



Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program

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EXECUTIVE SUMMARY

This report is a part of the California Energy Commission's Public Interest Energy Research (PIER) Advanced Automated HVAC Fault Detection and Diagnostics (FDD) Commercialization Program. The goals of the FDD Program are to develop and demonstrate advanced fault detection and diagnostic methods and measurement equipment for cooling, heating, and ventilating systems; more advanced and fault-resistant heating, ventilation and air conditioning (HVAC) equipment; and to work directly with manufacturers in order to implement improvements and innovations in commercially available equipment.

The desired outcomes are improved indoor environmental quality, reduced energy use, reduced peak demand, and reduced pollution for the citizens of California. More than 28% of the electricity used in California commercial buildings is for air-conditioning, heating, and ventilation. At least 10% of this energy is wasted due to excessive run time and problems in the HVAC equipment and controls, including equipment installation problems.

The program consists of five technical project elements:

1. Web-enabled Automated Diagnostics: A suite of web-enabled FDD diagnostic tools for air handling units (AHU's) in larger, built up systems.
Product status: The product is in early stage development with some initial market interest.
2. Air Handling Unit (AHU)-Variable Air Volume (VAV) Box Diagnostics: a set of algorithms embedded in ventilation system controllers found in built up HVAC systems in larger buildings.
Product status: The algorithms are being tested at several public and private sector building sites with positive results being reported.
3. Advanced Rooftop Unit (ARTU): a specification for 5-20 ton rooftop HVAC units that increases equipment robustness and includes fault detection and diagnostic capabilities tied to the refrigeration, air handling and control systems.
Product status: A draft set of features for the test unit specification is being finalized.
4. Rooftop Unit Diagnostics (RTU): A diagnostic tool that can be integrated into new units or retrofitted into existing 5-20 ton rooftop HVAC units. The features include FDD capabilities tied to the refrigeration, air handling and control systems.
Product status: A diagnostics package is currently being further refined and field tested with positive results being reported.
5. SpeciFlow™ Technology: An advanced method of more accurately controlling outside ventilation air in built up HVAC systems in larger buildings.
Product status: This product is available on the market through a well-known ventilation products manufacturer.

Scoping Study

This Scoping Study (Study) is a part of the Market Connection element of the FDD program managed by the New Buildings Institute (Institute). The Study's objective is to provide assessments of the market strengths and issues within the FDD program. The results of this Study will be used to develop a Market Connection Plan that identifies specific strategies and

actions to increase the market adoption and penetration of the technologies and products being developed the program.

The Institute established a set of criteria to assess the FDD technologies and practices, and focus on key areas known to affect the ability to successfully implement a technology or practice into the construction and energy efficiency marketplace, including into the codes and standards arena. The criteria were consolidated into four key areas:

1. Energy and Economics
2. Technology Performance
3. Market Factors/Likelihood of Success
4. Ability for Policy Change

Several experts in the HVAC area were selected to provide an assessment of the strengths, uncertainties and challenges facing the candidate FDD products through a scoring exercise. The results of the scoring are presented in Appendix A. Additional interviews were conducted with key persons within the HVAC private sector and in public state and regional energy efficiency market transformation organizations to solicit expertise and discussion of the criteria pertaining to the technology or practice. A preliminary scoring matrix was reviewed by the FDD Program's Public Advisory Committee and the project teams. Combining data provided by the project technical leads and team members with the knowledge and responses of the industry experts and scoring consultants, resulted in the overall Study results.

The Study is a reasonable assessment of market strengths and challenges based on the current development state of the projects and emerging market interest in automated FDD capabilities in HVAC equipment. The Study results and interpretations of priorities will be discussed with the CEC staff and FDD project teams in order to inform the Market Connections Plan. Addressing FDD market issues is important for providing a benefit to all potential FDD technologies—within this program, and other FDD programs and projects underway in California and nationally. The Study results indicate several common themes that impact all of the FDD products in terms of initiating Market Connections support. The consistency of feedback and scoring on these criteria indicates that they are priority areas for action in the Market Connections Plan.

This Study found that all projects:

- ◆ need additional cost and energy performance information.
- ◆ need to determine end user perception of value and acceptance.
- ◆ need to mitigate real or perceived risk related to the actual use of the products in various markets.
- ◆ need market leadership and demonstrated commitment from key market players in the private and public sectors.
- ◆ need significant support from electric utilities and their regulators if the products are to be considered for standards and/or code adoption.

Solutions to market barriers common in each project will support commercialization of all the products. This is true due to the critical need to alter fundamental relationships and approaches

within the HVACR market toward a design/manufacturing/installation/maintenance practice that seeks to continuously provide end use customers with high performance operating conditions at the system and whole building level.

Several overarching issues emerged from the Study:

- ◆ As emphasized by the outside scorers, the FDD products alone do not save energy.
- ◆ The scorers emphasized the need for substantial training and technical support.
- ◆ All of the projects are at varying stages of being able to produce useful cost and performance information vital to making the business case for each product.
- ◆ The degree and speed with which these products move toward commercial success will in large part be due to an informed market place.
- ◆ The performance oriented approach must be strongly supported by the electric utilities, allied energy efficiency organizations, and the regulators associated with building codes and the electric utilities.

All the FDD approaches under development in this program have merit to save energy and improve indoor air quality, serve a variety of market needs, and create business development opportunities for small, medium and large businesses within the HVAC marketplace. The current market strengths and issues in the Study specific to individual technical projects vary in large part due to the differences in each product's development stage and technical progress. The report presents an Overview of the Program and Scoping Study, Project Findings including the products' features, market strengths, guidance for Market Connections support and selected comments on the criteria from the reviewers, and conclusions. Additional information about this program is available at www.archenergy.com/pier-fdd/.

OVERVIEW

Program Background

The project teams in this Program are working with manufacturers to further develop innovative FDD techniques and systems that will be integrated with HVAC systems and controls. The projects include field demonstrations to document the energy performance, energy cost and related benefits of these systems, and develop and distribute information on the products to market decision makers.

