the comments from all four groups. Many participants indicated that selling management on such tools would be easy if savings with paybacks of 1-3 years were made credible through demonstrations or performance guarantees.

There were three basic types of objections raised by those having less interest in the WBD: doubt as to whether the technology would work, the desire to avoid financial risk when investing in an unproven technology, and objection to the lack of integration with their current DDC system. Demonstrations will play a key role in refuting the first two objections. Commercialization through a controls manufacturer should eliminate the third.

Response to Prototype

Although there was "guarded" interest among participants in the general FDD concept, for many participants, presentation of the prototype reduced their interest in the product offering. Among the service providers and those customer participants who were quite knowledgeable about HVAC systems, the decline in interest seemed to be attributable to skepticism about the accuracy of diagnostics and troubleshooting recommendations formulated without detailed information regarding the unique characteristics of the HVAC system and the building. The participants expressed concern about false diagnoses attributable to the prototype. They were concerned that these could result in increased, and unnecessary, service calls. Some participants had difficulty visualizing how a software application could detect problems beyond the DDC at the level of the mechanical systems.

Skepticism and Product Credibility

By far, the biggest barrier to marketability for WBD is the skepticism potential customers may have. Focus group participants often expressed significant skepticism regarding the ability of WBD to deliver energy/cost savings. This was driven by an expressed discomfort for "grandiose claims." They felt they were "on the front lines" where marketing promises about new technologies had to be delivered in practice by them, and felt charged with "making it work as advertised," an understandable concern from their viewpoint. Some service providers were skeptical of the original concept statement, and were not sure that any product could live up to it. When they viewed the prototype, however, they were relieved to see that the range of the diagnostics in WBD was limited in scope, making the system seem more plausible to them

The participants actually provided the answer to this barrier: demonstrations, case study data, beta tests, and availability of early-adopters to provide success stories. *"I don't want to be a guinea pig."* Participants wanted to see the tool working at another site for at least a year before they would consider buying it. Positioning WBD in carefully selected beta-sites that reflect the target market and collecting case study data would reduce customers' feelings of risk in investing in untried technology. The demonstrations would have to be carefully placed however, as they stated that they would want to see it in "*my building"* or in a building where they could talk to the engineers to get direct feedback on its performance. They stated that they might be interested in purchasing the "*third-generation"* of the software. They would be more willing to try out

the untested technology if it were offered on a shared savings basis or as a beta test, where their risk would be minimized. Even in these cases, however, the cost of instrumentation and disruptions of their existing systems would be a barrier.

Life Cycle Software

Part of the skepticism that participants expressed had to do with the levels of training, documentation and support, and upgrade path associated with WBD. These are needs that must be addressed to build confidence in the supplier of the product. A supplier with a good track record in these areas will be more likely to be accepted by the customer when new products are offered. Areas of concern that were mentioned were users' "distrust of computers", and the fear that the software would quickly become obsolete. It was mentioned several times that they typically invest heavily in a tool, and that by the time they have paid it off, the supplier has a "new and improved" version that they "have to" have. They wanted to know that future upgrades would be available to them without requiring large changes in hardware.

Similarity to Existing Energy Management Systems

Another major barrier is confusion customers may have about the similarity of WBD to their existing EMSs. Many of the participants, both service providers and customers, voiced the opinion that they felt that they already had these capabilities, in their EMSs. One customer noted that these capabilities were available in typical EMSs, although they were often not installed or implemented. Because of this, many felt that there was a limited value to an additional application with these features. One participant, however, added that if the proposed system was more accurate or reliable than the existing system, it would still be valuable. It was clear that the distinction between what existing EMSs can provide, how they typically use and don't use the data to provide information about system operation, and the additional functions available in the prototype diagnostic modules were not clear to the participants, and this is an important part of the education necessary for potential customers.

Knowledgeable customers from larger facilities felt that an ideal application of WBD was in tracking performance of multiple buildings—which they felt their existing systems could provide to a limited extent. One of the most important values identified by participants who had management responsibilities was as a tool for managing maintenance, prioritizing work, and dispatching technicians to the field. In general, the energy tracking features of WBD were seen as a helpful extension (e.g., longer trending duration, better energy usage modeling) to the capabilities of existing EMSs.

The less knowledgeable participants were impressed by the energy and outdoor air data presentation and were more likely to credit the diagnostic and troubleshooting information. Participants acknowledged that WBD supported trending over a longer duration than their existing systems and spontaneously commented that it was easy to understand and interpret the data. However, despite the trending capabilities, most participants expressed little interest in purchasing such a system.

