Onboard and In-Field Fault Detection and Diagnostics—Industry Roadmap

Completed June 20, 2013
Approved July 10, 2013

WESTERN HVAC PERFORMANCE ALLIANCE

ACKNOWLEGEMENTS

The FDD Industry Roadmap was developed with collaboration from the Western HVAC Performance Alliance's Fault Detection and Diagnostics Committee through former and current Committee participants including:

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CLTEESP GOALS, STRATEGIES, AND MILESTONES

Expanding and ensuring quality maintenance and installation of HVAC systems are central to the HVAC elements of the California Long-Term Energy Efficiency Strategic Plan (CLTEESP). Too many units are poorly installed and not commissioned and a lack of maintenance compounds this issue. All residential and commercial HVAC systems naturally degrade in performance over time. Occupant complaints are the main method through which building owners know that there are problems in the building's HVAC operation. However, most operating problems that degrade energy performance are not noticed by the owners or occupants and can result in wasted energy for years. The impact of this degraded performance on the life cycle cost assessment is important.

Onboard and in-field fault detection and diagnostic (FDD) systems are a potential solution to this problem. Onboard FDD utilizes permanently installed sensors to provide monitored data to an onboard data processor, to a computer that is permanently installed, or to a communications gateway that provides data to a site off the roof, either in the building or to a remote location across town or even across the country. In-field FDD utilizes portable equipment that is deployed on the spot or left on site for a limited amount of time. The CLTEESP established Vision, Goals, Strategies, and Milestones designed to promote the availability and use of FDD in commercial and residential buildings across California and elsewhere (see Table 1). To play a pivotal role in meeting the FDD goals of the CLTEESP will take a concerted effort by a broad range of industry stakeholders. This Roadmap describes the barriers to achieving the goals and the resources that can be brought to bear to meet the challenges. The Roadmap lays out the strategies and milestones defined by the CLTEESP, and proposes specific actions to meet these milestones.

The California Public and Utilities (CPUC) in collaboration with the utilities, support an extensive evaluation, monitoring and verification (EM&V) program to establish the energy and demand savings benefits of a range of energy efficiency products and approaches that use ratepayer funds. Sponsored research is ongoing to verify the savings from a range of HVAC diagnostic, commissioning, and repair services applied to HVAC equipment in utility HVAC quality installation and maintenance programs currently operating in California. Additional measures that save energy are being assessed continuously through the utility Emerging Technology Program and its Codes and Standards Enhancement program in collaboration with the California Energy Commission. Descriptions of the diagnostic related research projects either underway (2010-2012) or being planned for the 2013-2014 research cycle are available at the CPUC website. A number of the EM&V research activities support various FDD Roadmap elements by providing additional field data and market transformation information.

RESOURCES

The HVAC industry (broadly defined) will have to work in concert to address a series of gaps to have success with the strategies laid out in the CLTEESP. Some of the oversight of these strategies falls upon the Western HVAC Performance Alliance (WHPA). The WHPA is an important forum for HVAC industry members to work together to promote efficiency and performance in HVAC in California, the western states and ultimately, nationally. With over a hundred institutional members, this is the first alliance of its kind dedicated to energy efficiency. In addition to the WHPA, there are many different stakeholders, not the least of which are the individuals and businesses who require HVAC-related goods and services, that that can influence the FDD industry.

Industry

OEMs. The Original Equipment Manufacturers that produce residential and commercial HVAC systems and built-up system components, play an important role in delivering FDD to the marketplace. They conduct R&D (including FDD) and participate in industry-wide research and development activities. Some of the most active OEMs are Carrier, Daikin McQuay, Lennox, Trane, and York. This category should also include controls manufacturers such as Johnson Controls, Honeywell, Siemens, several smaller companies, along with AHRI that represents the OEMs.

Table 1: California Long Term Energy Efficiency Strategic Plan Vision, Goals, Strategies, and Milestones Related to Onboard and In-Field Fault Detection and Diagnostics

"Big Bold" Strategy 3: *Heating, Ventilation and Air Conditioning (HVAC) will be transformed to ensure that its energy performance is optimal for California's climate.*

CLTEESP HVAC Vision*: The residential and small commercial heating, ventilation, and air conditioning (HVAC) industry will be transformed to ensure that technology, equipment, installation, and maintenance are of the highest quality to promote energy efficiency and peak load reduction in California's climate.*

CLTEESP HVAC Goal 4*: New climate-appropriate HVAC technologies (equipment and controls, including system diagnostics)are developed with accelerated market penetration.* ***Goal Results****: At least 15 percent of equipment shipments are optimized for California's climate by 2015 and 70 percent by 2020.*

CLTEESP HVAC Strategy 4-5*: Develop nationwide standards and/or guidelines for onboard diagnostic functionality and specification for designated sensor mount locations.*