The Program has the following related goals or desired outcomes:

- ◆ The next generation of packaged and built-up HVAC systems and controls will have either on-board diagnostics or logged data sufficient to allow analysis by a supervisory building control system.
- ◆ Information about FDD enabled components and equipment will be available for use in HVAC engineering and technician training programs.
- ◆ Building automation vendors will include FDD reporting in their products.
- ◆ Commercial building owners and operators will use automated FDD reporting to correct problems in their building HVAC systems and reap corresponding benefits in better building environments, increased equipment life, and reduced energy use and costs.

The diversity of markets for the FDD products mirrors the need to provide a range of advanced, building performance tools to meet a variety of end use market requirements.

A Technology Transfer Template was developed by Institute staff based on work done for the California Energy Commission by Bevilacqua-Knight Inc. The Transfer Template included a comprehensive set of product and market related questions. In addition, the Template included a Business Case spreadsheet for estimating and calculating the potential energy costs and energy savings that might result from the FDD penetrating its target market in California.

The templates were completed by the project teams, reviewed by Institute staff who submitted comments and questions to the project teams. The Templates were then revised by the project teams based on these comments. The Templates form the basis for the Scoping Study and the scoring framework. Combining the information from the Technology Templates with the experience, knowledge and responses of Institute staff, industry experts and consultants, resulted in the conclusions presented in this study.

Scoping Study Approach

Scoring Process

The scoring exercise was conceived to help assess the early stage development potential and issues related to the eventual marketability of the FDD products.

It is important to emphasize that this report focused on developing scoring results based on more subjective information rather than a rigorous analytical approach. This approach was used because much of the information for these technologies and practices needs to be developed. By applying a rigorous approach to incomplete information on technology application, performance

and costs would be misleading. As such, the results of this scoring may be modified based on different weighting of key factors for success, results of ongoing research, or interpretation of technical data.

The scoring exercise was not designed to provide an absolute rank order such as highest-lowest, strongest-weakest. The scoring must be understood as relative due to a number of factors including the amount of information available to the outside scorers at the time they participated in the exercise; the active progress being made in each of the FDD projects; and some adjustments made by Institute staff and program reviewers based on more current information available on the projects. The results will provide guidance to the Institute staff on where to focus Market Connections plans and activities given limited budget resources.

Interviews were conducted with key persons within the research, engineering and manufacturing areas to solicit their expertise and discuss the criteria pertaining to the successful implementation of the technologies. A review of related literature was also performed to provide an overview of technical, economic and other market factors. Appendix B contains a listing of parties contacted and literature reviewed for this exercise.

Following the initial round of scoring, an impartial set of observers reviewed the scores and adjusted them according to any perceived bias introduced by the reviewers. For example, a particular technology could receive a high score because the individual strongly supports that technology. The individuals' scoring might be adjusted by the reviewers to account for any obvious bias in their scores.

Scoring Criteria

New Buildings Institute staff established the set of criteria for scoring the projects. Each project was scored individually and the results were then compared to identify the relative strengths and challenges for each of the selected FDD products. The results were reviewed by staff of the Architectural Energy Corporation (responsible for overall program management) and the California Energy Commission program manager. The technologies in this report were considered individually relative to the selected criteria. Four areas of importance were outlined for identifying the strengths and weaknesses of project by the consultants and the interviewed participants.

The four areas were:

1. Energy and Economics
2. Technology Performance
3. Market Attractiveness/Likelihood of Success
4. Ability for Policy Change

Energy and Economics

Energy efficiency (the potential for energy and demand savings) and economic viability were collapsed into one category as the energy efficiency performance of measures created favorable economics for those measures. In addition, cost and energy savings data is only estimated for

each FDD product with more or less researched and/or field data as the baseline. Energy efficiency is defined as the ability to strongly influence energy consumption in a positive way.

Key questions that factor into these criteria were:

- ◆ Is the magnitude of energy and/or demand savings of sufficient value to proceed? Are real savings over conventional technology achieved?
- ◆ Will the estimated energy savings be predictable and quantifiable?
- ◆ Will the energy savings persist overtime when compared with conventional equipment/approaches?
- ◆ Is the incremental cost of the FDD product/technology reasonable when compared with the conventional equipment/approach?
- ◆ Will the energy savings pay for the incremental cost?

Technology and Performance

Technology performance addresses the viability of the FDD product as useable product in new and/or existing commercial buildings. For the purposes of this scoring, assume that the FDD product is technically successful. Some of the key questions that factor into these criteria are:

- ◆ Is the useful life of the FDD technology is as good as standard technology?
- ◆ Is the product reliable and durable?
- ◆ Is the risk of using this technology less than conventional technology?
- ◆ Is the FDD product/approach easier to use than conventional technology?
- ◆ Does the FDD product/approach perform as well or better than conventional products?

Market Factors and Likely Success

Market factors and likelihood of success are directly related to the potential for the FDD product to succeed in the various markets that will be impacted by the product. The performance of the FDD product in the market will be critical to its potential for success and impact. Is it a defensible/reasonable/attractive alternative?

Market Attractiveness addressed the availability of adequate evidence from the marketplace to convince key stakeholders that technology/practice is interested and ready.

Likelihood of success evaluated if sufficient support could be gained for including the FDD product in the market. Is the FDD product/approach suitable for reaching high market penetration?

Key questions that factor into these criteria were:

- ◆ Is the FDD product suitable for reaching high market penetration? Is the perceived value of the product sufficient to interest the market?
- ◆ Is the market large enough for the FDD product to have an impact?
- ◆ Are there a wide variety of leaders/allies who would strongly support this technology through a technical, programmatic and/or relationship framework?

- ◆ Is there demonstrated support for the FDD technology by key market players?
- ◆ Will suppliers (or others) of conventional technology be disrupted if the FDD approaches are successful?

