Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program

California Energy Commission
Contract # 500-03-030

Deliverable 7.2b: Summary of Technology Transfer Templates

September 15, 2005

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Advanced Automated HVAC Fault Detection and Diagnostics (FDD) Commercialization Program

Deliverable 7.2b: Summary of Project Templates by Project Leads

Program Goals

The goals of the Advanced Automated HVAC Fault Detection and Diagnostics (FDD) Commercialization 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 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.

Technology Area Description

The project teams in this Program will work with major 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 and cost advantages of these systems, as well as develop and distribute information products to market decision makers. The Program has the following related objectives 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.

Project Summaries

Project 2: Web-Enabled Diagnostic System
Project Lead: Stuart Waterbury, Architectural Energy Corporation

Product Description: A web-enabled HVAC 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 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.

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 his or her own on-site data collection equipment. This data is 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.

Energy Savings Potential
The expected range of annual savings is from $0.10/sf to $1.00/sf, assuming the building size is over 100,000 sf, based primarily on energy savings and secondarily on equipment or service contract savings. A range of percentage savings (5% to 15%) was estimated based on simulations, experience with achieving savings using retro-commissioning, and demonstration projects where the results of retro-commissioning were monitored and published. Physical actions by facility operators based on the information created by using the software, as well as purchase of replacement or repair parts and components, are essential to having any energy savings.

Non-Energy Benefits

Non-energy benefits can be qualified at this time, but not quantified since we do not have sufficient operating experience with the product, which is in the alpha stage of development. The FDD system is expected to have the following potential non-energy benefits to the consumer:

- Prevent equipment failure by early diagnosis of developing problems
- Maintenance can be scheduled when it is necessary and more convenient
- Reduce building occupant discomfort by identifying problems

Product Cost

The FDD system may be licensed either as a standalone product or as part of service. Licensing will likely take the form of an annual fee per point monitored, ranging from $50/point to $150/point for the first year depending on the installation and whether analysis services are included. Pricing for subsequent years will be discounted and will include software upgrades. A typical installation may require about 100 monitored points. An authorized BAS partner will provide the hardware. Typical installation costs estimated for hardware, where needed, will be about $7000 per site. Analysis services based on the results from the FDD system provided by third party service providers may range from $200/month to over $1000/month, depending on the complexity of the facility.

Market Potential

There are approximately 14,000 buildings in California with annual peak demand over 500 kW. It is estimated that about 5,000 of these buildings have annual peak demands over 1,000 kW. It is anticipated that these buildings have a floor area of 150,000 sf or greater. These 5,000 large buildings are likely to have a BAS and central plant equipment, and are therefore potential customers for energy and maintenance savings based on FDD. Initial market estimates are for large office buildings, hospitals (and large medical facilities), and college campuses. Large hotels will be added as opportunities become available. Penetration rates are expected to be about 2% per year of large buildings with BAS. Initial market size estimate will be about 50% of the large buildings with BAS. These buildings have annual peak demand of about 1 MW and a floor area of 150,000 sf or more. The initial focus will be in large office buildings, hospitals, and college campuses. According to a PG&E survey, buildings with BAS are distributed among these building types as follows: 35% of large office buildings, 12% of hospitals and medical facilities, and 55% of college campuses. Assuming typical building areas of 140,000 sf for large offices, 200,000 sf for hospitals, and 635,000 sf for college campuses, we estimate that the number of target buildings to be about 900 large offices, 80 hospitals, and 110 college campuses. In Year 1, at least 3 systems are to be installed and will target to install 10. We anticipate installing at the rate 20 or more each year thereafter.

Project 3: AHU & VAV Diagnostics

Project Lead: Jeff Schein, National Institute for Standards and Technology

Product Description: Embedded AHU and VAV box diagnostics 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.

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. In contrast, NIST has developed FDD tools suitable for embedding in commercial AHU and VAV box controllers. 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 manufacturer offer its controller products with FDD "built in", competitive pressure will 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. NIST has secured verbal commitments from manufacturers and is currently working out the details of a written agreement.