Despite their recognition of the value of the performance tracking capabilities, many of the participants felt that this capability could be a double-edged sword. They thought that if non-technical management directly compared the data for various facilities, without making additional allowances for variations in building materials, equipment configurations, and weather conditions, those managers could draw erroneous conclusions about which facilities were well or poorly run. This possibility was of great concern to the focus group participants and will have to be addressed when marketing the tool.

The Need for Education

All of the above-mentioned problems lead to the requirement to fully educate potential customers. In these focus groups, participants either misunderstood or were skeptical about several fundamental features of WBD. Multiple participants evidenced misunderstandings in each of the following key areas:

- Instrumentation requirements
- Types of energy sources addressed by the application
- Role of the OAE as an outdoor air fraction diagnostician as opposed to an IAQ monitor/control
- Power of modeling to diagnose a system

It is clear that the eight to fifteen minutes allowed for the WBD prototype presentation, was insufficient to adequately explain all of its features and functions. The findings from the two customer focus groups do not directly portray the reactions of consumers to a product offering, as it would be presented to them for purchase. It was designed to be less than ten minutes, and to focus on a neutral-toned presentation of capabilities, rather than a "sales pitch." This was because the intent was to gauge interest in the actual product, rather than reaction to different marketing strategies, and this is appropriate for a focus group. However, successful marketing of this product will require careful preparation of explanatory materials and careful positioning of the product with respect to the customers' perceived needs.

Ideal Users

The focus groups help to identify the best target audience for this tool, as it became clear that some of the participants would be poor candidates. The service-providers group consisted of five technicians who conduct field maintenance and three resource managers in charge of specific operation and maintenance (O&M) service agreements. One potential application of the WBD is as a tool to support maintenance provided by O&M contract service personnel; this group was designed to explore this application.

This focus group identified, however, that technicians are not the ideal users for WBD. The best users of the WBD would be those who, as part of their job assignment, make decisions to prioritize and plan execution of work for themselves and/or others. We suspect that the technicians in this group, in general, do not prioritize and plan their own activities. Instead, they are dispatched by a resource manager or a dispatch center, typically in reaction to a customer complaint or a control-system alarm. It is this need to detect a problem, prioritize a response to it among other needed O&M activities, and provide some guidance on what to look for upon arrival at the site that is better served by the WBD modules. Further, these technicians have a very high level of experience and a wealth of diagnostic insights to draw upon when troubleshooting. In a very real sense, the WBD was perceived as more of a threat to their jobs than an aid in conducting them. They expressed this sentiment repeatedly during the discussion in terms such as "we can do this better…you can't take the human out of the process… we know more about these systems that the tool does…we could build a tool in our systems to do this."

In contrast, the account managers in the service providers group were much closer to the target audience envisioned by the WBD developers. They are responsible for maintaining client satisfaction in a customer's buildings while minimizing maintenance and troubleshooting labor (i.e. maintaining comfort and energy efficiency while maximizing profit). As noted subsequently, they were markedly more positive in their response to the WBD, probably because it better matched their job responsibilities.

To some extent, the facility operators/managers groups also did not well represent the target users for the WBD. Almost half were from major hospitals. Hospitals generally have very special needs and HVAC systems to serve them. For example, the outdoor air module, in its current form, is not particularly well suited to the outdoor-air systems and needs in hospitals, which often use 100% outside air with absolute requirements for positive or negative pressurization. They also generally have relatively large, well trained,

operating staffs who may be less likely to need troubleshooting advice than staff from other building types. We suspect their dominance of the two operators/managers focus groups may have led to somewhat overly negative reactions to the WBD.

Ideal Market Sector

The focus groups also helped to identify the best market sector for WBD. There seem to be two potential audiences for WBD. The first is customers with larger facilities and staff with considerable in-house expertise, typically either a single large building or multi-site facilities. These users typically have a technical staff who are knowledgeable about HVAC equipment and who would be able to use and understand WBD and appropriately interpret its output in the context of their buildings. These customer participants tended to think that WBD might be a good enhancement to their existing EMSs and could be used to help detect and prioritize building operation problems. Two participants thought that the proposed product would be especially valuable for multi-building or multi-site settings. *"If a person had several buildings that were remote and you used one system to look at all those buildings, I would think it'd be real handy in a case like that."* Multi-building and multi-site participants particularly valued the fault detection potential of the software very highly since it would allow them to detect problems more quickly. While these participants were somewhat dubious regarding the ability of the system to diagnose problems, they felt that if it could do so, that would be even a bigger time saver for their staffs. Participants who contracted their services out also valued the fault detection and diagnostics features, since it would alert them earlier and help them request the correct service personnel from their service provider.

However, before considering such a purchase, these customers wanted to see a much more mature product incorporating additional features. In some cases they did not understand that these capabilities are already inherent in the WBD, such as the ability to account for building-specific information such as local weather, building materials, and specific equipment configurations.