Ability for Policy Change

Policy changes cut across a wide spectrum of institutional constituencies involved in public policy regarding energy efficiency. The public agencies involved have the authority, mandate or interest in providing information, training, financial incentives and regulatory requirements. These include state legislatures, related building code, energy agencies and utility regulators; regional market transformation entities; national voluntary programs (Energy Star and LEED); national codes & standards organizations (IECC, ASHRAE, ARI); and electric utilities.

Key questions that factor into these criteria were:

- ◆ Has the availability of public benefits funding provided a distinct advantage for the development of the FDD product?
- ◆ Are there technology or practice alternatives currently in the marketplace?
- ◆ Is there dedicated leadership available who would strongly support public policy on this technology through a technical, programmatic and/or relationship framework?
- ◆ Is there demonstrated support for the FDD technology by key policy makers?
- ◆ Are industry stakeholders willing to advocate for FDD technologies in code deployment?

Next Steps

Following the guidance from the Scoping Study, the Institute will develop a Market Connection Plan that supports the introduction of the overall FDD concept and the candidate technologies into the marketplace. The focus of the Market Connection Plan will be on mapping a path to commercial success by providing the commercial HVAC and buildings marketplace a foundation for understanding and incorporating FDD technologies within the larger framework of whole building performance.

In addition, Institute staff will focus on the areas identified in the scoring exercise as requiring priority support. Elements of support may include securing of manufacturer commitments, assessing owner/operator evaluations of the product's perceived value, educating key decision makers and intermediaries, reaching an initial market, demonstrating and documenting value, refining and expanding applications, resolving state, regional and national codes and standards issues as well as beyond-code (i.e. financial or other incentives, utility regulatory framework) opportunities, providing aids for equipment designers and specifiers, and assuring continued manufacturer commitment to advancing the market and product supply.

These projects, combined with other statewide and utility efforts, will provide a foundation for public and industry discussion and consensus building. Through efforts made early in the FDD product development process, comprehensive technical and economic analysis and cooperation of interested parties, this program may achieve the significant public benefits of improved fault detection and diagnostics in small and large HVAC systems in California and nationwide.

PROJECT FINDINGS

Interviews were conducted with key persons within the manufacturing, controls engineering, and regional market transformation sectors to solicit expertise and discussion of the criteria pertaining to the technology or practice. Combining the Technology Template materials with the experience, knowledge and responses of the industry experts and scoring consultants resulted in the current rankings. Appendix B contains a listing of parties contacted and literature referenced for the Scoping Study.

The results indicate several common themes that impact all of the FDD products in terms of the need for specific Market Connections support within the context of overall support for the FDD concept.

All of the projects:

- ◆ need to produce additional cost and energy performance information.
- ◆ need to determine end user/operator perception of value and acceptance.
- ◆ need to mitigate real or perceived risk related to the use of the products in the market.
- ◆ need market leadership and demonstrated commitment from key market players in the private and public sectors.
- ◆ need significant support from key stakeholders if they are to be considered for code and/or standards adoption.

Project Descriptions

The following section provides a more detailed description of the each of the projects in the program and their development progress.

Web-Enabled Automated Diagnostics

Lead Product Developer: Architectural Energy Corporation (AEC)

The FDD product is a web-enabled automated diagnostics system that detects and reports significant faults in air handlers; chiller, boiler, and cooling tower systems; and associated fans and pumps. The suite of diagnostic applications will run on a centralized, web-accessible server. Any changes and improvements to the data analysis and diagnostic methods can be implemented quickly and easily at a central location. The primary target market for this suite of applications will be buildings with built-up HVAC systems. The first stage product development involves AHU's in chillers systems.

The diagnostic applications will be designed for use primarily in an off-line mode. The purpose of the diagnostic applications is to find problems related to energy waste, although the installation of the diagnostic tool does not directly create energy savings. Information provided by the diagnostics system must be acted upon by the appropriate personnel.

The integrated diagnostic engine developed in this project will be available to any Application Service Provider (ASP) who wishes to incorporate it into its offering. To facilitate licensing this capability to third parties, data transfer interfaces will be developed using Extensible Markup

Language (XML) over Hypertext Transfer Protocol (HTTP). XML over HTTP uses Uniform Resource Identifiers (URI's) with specific name/value pairs to invoke methods and processes within the web services framework. Once the URI is processed, a well-formatted XML document is returned as a response. To allow quick adoption, the system may provide simple Extensible Style Language Transformation (XSLT) service to parse the XML and convert it to a Hypertext Markup Language (HTML) document. The advantages of this approach are well understood by software developers, providing easier maintenance and development for both the ASP and diagnostic engine provider.

Each service provider will have its own on-site data collection equipment. This data will be transferred to the ASP servers at least daily. Next, the data is transferred to the diagnostic web server for analysis. The results of this analysis are returned to the ASP, and then made available to the users via the World Wide Web in the form of reports or notifications.

For the diagnostic framework, AEC is utilizing and adapting the APAR set being developed by the National Institute of Standards and Technology (see next FDD project). The APAR algorithms evaluate knowledge-based rules to detect faults in constant volume AHU's with airside economizers. The rules assess up to 28 potential fault conditions in the AHU's. The fault conditions (reported as alarms) are matched with potential causes, but with few exceptions, a single specific cause for a given fault cannot be identified.

Market Strengths

The use of a web platform for data collection is a well-known path with stability and widely available access assured. The XML over HTTP format of the proposed data transfer interfaces is also well developed.

The product developer, AEC, has signed an agreement with Tridium, a global software and services company that develops and markets a universal software framework. Tridium's core technology, the patent-pending Niagara Framework™ (or "Niagara"), a Java-based framework, provides a software infrastructure to integrate diverse systems and devices into a unified platform that can be easily managed in real time over the Internet using a standard web browser. This platform is a commercial product with an existing user base. The agreement is a non-exclusive software developer's agreement. This allows AEC to develop software that is compatible with the Niagara platform. AEC is responsible for marketing and licensing the web-enabled FDD application to either Tridium end users or Tridium Partners (system integrators). There may be a joint marketing effort, but that is not currently part of the agreement. AEC is free to develop interfaces for other building automation system platforms.