Energy Savings Potential

There have been a number of studies to determine the energy saved as a result of FDD, with somewhat divergent results. In general, the studies reported savings ranging from 10% to 30% of HVAC energy consumption, depending on the age and condition of the equipment, maintenance practices, climate, and building use. The conservative end of this range, 10%, was used in the proposal for this project. Therefore, the technology has a load reduction potential of 56 MW in the state of California. Caution must be taken when using this estimate since there is a large variation in the energy savings from one building to the next. The estimate provided here is intended to be used to calculate potential energy savings for a large aggregation of buildings, for example for the state of California, not for application to individual or small numbers of buildings.

Non-Energy Benefits

There are significant non-energy benefits of FDD that result from improved operations and maintenance (O&M) and from better control over the environmental conditions in the occupied spaces. APAR and VPACC can improve O&M by identifying minor problems before they become major problems, thus extending the useful service life of equipment.

Also, repairs can be scheduled when convenient, rather than causing undesirable downtime and costly overtime work. Depending on the building use, better control of the temperature, humidity, and ventilation rate of the occupied spaces can improve employee productivity, guest/customer comfort, and/or product quality control. In some cases, identifying and repairing faults may make the difference between regulatory compliance and noncompliance. The non-energy benefits of FDD are clearly substantial, but they are difficult to quantify. Although there has been some research on the effect of thermal comfort on employee productivity, there is no scientific consensus on this issue, or on the economic effects of guest/customer comfort. The quality control and regulatory issues are important as well, but the associated cost savings haven't been the subject of anything other than anecdotal study.

Product Cost

Each BAS manufacturer provides free of charge, a library of standard control application programs for use by application engineers. The proposed deployment path for APAR and VPACC is to develop versions of the existing AHU and VAV box control application programs that have been modified to include logic to perform the appropriate FDD calculations. In order to install the FDD tools at a specific site, the BAS dealer/representative would select application programs from the library close to the desired sequences of operation, identify the applicable threshold parameters from tables provided by the manufacturer, and configure alarm or event points for each AHU and VAV box. The cost to the BAS manufacturer of providing FDD technology consists of the cost of modifying the standard control application programs and the cost of training its dealer/representatives to apply FDD. The cost to the BAS dealer/representative is the time to receive the training and the time to configure the threshold parameters and configure the alarm/event points. It should be noted that labor represents the bulk of the costs to both the manufacturer and to the dealer/representative. It is not yet known how much of the cost of providing FDD will be passed on to the building owner by the manufacturer and to the dealer/representative. There is also a cost to the building owner to commit time to review and follow up on fault reports from FDD.

Market Potential

Given the absence of hard data on potential pricing of FDD, along with the significant effect of factors other than price on the buying decision, it is difficult to predict the rate of diffusion of FDD into the market. A technology adoption curve for high performance buildings indicates an approximately 2 percent per year market penetration rate involving 1000's of buildings over 20 years.

Project 4: Advanced Roof Top Unit (ARTU)
Project Lead: Doug Dougherty, Architectural Energy Corporation

Product Description: 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.

Energy Savings Potential

Energy savings on a unit basis is estimated to be approximately 1.7 kWh / sqft – yr out of an average total building load of 20.9 kWh / sqft – yr, or about 8%. For all scenarios, the energy savings in year one are 6,926 MWh / year, with a corresponding cost savings of $948,000. For Scenarios A and B, corresponding to a year-one market penetration of 10% with annual increases of an additional 1% per year, the ten-year cumulative electrical energy savings are 495 GWh, with energy cost savings of $68 million.
For Scenario C, corresponding to an initial market penetration of 10% with annual increases of 5% per year, the ten-year cumulative electrical energy savings are 952 GWh, with energy cost savings of $130 million. For Scenario D, corresponding to an initial market penetration of 10% with annual increases of 10% per year, the ten-year cumulative electrical energy savings are 1409 GWh, with energy cost savings of $193 million.