Short Term Milestones*:*

- *Establish an industry-wide task force to develop national standard diagnostic protocols.*
- *Begin implementation.*
- *Incorporate into HVAC industry and utility programs.*

Mid Term Milestones:

- *Incorporate diagnostic standards into the equipment codes.*

CLTEESP Strategy 4-6: *Prioritize in-field diagnostic and maintenance approaches based on the anticipated size of savings, cost of repairs and the frequency of faults occurring.*

***Short Term Milestones**:*

- *Benchmark existing diagnostic, repairs and maintenance protocols and develop appropriate products.*

***Mid Term Milestones**:*

- *Commercialize On-0board Diagnostic systems*

***Long Term Milestones**:*

- *Incorporate mandatory Onboard Diagnostic Systems in California Building Codes*

Third Party Developers. Smaller niche companies have also done work relevant to FDD. Some of the most advanced tools are provided by these third-party developers, including among others: Architectural Energy Corporation, ClimaCheck, Ezenics, Facility Dynamics, Field Diagnostic Services, and Virtjoule. Large controls companies such as Johnson Controls, and Siemens, also offer a range of FDD functions embedded in their centralized building energy management systems.

Other Industry Stakeholders. There are other industry constituents, such as distributors (represented by Heating, Air-conditioning & Refrigeration Distributors International (HARDI), contractors (represented nationally by Contractors of America (ACCA) and the Sheet Metal and Air Conditioning Contractor's National Association (SMACNA), and in California by the Institute of Heating & Air Condition Industries, Inc. (IHACI), and labor (represented by the Sheet Metal Workers International Association (SMWIA).

Researchers

Universities. There are a number of universities that conduct research relevant to FDD. They include the Massachusetts Institute of Technology, Purdue University, Texas A&M, University of California Davis Western Cooling Efficiency Centier, and the University of Nebraska.

Research Institutions. There are a number of private and public entities that conduct research relevant to FDD. They include Lawrence Berkeley National Lab, New Buildings Institute, National Institute of Standards and Technology, PECI, and Pacific Northwest National Lab.

ASHRAE.

- *TC 7.5* The "Smart Buildings" Technical Committee of ASHRAE is responsible for programs, standards, research, and handbook information related to FDD. It is the TC responsible for the Standard Method of Test for FDD in Commercial Air Cooled Packaged Systems.

- *SPC 207* The Standards Project Committee is tasked with developing the "Laboratory Method of Test of Fault Detection and Diagnostics Applied to Commercial Air-Cooled Packaged Systems" to be proposed as a national standard.
- *SSPC 90.1* The Mechanical Subcommittee RTU Working Group has been focused on RTU issues as they relate to the 90.1 Standard.
- *SSPC 189.1* This standard for high performance buildings could be a tool in disseminating information about FDD.

WCEC. Staff of the Western Cooling Efficiency Center are providing support to the IOU HVAC Technology and System Diagnostics Advocacy Program (HTSDA) and to the WHPA FDD Committee. This support includes facilitating committee meetings, and conducting market transformation and research activities.

Users

US DOE. The U.S. Department of Energy has supported the development of the Better Building Alliance and the Better Building Challenge for larger national business groups. DOE provides commercial building owners with a forum to discuss matters related to energy efficiency in their specific commercial markets. Along with DOE, the Better Building Challenge issued a specification for a High Performance Rooftop Unit Challenge, which includes requirements for FDD.

BOMA. The Building Owner and Managers Association represents the interests of building owners and managers.

Government

CEC. The California Energy Commission sponsors a great deal of FDD-related research through its Public Interest Energy Research program (PIER). CEC is also responsible for issuing the State's Building Code, Title 24, which includes requirements for energy efficiency in equipment and buildings. The 2008 Title 24 requirements currently include an option for FDD for rooftop units and terminal air handling systems. A mandatory FDD measure comes into force January 2014 for all commercial systems 4.5 tons and larger.

CPUC. The California Public Utilities Commission regulates privately owned electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies. The CPUC serves the public interest by protecting consumers and ensuring the provision of safe, reliable utility service and infrastructure at reasonable rates, with a commitment to environmental enhancement and a healthy California economy.

US DOE. The U.S. Department of Energy sponsors a great deal of FDD related research. DOE is also responsible for facilitating the CBEA, and they have issued a specification for a High Performance Rooftop Unit Challenge, which includes requirements for FDD. DOE also co-sponsors the ENERGY STAR Program, along with EPA, that will soon include requirements for FDD.

EPA. The U.S. Environmental Protection Agency co-sponsors the ENERGY STAR Program, along with DOE, that will soon include requirements for FDD.

IEA Annexes. The International Energy Agency has sponsored a set of "annexes" to develop, implement, and test FDD algorithms.