Market Connections Support

The FDD product is in the initial stages of development. Significant product development activities must be continued with AEC's current development partner including but not limited to: the technical and communications interface with the Niagara Framework, identifying a system's integrator to partner with to conduct in-building field testing, establishing the business case and pricing for the FDD service, and finding additional commercial partners for the product once the initial product is finalized. AEC's goal is to expand the product's usability to AHU's in boiler and cooling tower systems.

Criteria Comments

Key comments on the criteria from the scorers included:

Energy and Economics

- ◆ Energy savings will depend on how well the equipment is being maintained today.
- ◆ This is not a widget - benefits depend on actions being taken to correct the detected problems.

Technology Performance

- ◆ Web platform is robust and well understood.
- ◆ Additional training is needed for new technical approaches.

Market Factors and Likely Success

- ◆ Technical support is a major issue.
- ◆ Needs market leader support.

Ability for Policy Change

- ◆ Growing interest in this type of capability in parts of market.
- ◆ Still in R&D phase; has not quite reached critical mass.
- ◆ Not necessarily a fit for building codes.

AHU-VAV Diagnostics

Lead Product Developer: National Institute for Standards and Technology (NIST)

The FDD product is diagnostic algorithms that are embedded in AHU and VAV box controllers that provide automated methods of determining and setting appropriate control factors to assure valid detection and reporting of faults and avoid or minimize false positive reporting of faults.

NIST has developed algorithms, suitable for embedding in commercial AHU and VAV box controllers, that can detect and partially diagnose faults including stuck or leaking dampers and control valves, sensor failure or drift, and improper control sequencing. These algorithms are executed by the equipment controller as a component of the control logic, therefore they are not complete end-use products, but software enhancements for control application programs.

There are two separate FDD algorithms: The APAR set evaluates knowledge-based rules to detect faults in single duct VAV and constant volume AHUs with airside economizers, while VAV box Performance Assessment Control Charts (VPACC) implements a statistical quality control method to detect faults in most VAV box types. Both algorithms are intended to be written into manufacturer-specific control application programs along with the actual equipment control logic. Each AHU or VAV box will be monitored by an algorithm running in its local controller. Trend logging picks up equipment operating faults that are reported to the building operator through the alarm and event handling features of the building automation system (BAS).

A total of 28 faults can be assessed through the APAR set and 20 faults through the VPACC.

Most of today's emerging FDD tools are stand-alone software products that do not reside in a building control system. Thus, trend data files must be processed off-line or an interface to the building control system must be developed to enable on-line analysis. This approach does not scale well because all of the data must be obtained at a single point. A series of research projects in which batch implementations of these tools were developed and refined using data collected from simulation, emulation, laboratory testing, and real buildings are documented in reports under the previous PIER Buildings Program (contract #400-99-011). These tools were found to

be successful at finding a wide variety of faults including stuck or leaking dampers and control valves, sensor drift, and improper control sequencing. Preliminary investigations to study embedding the tools in AHU and VAV box controllers were conducted.

The research described in this project will build upon past work to resolve the remaining barriers to commercialization of FDD: the lack of confidence in automated diagnostics, the specialized knowledge required to embed FDD in HVAC controllers, and the trial and error method of determining fault thresholds. By having one or more manufacturers offer its controller products with FDD integrated at the front end, competitive pressure should give the other manufacturers a powerful incentive to provide their controller products with similar capabilities. Securing the commitment of one or more potential partners to commercialize AHU and VAV box diagnostics is critical to the success of the proposed project.

Market Strengths

The underlying technical challenge for each of the FDD products is the establishment of fault reporting thresholds. While there is no practical limit on how much data can be acquired from sensors and data logging equipment operations and reporting the data to the building operator, there is a practical limit on the amount of information that can be usefully applied by building operations/maintenance staff. All FDD approaches have to establish key threshold parameters for identifying and reporting faults to the operator before it is positioned for commercialization support. In addition, although the market is not actively knowledgeable about or seeking these capabilities, when the concept is presented to building operations and controls design engineers, enthusiastic interest is expressed for having and using these capabilities.

The use of algorithms for control diagnostics appears to result in a very robust approach. The software can be reprogrammed from a central station to reach multiple controller locations within an entire built-up HVAC system. The NIST project manager has secured Cooperative Research and Development Agreements (CRADA) with manufacturers - Alerton and Automated Logic Corporation (ALC) – to provide the software-based algorithms to their dealer networks. The FDD capabilities can be provided at no cost in the dealer's library of controller algorithms. The NIST project manager is continuing efforts to secure CRADA's with Delta Controls and Tour Andover Controls. The consulting engineer who specifies the control sequence and operation must then sell this enhanced performance maintenance service to the end-purchaser sell. The controller algorithms are being tested in ALC and Alerton's company headquarters buildings, and in the 450 Golden Gate Building in San Francisco. Additional sites for algorithm field testing are under active consideration. The current users of the algorithms are impressed with fault data that is coming back through their building automation systems.

Market Connections Support

The major challenge for Market Connections support will be making the business case for incorporating the FDD capabilities into building energy management practices. Key users must be informed about the management impact of this advanced operating mode. These users include 1) the specifying engineer who is responsible for selecting the control logic programming functions for operating the HVAC system, and 2) whomever is responsible for building energy management whether it be building personnel or an outside energy management service provider, it is critical to establish the business case from the enhanced diagnostic framework

based on additional benefit and cost information for energy and related cost savings, equipment cost savings (maintenance and replacement), and occupant comfort.

Criteria Comments

Key comments on the criteria from the scorers included:

Energy and Economics

- ◆ Should have a good payback especially if it is integrated into control units upfront.
- ◆ Savings will depend on maintenance work that is done to solve the problems identified.