Non-Energy Benefits

The non-energy benefits of units complying with the ARTU specification may have particular value to the user, such as reduced maintenance costs, improved HVAC system life, and better indoor air quality. Benefits include:

- More fault resistant HVAC equipment
- Improved reliability and control
- Improved misaligned damper blades, loose linkages
- Automatic fault detection and reporting
- Reduced maintenance requirements.
- Indoor environmental quality (equipment provides continuous ventilation according to prevailing standards)

The on-board self-diagnostics and troubleshooting capabilities of the ARTU controller should be able to report the following problems (a partial list):

- Improper wiring
- Dirty air filters
- Inadequate unit airflow
- Inadequate ventilation (outdoor) air
- Fan failure
- Improper refrigerant charge
- Dirty refrigerant filter
- Catastrophic mechanical and electrical failures. Incorrect accessory economizer installation
- Incompatible economizer and thermostat controls
- Incorrect economizer controller field setup
- Stuck or misaligned damper blades, loose linkages
- Improper wiring
- Dirty air filters
- Inadequate unit airflow
- Inadequate ventilation (outdoor) air

- Fan cycling on and off rather than providing continuous ventilation air
- Fan running during unoccupied periods

Product Cost
Present-day hardware costs for a standard 5-ton rooftop unit are on the order of $3500 to $5000. A reasonable target cost for ARTU improvements that would be immediately attractive to an owner would be on the order of 10% of the unit cost, or about $500. However, to be conservative, an incremental cost of $1000 is used in the analysis. For a 10-ton ARTU, the incremental cost is not double because much of the control costs are for the same hardware in either case, thus a value of $1400 is chosen.

Market Potential
There is a large market potential although it is likely that the initial market interest will come from businesses that choose to closely manage their energy costs. In addition, private sector energy service providers who provide services to 'high end' customers will be interested in this unit. Manufacturers will position the unit as their top tier unit.
Four scenarios are presented: Scenarios C and D repeat the 5-ton case (Scenario A), but with accelerated levels of market penetration. Scenario A assumes a first-year market penetration of 10%, with growth in that percentage of 1% per year thereafter (i.e., 11% in the second year, 12% in the third year, … 19% in the tenth year). This is a very conservative growth projection that was used in previous PIER research. There are many examples in technology, however, where an improved technology is completely adopted within a decade. Therefore, Scenarios C and D assume market penetration growth of 5% and 10% respectively. These rates result in ARTU technology making up 55% of the units sold in the tenth year for Scenario C, and 91% of the tenth-year units in Scenario D. These rates of penetration are not guaranteed, but they are not unreasonable to discuss – if ARTU technology is successful, market penetration could be very rapid.

Project 5: RTU Diagnostics
Project Lead: Todd Rossi, Field Diagnostic Services, Inc.

Product Description: Embedded FDD methods in selected controller components for use with rooftop HVAC units.

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 PIER Contract 400-99-011. In addition to the controller's normal control functions, the combined system will provide diagnostic and performance information. It will be integrated into packaged units with or without economizer and demand-controlled ventilation controllers. The 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. Provides important diagnostic and performance information with a compelling business proposition for achieving significant energy and demand savings in commercial buildings. 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 to remote servers for web- and email-based reporting.

Energy Savings Potential
4.5% of heating energy; 14.7 % cooling energy; 4.5% ventilation

Non-Energy Benefits
The FDD system has the following potential non-energy benefits to the consumer:

- Prevent equipment failure by early diagnosis of developing problems
- Maintenance can be scheduled when it is necessary and more convenient
- Reduce building occupant discomfort by identifying problems

Depending upon the size and type of the building, the O&M may be handled by onsite personal, service contractors, or a combination of both. System maintenance costs (contract) were estimated at $270 per unit per year based on information provided by a service provider. The FDD system was estimated to reduce service costs by 50%.

Product Cost
The FDD system is most cost effective for buildings with four or more units. The lowest estimated payback period of 0.9 years was for Hospital and Healthcare building type because of the significant energy savings. This energy savings estimate may be high for the healthcare buildings that have packaged HVAC units. Colleges, Hotels and Motels, Restaurants, and Miscellaneous building types had payback periods between 1.6 and 1.9 years due to comparable savings for energy and maintenance. Small Office, Retail Stores, Schools, and Food Stores had payback periods between 2.0 and 2.7 years and were more influenced by maintenance savings.