The second audience for WBD might be smaller commercial building managers who typically contract out all of their service needs. For this audience, WBD could be delivered either as an adjunct to the EMS or as a standalone application. This audience was primarily interested in the WBE module. Their interests also seemed to be more focused on fault detection with, perhaps, some limited diagnostics. They felt that troubleshooting assistance was of minimal use to them, as they had no staff to work on the systems.

Instrumentation Requirements

A key issue for all participants was concern about the cost of the instrumentation needed to support the application and the maintenance of such a sensor suite requires to assure accurate data. This was always the first question they asked after the demonstration. WBD's outdoor-air module requires little, if any, instrumentation beyond what is ordinarily installed for the control system. It has a built in mechanism to check the primary sensors against each other. Since these measurements are typically used to control one or more of the building systems (they are not installed for the WBD's use), sensor errors result in control problems, not just problems that need to be solved to make the WBD work. . Although these points, which are energy-use sensors, were mentioned during the presentation of the WBD, they were clearly not communicated strongly enough. More emphasis on these key points is clearly essential for successful marketing of the WBD. There was also concern raised about the adequacy of existing sensors.

Whole Building Energy vs. Outdoor Air / Economizer

Some of the motivations of participants for implementing FDD became evident when we compared response to WBE and OAE. Participants were more interested in the WBE module more than in the OAE module. This may be because the WBE was better understood than the OAE. The service providers had little interest in the OAE, feeling that their expertise, combined with their knowledge of the particular building

outweighed any value it could add. Most customers felt that the existing EMSs do an effective job of handling the outdoor air fraction.

A number of participants remarked that their primary interest was in energy saving , now, and in the future, although the participants felt that the underlying technology represented by the application was "not revolutionary in any way." On the other hand, they felt that customer comfort was paramount in many situations, and that energy saving will be subjugated by the need for increased comfort. In such situations, it was felt that there is little you can do to control energy use so why track it. Some participants were also concerned that the system did not take into account the potential failure of sensing equipment (e.g., bad or poorly calibrated sensors).

It should also be noted that one participant commented that outdoor air is the most important determinant of energy consumption—and the one which he could do something about. Indoor air quality (IAQ) was also a very important issue to most participants (particularly those who worked with hospitals), although they were disappointed to see that the OAE module did not go far enough to ensure and monitor indoor air quality directly.

Fault Detection vs. Diagnostics

The focus groups also helped to understand the relative value participants place on fault detection and diagnostics. The service providers felt that fault detection was valuable but they tended to discount the value of automated diagnosis and troubleshooting aids. They felt that the *"hands-on"* involvement of technicians was essential to reliable diagnosis. This belief was based on two factors:

1. only the human being can take situation-specific variables into account in analyzing the fault, and
2. fault detection relies on sensors and other instrumentation which itself may be faulty.

Some participants were of the opinion that a diagnostic and troubleshooting software aid such as this might be useful for an inexperienced person just learning about HVAC systems. One participant commented that the tool should be perceived as a tool to help him, rather than an automated diagnostic system. Another participant noted that the system could probably only find trivial problems anyway.

The two focus groups of customers shared similar reactions when asked about the relative importance of fault detection, diagnostics, and troubleshooting. In general, fault detection was seen as the most valuable element and most participants felt that that need was already adequately addressed by their EMSs. In addition, many were doubtful of the ability of the system to diagnose problems, especially beyond the DDC level and down to the mechanical and pneumatic levels. In addition to these doubts, participants could not visualize how the system would ever be able to deal with non-standard equipment configurations and unique installations. Several participants also expressed concern about the instrumentation cost that a diagnostic system would entail. *"I can see the dollars going through the ceiling here for a system like that."*

There were differences among the respondents with respect to the value they placed on diagnostics. For participants with larger facilities and maintenance staffs qualified to work on the equipment, diagnostics were seen as a potential aid and time saver. *"I think that going beyond it [fault detection] would be great from a possible time savings area."* Smaller organizations that typically would call a contractor when a fault is detected generally saw less value in diagnostics and troubleshooting since they saw the diagnostics task as the responsibility of the contractor. One participant in this category, however, expressed an interest in diagnostics so that he could tell his contractor where the problem was so the correct service personnel could be sent out, with the correct tools.

Delivery Mechanisms

One of the most important questions on which marketers wanted information on from the focus groups was the most appropriate mechanism for delivering the product to customers. The most commonly discussed delivery mechanism for WBD was as an addition to the existing EMS. *"Not interested in a standalone. We already have too many systems that don't work together."* However, some participants would prefer a standalone. The reasons were either that they did not currently have an EMS and saw this as an improvement over what they currently have, or, that they had concerns that it might negatively affect the operation of their current EMS. There was little interest in the product as a service. Additional comments about the product delivery included a concern about provision of training, documentation and support, and an upgrade path for the software. However it is delivered, the participants felt that detected faults should be annunciated via an alarm bar or icon, rather than through a spreadsheet that they would have to spend time looking at.