Technology Performance

- ◆ Lifetime should be as good as controller lifetime.
- ◆ Will require new service practices, procedures and training.

Market Factors and Likely Success

- ◆ Market penetration could be high depending on regulatory and market transformation incentives.
- ◆ Needs market leader support.

*Ability for Policy Change

- ◆ If ASHRAE required this capability on all equipment it would make a huge difference.
- ◆ Several market players working on FDD approaches for this market.

Advanced Rooftop Unit (ARTU)

Lead Product Developer: Architectural Energy Corporation (AEC)

The FDD product is a specification for a cost effective advanced packaged rooftop air conditioner and a laboratory prototype to evaluate the improvements. This project will develop, test and demonstrate an ARTU prototype of 5 ton cooling capacity that addresses many of the energy and ventilation problems found in commercial building mechanical systems. Features of the ARTU will include improved outdoor air control, improved economizer reliability, diagnostics and troubleshooting capability, and fault-tolerant design. The end result will be a unit that operates according to prevailing ventilation standards, reduces energy use and requires less maintenance.

The project's Technical Advisory Group screened a list of FDD and equipment reliability/robustness characteristics. It was determined that the ARTU would be described as having two levels of advanced capabilities. The first level capability set was determined by assessing currently available products and approaches that had not been combined into a single unit. The second level capability set was determined by assessing more advanced features that were not quite ready for commercialization for one reason or another, but could be incorporated in a future ARTU. The unit's FDD capabilities are the *same as those being developed in the Rooftop Unit Diagnostic project.

Market Strengths

There is a very large market for the ARTU product. The proposed features promote higher efficiency performance from these units and will encourage far better maintenance practices throughout the market.

The feature set involving the FDD capabilities and robustness characteristics has been identified and assessed by a knowledgeable advisory group including manufacturers, engineers and installers.

HVAC manufacturers have already indicated interest in FDD features for rooftop units. Some fault detection, with limited diagnostic capabilities, is being introduced in commercial and residential markets.

Several of the proposed features for the ARTU appear to be known and understood by the manufacturing and installer/contractor communities, and are likely to be incorporated without major disruption or cost. In addition, allies could be gathered from the indoor air quality community as better performing outdoor air handling controls including diagnostics, would provide a quality indoor environment for building occupants.

The FDD feature set being developed for the Rooftop Unit Diagnostics project (next project) has been provided to this project development team for integration into the ARTU design. It is important to note this critical design and performance synergy between these two FDD products will meet help their respective market's needs.

Market Connections Support

This product has important potential to impact state and national standards and codes based on its inherent design that promotes a performance maintenance approach. The new features should increase the likelihood that the energy savings potential of new HVAC equipment is achieved. The final selection of the Level 1 and 2 features sets was still underway at the writing of this report. The lack of a final feature set currently limits an assessment of the cost and benefits of the specifications, and therefore the unit's likely price in a particularly first cost sensitive part of the market. Manufacturer buy in will have to be one focus for Market Connections activities. Although the inclusion of diagnostics and more robust equipment features adds a great deal more value to these ubiquitous rooftop units, it remains equally critical to address the installation and maintenance issues associated with existing rooftop units.

Criteria Comments

Key comments on the criteria from the scorers included:

Energy and Economics

- ◆ Depends on new service contracts being established to take advantage of the information provided.
- ◆ Potential is great, but this is a highly first cost sensitive market.

Technology Performance

- ◆ Most of the technology enhancements are not considered radical.

- ◆ Should be easier to service and more reliable, but new training will be required.
- ◆ Will depend on how the manufacturers meet the specifications.
- ◆ Needs thorough testing.

Market Factors and Likely Success

- ◆ Market is very large.
- ◆ Technician training will be an issue.
- ◆ Many companies are evaluating FDD; some have introduced limited features.
- ◆ Would the California utilities unite to make this happen?

Ability for Policy Change

- ◆ A number of HVAC manufacturers have fundamental work in this area underway.
- ◆ This will require financial incentives for a while before it could be put into codes.

Rooftop Unit Diagnostics

Lead Product Developer: Field Diagnostic Systems, Inc. (FDSI)

The product will be an automated data acquisition system with sensors embedded in rooftop packaged air conditioners that will report out alarms and operating data. The alarms and data will be transferred wirelessly to on site or remote servers for web- and email-based reporting. The product developed in this project will enhance packaged air conditioning equipment controllers used in commercial buildings. It will be based in part on research conducted under the PIER “Energy Efficient & Affordable Small Commercial & Residential Buildings for a Growing California Program” (PIER Contract 400-99-011).

In addition to the controller's normal functions, the combined system will provide diagnostic and performance information on eight fault conditions in both the unit's refrigeration and air handler operations, and nine fault conditions in the unit's controls. The diagnostic hardware will be integrated into packaged units with or without economizer and demand-controlled ventilation controllers. A customer's building automation system could provide for data communication and customer access to web-based reports as well as email alerts quantifying equipment performance and identifying equipment problems needing attention. There will be a technician interface at the unit for diagnostic information and immediate feedback on repair effectiveness.

Market Strengths

There is a large market for this product. FDSI has strong HVAC performance oriented market credentials. The company developed the Honeywell HVAC Service Assistant™, a respected rooftop HVAC performance monitoring tool with fault detection and diagnostic capabilities. FDSI has initially partnered with Computnetix, a Honeywell company, to manufacture the demonstration module. Ten RTU diagnostic beta units are being tested at chain store sites in Anaheim and Rialto, California and five units by Honeywell Services in Georgia. Up to 21 units are planned for installation at three California university campuses.

The FDD alarm information identifies whether the fault condition will impact occupant comfort and safety, as well as estimating the energy costs of the fault condition.

The FDD feature set for the diagnostic module may be customizable, with a range of feature options available at different price points for the customer to meet their requirements as well as installation and operating conditions. The flexibility of the diagnostic implementation platform either as a standalone unit or embedded by a manufacturer in a rooftop unit, should also strongly enhance market interest.