National Labs. The US DOE-funded national laboratory network conducts a significant amount of research and development in FDD. The most active FDD labs are Lawrence Berkeley National Lab, Brookhaven National Lab, Oak Ridge National Lab, and Pacific Northwest National Lab.

NIST. The federal National Institute for Standards and Technology under the U.S. Department of Commerce, has long been involved in developing FDD protocols and algorithms, as well as developing ways to evaluate them. They remain active in working with Purdue University on the now concluded PIER FDD diagnostic evaluator project.

<u>Utilities</u>

IOUs. The California Investor Owned Utilities seek to promote customer energy efficiency through:

- HVAC energy efficiency programs
- Demand response
- Emerging markets
- Emerging technologies research
- Codes and standards developments
- *HTSDA Program:* This HVAC Technology Systems Diagnostics Advocacy program is one of the California IOU's HVAC Energy Efficiency initiatives. This non-resource program seeks to promote and advance innovative technologies including FDD and works closely with the Emerging Technology programs that all the IOUs operate.

CEE. The Consortium for Energy Efficiency is an organization of efficiency program administrators from across the U.S. and Canada who work together on common approaches to advancing efficiency. CEE establishes a set of Tiers for HVAC energy efficiency levels that could potentially expand to include requirements for FDD functionality.

ACTION ITEMS FOR STRATEGY 4-5

Table 2 lays out the timeline for the Action Items required to address the gaps related to Strategy 4-5. For each Action Item, the timeline distinguishes between Short Term activities (shown by quarter, 2010-2013), Mid Term activities (2013-2015) and Long Term activities (2016-2020). The Action Items are described below in more detail. It is organized by gap.

Table 2: Action Items Required to Meet Strategy 4-5 of the CLTEESP.

	Q3 2011	Q4 2011	Q1 2012	Q2 2012	Q3 2012	Q4 2012	Q1 2013	Q2 2013	Q3 2013	Q4 2013	Mid-Term	Long-Term
Research into Residential FDD												
Research into FDD on Thermostat												
Research into Non-Microprocessor Rooftop Units												
Research FDD for Different HVAC System Types												
Collaboration with CEE	☑											
ENERGY STAR "Most Efficient" Criteria	☑											
2013 T24 Standard	☑	☑	☑	☑	☑	☑						
ASHRAE Standard method of Test for RTU FDD	☑	☑	☑	☑	☑	☑						
Research Laboratory Methods of Test	☑	☑	☑	☑	☑	☑						
Inventory Reach Codes												
Propose Reach Code FDD Requirements												
Propose ASHRAE Std. 90.1 FDD Requirements												
Propose ASHRAE Std. 189.1 FDD Requirements												
2016 T24 Standard												
Research into Maintenance Behavior	☑	☑	☑	☑	☑	☑	☑	☑	☑			
High Performance RTU Challenge	☑						☑					
Research into Fault Incidence												
Cost Effectiveness Assessment and Dissemination	☑											
Program Pilot Test												
Case Studies												
Research into Market Acceptability												
Design IOU FDD Program												
Launch IOU FDD Program												

Lack of Availability. Existing residential and commercial HVAC systems have limited ability to detect operating faults. There are third-party FDD tools, but most are not readily available or understood by consumers. Few embedded, automated residential FDD tools are available. There are no tools that can detect multiple faults, which are much more common than individual faults. Action items to address this gap are described below.

Research into Residential FDD. While there are several automated FDD tools for commercial buildings and in-field tools for residential buildings, there are no automated tools for residential buildings. Research and Development is needed to develop tools that are appropriate at a residential scale. Although the economy of scale does not favor an individual residential unit, there are such a large number of units that any investment in this sector would be worthwhile.

Research into FDD on Thermostat. The thermostat can serve multiple roles in FDD. It can be the mechanism to annunciate a detected fault in such a way that occupants will be made aware of the situation. It can also serve as the processor for FDD algorithms, especially for units without microprocessor control. Simple alarms such as excessive runtime can only be annunciated with the information from the thermostat, so it is the logical place to carry out this diagnostic.

Research into Non-Microprocessor Controlled Units. Most automated FDD tools require that the unit have a microprocessor control capability. The majority of commercial RTUs have electro-mechanical controls and therefore have limits on detecting faults related to refrigerant levels, for example.

Research FDD for Different System Types. Most FDD tools have been developed on and validated on, a single type of AC unit. There are different types of air conditioning systems, such as those with inverter compressors, micro-channels heat exchangers, different refrigerants, and multiple stages. The FDD existing tools should be validated on a wider range of equipment. R&D should be done if they are found not to be appropriate to these types of systems.