Estimated Product Cost

Description	Equipment Cost per module (3)	Field Material Cost per module	Field Installation Time per module	Installation Cost	Total Installed Cost per Module	Notes
Compressor Module (1)	$80.00		0.5	$32.50	$112.50	one per compressor
Air Handler Module (2)	$100.00		0.5	$32.50	$132.50	one per unit
Thermostat Module	$50.00		0.5	$32.50	$82.50	one per unit, includes sensors
Communication Module	$50.00		0.25	$16.25	$66.25	one per unit
Master Unit	$350.00		0.5	$32.50	$382.50	one per site

Market Potential
The cumulative projected market for ten years is 87,780 buildings.

Project 6: SpeciFlow Technology
Project lead: Cliff Federspiel, Federspiel Controls

Product Description: Make technical improvements to the SpeciFlow™ SF-1000 technology to improve its accuracy at high damper opening positions and data I/O to accelerate its entrance into the marketplace.

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 technology is owned by Clifford Federspiel and has been licensed to Greenheck Fan Corporation. The license to Greenheck is non-exclusive. It is expected that the Greenheck-named SpeciFlow product (IAQ-42), will come into the market in the first quarter of 2005.

The SpeciFlow™ SF-1000 performs better and is less expensive than the leading product of its kind on the market. However, there is a need for further development in three areas: generic calibration curve, sensitivity to non-uniform flow, and new I/O features. 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 calibrate every unit.

The SF-1000 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 SF-1000 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 low-cost method that will make it insensitive to non-uniform flow. The low-cost method of reducing sensitivity to non-uniform flow will require additional I/O.

Energy Savings Potential
We estimated savings from improved economizer FDD from numbers published by Jacobs (2003). Cooling energy savings for the over-ventilated scenario (and penalty for the under-ventilated scenario) are based on published calculations using standard energy models. Savings figures for the three scenarios are 3.7% of cooling, 10% of cooling, and -2.5% of cooling, respectively. Energy savings are dependent on building type. For small office buildings, the savings are 0.09, 0.25, and -0.06 kW-h/sqft/year for each of the three scenarios, respectively. For large buildings, the savings are 0.15, 0.42, and -0.1 kW-h/sqft/year. For all building types, the statewide energy savings for year one are 61, 375, and -94 MW-h for each of the three scenarios, respectively. The associated year-one energy cost savings are $13,300, $82,400, and ($20,600), respectively. The cumulative 10-year energy savings are 7757, 47967, and -8244 MW-h, respectively. The cumulative 10-year cost savings are 1.7, 10.6, and -2.6 million dollars, respectively.

One-year energy and cost savings for California

Scenario	Faulty economizer	Over-ventilated	Under-ventilated
Energy savings, MW-h	61	375	-94

Cost savings, $	13,300	82,400	20,600

Ten-year energy and cost savings for California

Scenario	Faulty economizer	Over-ventilated	Under-ventilated
Energy savings, MW-h	7757	47967	-8244
Cost savings, $MM	1.7	10.6	-2.6

Non-Energy Benefits

For the under-ventilated building scenario, we estimate the non-energy benefits as 10% of the average of $274/employee/year avoided sick leave cost estimated by Milton et al. (2000) and $285/employee/year predicted by Wargocki et al. (2003). The 10% is an attenuation factor that accounts for the fact that not all employees are paid sick leave, that in many cases employees or their co-workers make up work not performed while they were sick, and that similar mechanisms prevent most productivity loss due to under-ventilation from being incurred by employers.

There is also the non-energy benefit of reducing liability risk and O&M costs associated with OSHA violations. Title 8 of the CA Health and Safety code requires outside air ventilation documentation and holds the employer responsible when standards are not met. Unfortunately, there are no data that can be used to quantify this benefit.

Product Cost

Simple payback is estimated as 1.3, 2.1, and 0.4 years for three scenarios, respectively.

Scenario	Faulty economizer	Over-ventilated	Under-ventilated
Payback, years	1.3	2.1	0.4

Market Potential

Market segments include new construction and retrofit, HVAC system type (packaged/built-up), and public/private sectors. Price will significantly affect the size of each of these markets. The technology is not limited by system size, though large systems may have to use multiple IAQ-42 units, one for each damper section.

Projected amount of sq. ft. per year of buildings with the IAQ-42 installed.

Year 1	Year 2	Year 3
489,923	1,388,724	1,388,724