Market Connections Support

Energy costs and savings benefits attributable to the diagnostic unit still have to be determined and will be very site specific. The benefits of the FDD tools in reducing equipment downtime, increasing equipment life, and providing consistent ventilation for occupant safety and comfort, will have to be further assessed in commercial use.

Information about this technology and its technical and service requirements must be disseminated nationally to HVAC industry-related training and certification organizations in order to impact the contractor/installer market. In addition, a wider information distribution effort will be required throughout the entire industry.

The dramatic increase in system operating performance information provided by the FDD capabilities of the diagnostic module will likely be of interest initially only to the top tier contractors who already provide quality installation and comprehensive maintenance services that support high performance HVAC system operation. Lower tier contractors are unlikely to be interested in trying to sell the additional features with the additional equipment cost and potential increased service costs.

Criteria Comments

The FDD feature set being designed into this product may be suitable for consideration for national market introduction through national standards venues including the Consortium for Energy Efficiency and ASHRAE.

Key comments on the criteria from the scorers included:

Energy and Economics

- ◆ It is likely that savings on older units can be higher.
- ◆ Potential is great, but this market segment is highly first cost sensitive.
- ◆ Savings will depend on maintenance work that is done to solve the problems identified.

Technology Performance

- ◆ Way better than conventional technician diagnosis.
- ◆ Will require new service practices, procedures and training.
- ◆ Needs to be thoroughly tested.

Market Factors and Likely Success

- ◆ Market is very large.

- ◆ Technician training will be a major issue.
- ◆ Tilts the contractor playing field; will show how bad some service contracts really are.

Ability for Policy Change

- ◆ Market leaders have to promote technician training.
- ◆ This is not a code issue unless performance verification is required in significant upgrades and in new buildings.

SpeciFlow Technology™

Lead Product Developer: Federspiel Controls

Federspiel Controls has developed a new airflow measurement and control technology called SpeciFlow™. SpeciFlow technology is a proprietary technology protected under U.S. patent number 6,557,574.

The SpeciFlow technology does not fit the scope of the FDD capabilities that are being developed in the other four products in the FDD program. The technology is stated to be advancement in the control and operation of outside air ventilation system dampers. SpeciFlow technology determines airflow by measuring the pressure difference across damper blades, the position of the damper blades, and the temperature of the air flowing through the damper. Damper position measurement is integrated into the damper actuator. A micro-controller circuit measures the pressure, position, and temperature, computes the airflow rate from these readings, and performs the required damper control actions. The technology automatically compensates for the effects of air temperature on air density, which can result in errors of up to 15% if not performed, and consequently provides outdoor temperature measurement to the building control system. SpeciFlow technology is inherently insensitive to condensation, which causes problems for hot wire technology. The technology includes an integral controller, so it can operate as a standalone unit or be integrated with a DDC building control system.

The primary benefit of the technology is improved indoor air quality along with performance efficiencies linked to the building's energy related mechanical systems. This technology should be a more robust product that provides more accurate operation of the ventilation dampers in response to ventilation requirements inside the building.

The technology, named the IAQ-42, helps buildings meet the minimum outdoor air requirements of ASHRAE Standard 62 and California Title 24 by providing accurate monitoring and control of outside air. The IAQ-42 enables a LEED-EB credit for Outdoor Air Delivering Monitoring and another LEED-EB credit for Increased Ventilation. It is also International Energy Consumption Code compliant.

The IAQ-42 is claimed to perform better and be less expensive than the leading product of its kind on the market. However, the product needs technical improvements to improve its accuracy at high damper opening positions with related data input and output. The IAQ-42 is insensitive to non-uniform flow when the control damper on which it is installed is less than 70% open. When the damper is 70-100% open, the unit is sensitive to non-uniform flow, and it is necessary to use expensive flow straighteners to reduce the sensitivity to non-uniform flow in that operating

range. Consequently, there is a need to develop a lower cost method that will make it insensitive to non-uniform flow.

In addition, there is a need to develop a generic calibration curve that compensates for the effects of geometry and damper design so that it is not necessary to factory calibrate every unit, which can significantly increase the retail cost of the product.

Market Strengths

The product is available in the market with the improvements noted above being developed. The product has been licensed and is being offered by the Greenheck Fan Corporation, a \$300 million/year, global business. The technology is claimed to be more robust and lower cost than the main competitor's product. Greenheck has released the first press notice on the product through *The Air Conditioning, Heating, Refrigeration Weekly News*, an online, widely read HVACR industry publication.

Significantly, the IAQ-42 already meets California Title 24 energy code requirements for ventilation as an alternative path compliance option. Other ventilation devices also meet this option. There is also a potential liability reduction for the employers because Title 8 of the California Health and Safety code requires outside air documentation and holds the employer responsible for compliance.

SpeciFlow technology may capture further market interest as an integral component of a whole building performance approach that supports the achievement of both energy and environmental performance goals for the building operator in existing buildings, and in the design of new buildings and facilities. The product's linkage to LEED, an increasingly important factor in the retrofit and new building markets, will serve to enhance the product's image.

Costs are increasing to provide adequate ventilation to occupants in buildings. The cost to the building owner and occupants of not having adequate ventilation is likely to be higher in several respects than the cost of the IAQ-42.

With a number of mechanical systems in buildings not providing adequate ventilation, the use of Speciflow technology can increase energy use as required minimum ventilation standards are consistently met for the occupants. In another set of buildings, where there is too much ventilation air, the use and cost of energy to adequately meet ventilation standards will decrease. Using available data, preliminary estimates of the energy savings benefits of the technology completed by the product developer indicated that there were far more over ventilated buildings than under ventilated buildings.^{1 2}

¹ Jacobs, P., 2003, "Small Problems and Potential Savings Reports," Appendix 25 of *Integrated Energy Systems: Productivity and Building Science*, California Energy Commission report number 500-03-082.