Pricing Strategies

Another key question for marketers was what pricing structure would be most appropriate, and what price participants would expect to pay for WBD. The customer participants were much more willing to entertain a "shared savings" pricing approach than any other. *"Fifty percent of savings, which may be a lot—or nothing."* They acknowledged that they had no idea how the savings would be measured, however. This preference may be attributable to the general view that the offering is not yet a proven product: *"There's just no way anybody's going to put a lot of money down on something like this without a history—a good history—behind it."* It also reflects the general view that the product is immature and needs additional features before it adds significant value over the existing EMS. A strong concern was voiced around the question of how savings could be documented using the system.

This preference may be attributable to the general view that the offering is not yet a proven product with case studies to document its performance and energy/cost savings potential. It also reflects the general view that the product is immature and needs additional features before it adds significant value over the existing EMS. A strong concern was voiced around the question of how savings could be documented using the system. Customer participants also strongly expressed the need for a short-term payback in the range of two to three years for any purchase to be considered.

After discussion of the pricing structure, participants were asked to state what price they would expect to pay for this tool, either as a monthly service, an add-on to an EMS, or as a standalone software application. In some cases the participants provided dollar values, and in other cases they provided the answer as a percent of savings. Because the building types varied so widely, and the participants obviously did not have common assumptions as to what would be included in the service and product (e.g., would the cost include sensors?), it is difficult to analyze their responses. For the tool provided as a service, participants indicated they would pay from 10% to 50% of the savings , or $29 - $300 per month. When provided as a part of the EMS, they would pay from $500 to $20,000. When provided as standalone software, they would pay $200 to $250,000.

Additional Diagnostics

Although it was not a strong objective of these focus groups, information was gained on what other diagnostics customers would value. Customer participants expressed an interest in automated diagnostics for vibration analysis and noise attenuation on large HVAC equipment. Power quality was also an area of interest. Indoor air quality diagnostics were of interest to hospital, school, and office building facility managers. In addition, zone air pressure monitoring was of particular interest to participants from hospital facilities. The WBD is intended as a framework that can be extended to include a multitude of diagnostic tools. This extension is a natural desire on the part of consumers, many of whom recognized that the WBD

only deals with a limited, specific set of problems. It is also a message to commercializers of diagnostic tools that there is some pent-up demand for such products.

Summary

For development of FDD products that are successful in the market, and provide real solutions to their users, technology and market considerations must be made hand in hand, and good communication must be ensured between technology developers, in-field marketers, and the target user and purchaser population. Technology developers should consider a number of market-related questions as early in the development process as is practical. They should at least be aware that these questions will be asked when presenting a technology to a marketing organization. Technology developers, potential marketing organizations, and interested early-adopter customers should all take the initiative to engage in ongoing dialog on these topics sooner rather than later.

In order to address this concern, several focus groups were held to identify marketability issues for Fault Detection and Diagnostics in general, and for the WBD tool in particular. This method of research does not result in statistically significant findings, but in raising issues that are on the minds of potential users and customers. This research was successful in assessing the interest in WBD, and in identifying the marketing challenges that must be faced before the product can be marketed with confidence.

In summary, it should be highlighted that participants felt that a diagnostics tool such as WBD could be helpful. However, they generally indicated a hesitance to purchase WBD, due to several barriers. None of these barriers are insurmountable, however, the technical and marketing challenges must be addressed if WBD is to be a successful product implemented in a large number of buildings. Some of the most significant issues that were identified were:

- Potential customers are *very* skeptical about the ability of a tool to identify and reduce energy waste and outdoor air problems in their buildings, in a way that will save them money and effort.
- FDD tools must be demonstrated in buildings that potential customers can relate to, in order to overcome this skepticism.
- It is important to clearly communicate to customers that their existing EMSs *are not* already providing the functionality that is found in these tools. Alternatively, these functions could be added to their existing EMSs.
- Potential customers will want to know what the cost of the system and the expected savings *in their buildings*, in the form of a payback time. Alternatively, they will want to reduce their risk in implementing the technology by acquiring it on a shared-savings basis.
- One of the first questions potential customers will have is *Where are the data coming from?*
- Focus groups should be done earlier in the product development process, to help identify the most necessary areas for diagnostics, the required functionality, and the best user. Several rounds of focus groups may be necessary, to ensure that valuable information is obtained from the target population.

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