² Katipamula, S., M. R. Brambley, N. N. Bauman, R. J. Pratt, 2003, "Enhancing Building Operations through Automated Diagnostics: Field Test Results," *Proceedings of 2003 ICEBO*.

Market Connections Support

The product is at its market introduction stage. The unit cost is still at least 30 percent higher than the developer would prefer. Work is being done to increase its accuracy in non-uniform airflow rates of 70 percent and higher. In addition, work is continuing on streamlining the factory calibration requirement or possibly outsourcing this critical task to the system installer.

Criteria Comments

The assertion that the unit costs less than its main competitor is being independently verified. As the product is further refined and sold, more information will be available for expanding marketing efforts and increasing product sales, regarding its accuracy, robustness and cost in commercial use.

Key comments on the criteria from the scorers included:

Energy and Economics

- ◆ Couldn't find any real cost data.
- ◆ Highly variable savings.

Technology Performance

- ◆ Could be beneficial on variable air volume systems, but not so much on constant volume systems.
- ◆ There are other alternatives including demand ventilation and intelligent damper control routines that can duplicate the benefit at lower cost.
- ◆ Need to see extended field testing.

Market Factors and Likely Success

- ◆ Greenheck is well positioned to make this happen.
- ◆ Market penetration could be high depending on regulatory and market transformation incentives.

Ability for Policy Change

- ◆ Ventilation is already difficult to enforce.
- ◆ Will definitely require utility incentives to make this happen.
- ◆ Not sure who would lead the charge on this one.

CONCLUSIONS

The Study identifies the inherent conflict between the rated or assumed design efficiency of technologies and the actual field performance as a key market barrier. Although the FDD solutions may remedy known problems and result in significant realized savings, most current voluntary and regulatory systems lack a method to “credit” the identification and correction of these problems. Getting systems to perform as designed does not allow a margin of improvement

over what regulators or consumers already count as the baseline condition. This includes the energy/demand savings that electric utilities have paid for through various incentive programs. FDD represents a near term, technically sound approach to ensuring that the energy savings that are being acquired through various utility and market transformation HVAC efficiency programs for small and large commercial buildings are achieved and maintained as close to the forecast savings levels as possible.

Overarching Issues

There is no shortage of opinion in all sectors of the HVAC market on the options for changing building energy management practices. There is little doubt that it is a multilayered, interdependent system that requires points of leverage to be identified in order to provide key individuals and organizations both public and private, with the awareness and motivation for changing certain fundamental business practices within the HVAC market.

- ◆ *As emphasized by the outside scorers, the FDD products alone do not save energy.*

Only actions of the people responsible for building operations taken in response to the FDD information can restore the operating performance efficiency that is designed and built into a rooftop HVAC unit or a built up system. This points to some emphasis on Market Connections support directed to building owners and the range of energy service providers that serve the commercial building HVAC market.

- ◆ *The scorers emphasized the need for substantial training and technical support.*

The reality of the HVAC equipment situation up on the rooftops should stimulate manufacturers to substantially increase internal, vertically integrated quality control efforts throughout their entire business networks. FDD training should be provided by the manufacturers down through their internal market chain through the distributors and on to the dealers/ specifiers/installers /service providers related to their products. Market Connections outreach may be directed to the thirteen national organizations that provide some form of training and/or certification to the HVACR industry.

- ◆ *All of the projects are at varying stages of being able to produce useful cost and performance information vital to making the business case for each product.*

As more representative information is available from each of the projects to support public and private sector interests, Market Connections initiatives can be matched to the required product commercialization goals and needs.

- ◆ *The degree and speed with which these products move toward commercial success will in large part be due to an informed market place.*

Market Connection activity will include substantial outreach to the HVACR industry on FDD within the context of a transition from an ‘operational’ maintenance to a ‘performance’ maintenance approach.

- ◆ *The performance oriented approach must be strongly supported by the electric utilities, allied energy efficiency organizations, and the regulators associated with building codes and the electric utilities.*

Methods for valuing and incentivising a more comprehensive, performance-based energy efficiency approach must be more fully developed within the utility regulatory framework to account for the increasingly robust energy savings benefits created by these new technologies and applications.

Investment through this PIER program in the FDD related technologies is driven by credible findings regarding the potential to correct significant wasted energy through the identification and correction of problems with equipment maintenance and operations.

In 2004, the Institute published a summary of findings from five rooftop HVAC inspection/maintenance programs for 5-20 ton units,³ brought into sharp focus the FDD and its relationship to the issue of incorporating building performance metrics rather than nameplate ratings as the basis for electric utility sector programmatic initiatives and ultimately regulatory support. The study noted the following issues that impact the operating efficiency and therefore energy efficiency of these rooftop systems appear to be widespread and not limited to older systems only. For example, the largest study cited in the summary, covered 215 buildings in California with recently installed rooftop units. A full 2/3's of the units had one or more problems affecting operating and performance efficiency.

The Institute's review concluded that "the frequency of significant energy wasting problems is large." The findings appear to hold true for newly installed units as well as those that have been in service for some time.

The Study noted problems with:

- ◆ manufacturer design
- ◆ quality of specification
- ◆ quality of installation contracting
- ◆ equipment energy performance efficiency
- ◆ ongoing maintenance

The conventional paradigm for operation and maintenance of rooftop systems is what many describe as "if it isn't broken, there's nothing to fix" or "if no one complains, nothing is wrong." The same conclusion can be reached regarding the operating conditions and performance of built up systems in many large buildings.

It appears that the majority of system owners and service contractors are either unaware of, or are allowing for a variety of reasons, ongoing poor performance of HVAC equipment to increase direct customer energy costs, increase utility system costs and associated greenhouse gas and other emissions, and potentially impact occupant comfort and safety. There is clearly an assumption in the market that the HVACR equipment is working properly if heat and/or cool air are being produced at least at a minimally acceptable level.

³ *Report to the Northwest Power & Conservation Council on the Review of Commercial Roof Top Unit Field Studies*, New Buildings Institute, October 2004

Market Benefits

The FDD concept brings to all segments of the HVAC market a means to offer and ensure the lowest operating cost and highest level of performance along with the lowest environmental cost to:

- ◆ individual customers whose operating environment and costs will be more efficiently and effectively managed;
- ◆ energy management service providers who will have a new product and service package to sell that provides customers the highest possible level of ongoing service, essentially a form of continuous commissioning;
- ◆ the HVAC manufacturing sector that can further strengthen its position in providing higher energy and environmental performance and more robust products to an increasingly demanding market;
- ◆ electric utilities that need to forecast and meet rising electricity demands, and are committing tens of millions of dollars to improve the design/installation/operation of HVAC systems in small and large commercial buildings;
- ◆ utility regulatory authorities that are approving increased utility energy and demand management acquisition program expenditures within a framework of growing energy cost and conventional energy supply constraints;
- ◆ the building codes community who need code options that are technically safe and sound, and which lend themselves to straightforward compliance inspection;
- ◆ the national standards community that should welcome this leap forward toward advanced building engineering; and
- ◆ national training and certification organizations in support of their industry's rapidly growing interest in quality contracting.

What has emerged from the Scoping Study and related discussions with professionals in the field, along with previous research work in the field, is the compelling vision that the role of FDD in buildings lies in its capacity to transform the current approach to building operations. FDD represents the “intel –intelligence” inside a ‘whole building performance’ approach. The products are designed to enhance total energy and environmental performance (internal and external) in commercial building operations. The products under development in the FDD program have the potential to significantly advance California’s goal of reducing energy use and improving environmental quality.

APPENDIX A

PIER-FDD Scoping Study-Scoring Summary

Key:

- Less agreement on the criteria
These are priority areas for Market Connections Support
- ◐ Medium agreement on criteria
The scorers believed that the criteria could be met to some extent
- Strong agreement on criteria
The scorers agreed that the criteria was clearly accurate

I. Energy and Economics Criteria	Project 2 Web Diag	Project 3 AHU-VAV	Project 4 ARTU	Project 5 RTU	Project 6 SpeciFlow
A. Achieves real savings over conventional technology	◐	◐	●	◐	◐
B. Predictable and quantifiable savings	○	○	○	○	○
C. Energy savings persists over time compared to conventional	◐	◐	◐	◐	◐
D. Incremental cost is reasonable compared to conventional	◐	◐	◐	○	◐
E. Energy savings pay for incremental cost	◐	◐	●	◐	◐
II. Technology Performance Criteria					
A. The life of the technology is as good as standard technology	◐	◐	◐	◐	◐
B. It is reliable and durable	◐	◐	◐	○	○
C. The risk of using this technology is less than conventional	○	○	○	○	○
D. It is easier to use than conventional technology	◐	◐	◐	○	◐
E. It performs as well or better than conventional	●	●	●	◐	●
III. Market Factors and Likely Success Criteria					
A. Is suitable for reaching high market penetration	○	◐	◐	○	○
B. The market size is sufficient to have impact	●	●	◐	●	◐
C. Dedicated Leadership Available (technical, program, relationship)	○	○	○	○	○
D. Demonstrated Support of Key Market Players	◐	◐	◐	◐	◐
E. Will the technology disrupt current market players	○	◐	○	◐	○
IV. Ability for Policy Change Criteria					
A. Public Goods Charge Assets Lend Distinct Advantage	◐	◐	◐	◐	◐
B. Technology or Practice Alternatives currently in Marketplace	◐	◐	◐	◐	◐
C. Dedicated Leadership Available (technical, program, relationship)	◐	○	◐	◐	◐

APPENDIX B**Reference List**FDD Scorers

Jeff Harris, Northwest Energy Efficiency Alliance
 Dick Lord, Carrier Corporation
 Adam Wheeler, Sherrill Engineering

Fault Detection and Diagnostic Literature Resources

Five FDD Technology Transfer Templates

Four FDD Technology Transfer Business Case spreadsheets prepared for this program
 ARTU Draft Features List, PIER-CEC FDD Project 4, February 2005
 Braun, J., Li, H., Automated Fault Detection and Diagnostics of Rooftop Air Conditions for California, August 2003, Purdue University/California Energy Commission
 Braun, J., Advanced Diagnostic Tools for Rooftop Air Conditioners, presentation, December 2, 2004, San Francisco, CA, Consortium for Energy Efficiency Meeting
 Cowan A., Report to the Northwest Power & Conservation Planning Council on the Review of Commercial Roof Top Unit Field Studies, October 2004, New Buildings Institute
 Eugene Water & Electric Board, Western Premium Economizer Outside Economizer Requirements, 2002
 Freeman, H., Piette, M.A., Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems, May 2001, PIER/California Energy Commission, LBNL-48629, Integrated Energy Systems: Productivity & Building Science Program Final Report, October 2003, New Buildings Institute/California Energy Commission
 Motegi, N., Piette, M.A., Kinney, S., Herter, H., Web-based Information Systems for Energy Management and Demand Response in Commercial Buildings, April 2003, PIER/ California Energy Commission, LBNL-52510

Resource People Interviewed by Telephone

Chris Clark, New York State Energy Research and Development Authority
 David Cohan, Northwest Energy Efficiency Alliance
 Terry Egnor, Microgrid
 Tom Hartman, Hartman Company
 Philip Haves, Lawrence Berkeley National Laboratory
 Glen Hourihan, Air Conditioning Contractors of America
 Mark Hydeman, Taylor Engineering
 Ron Kent, Southern California Gas Company
 Michelle Kwok, University of Oregon
 Mark Levi, GSA Region 9
 Skip Schick, BetterBricks
 David Smith, Alerton
 Steve Tom, Automated Logic Corporation
 Mark Tuffo, Northwest Energy Efficiency Alliance
 Mary Ann Piette, Lawrence Berkeley National Laboratory
 Jay Santos, Facility Dynamics