Lack of Standards

Currently, there is no established method to prove that an FDD tool works properly and will not generate excessive false alarms. Without such proof, it is difficult to incorporate the technology into codes, utility programs, marketing and other market transformation efforts. There are no best practices defined for factors such as sensor mount locations. There is also a lack of standardization in terminology. Definition of a fault is meaningless without a specified sensitivity or threshold that defines the presence of any given fault. Market transformation efforts will require sensitivities to be included in definitions of FDD requirements. Test standards are a prerequisite to this type of sensitivity rating. Action items to address this gap are described below.

Collaboration with CEE. CEE has an "Initiative" process through which it launches new measures that its members utilize in their programs. An Initiative might be developed around FDD. CEE operates its Initiatives at the national level only.

ENERGY STAR "Most Efficient" Criteria. In the new Rating system, DOE/EPA are defining a category of "Most Efficient" systems. This includes the "best in class" system for each type of equipment. It includes a specification for FDD in residential forced air and furnace systems, requiring that faults be annunciated to a remote device.

2013 Title 24 Standard. The CEC approved a code change proposal to include mandatory requirements for FDD in the 2013 version of Title 24 that will go into affect in January 2014 for commercial air conditioning systems 4.5 tons and larger. Based on this California initiative, the International Code Council is considering a similar mandatory measure for its 2015 International Energy Conservation Code.

Research Laboratory Methods of Test. Methods are needed to test a FDD tool and ensure that it adequately detects the faults it promises to detect. Right now, Southern California Edison (SCE) is developing such methods. This project is being overseen by a panel of industry advisors.

ASHRAE Standard Method of Test for RTU FDD. A national Standard is needed to provide the methods with which an FDD tool will be tested in a laboratory to assess how well it achieves its stated objectives. ASHRAE has recently established a committee to develop this standard: SSPC-207P. Development may continue for 2-3 years.

Inventory 'Reach' Codes. Reach Codes (that go beyond the minimum base code) are an effective way of stimulating energy efficiency measures that are not included in the building code. The utilities provide technical support to local governments that are interested in adopting reach codes. Compliance issues have to be addressed when discussing reach codes with related actions inventoried.

Propose Reach Code FDD Requirements. No California reach codes currently include FDD requirements. Such requirements must be developed. Utilities are currently preparing Codes and Standards Enhancement (CASE) proposals for the 2016 Title 24, Part 6 and Title 24, Part 11 reach code sections.

Propose ASHRAE Std. 90.1 and 90.2 FDD Requirements. The ASHRAE Standards that address commercial and residential buildings are Stds. 90.1 and 90.2, respectively. These provide mandatory and prescriptive requirements for mechanical and other systems within a building. While neither includes FDD requirements currently, it is beginning to be discussed within the Mechanical Subcommittee.

Propose ASHRAE Std. 189.1 FDD Requirements. ASHRAE's Standard for High Performance Buildings is Standard 189.1. This currently does not have requirements for FDD, but they should be considered for future versions.

2016 Title 24 Standard. A code change proposal, including additional and/or refined requirements for FDD, should be drafted for the 2016 version of Title 24.

Lack of Customer Pull

Before a technology can be successful, there must be a demand from the customer base. Customers must perceive value in the tools. There is no good data on FDD costs, and there is not much good data on FDD savings. There is a lack of field data on both. No savings result if building operators ignore the alarms generated by FDD tools. Response by operators is determined by complex institutional and behavioral factors. There is a lack of understanding of the influences on behavior, for different customer types. FDD benefits are probabilistic in nature: any particular fault will only occur in a fraction of systems. There needs to be data on fault incidence in order to better understand the benefits of FDD. Action items to address this gap are described below.

Research into Maintenance Behavior. SCE has recently launched a research project into the behavior of customers related to maintenance. This should shed some light on why customers do or do not perform maintenance on their systems, and what it would take to get them to obtain periodic maintenance. This project will continue until mid-2012. There may also be a project launching soon to look at the behavior of contractors and technicians, as it has an influence on maintenance services.

High Performance RTU Challenge . In collaboration with the DOE, the CBEA has produced a set of requirements for a high performance RTU. These requirements include a set of FDD requirements. However, additional work is needed before these requirements can be met, such as setting a standard definition of the faults cited, and developing a method of test.

DOE has launched an Advanced Rooftop Unit Campaign (ARC) to focus market attention on more efficiency new and retrofit products.

Research into Fault Incidence. To have greater confidence in the estimates of savings attributable to FDD, more information needs to be known about fault probabilities. This falls into two categories: instantaneous *prevalence* and annual *incidence*. The latter is most significant for cost-benefit calculations, while the sparse information that does exist is in the form of the former. Work is underway through CPUC/IOU-sponsored evaluation, monitoring and verification research on the energy impacts of selected faults.

Cost Effectiveness Assessment and Dissemination. As a part of the 2013 T24 Standard activity, the cost effectiveness of FDD was initially assessed. More research is needed to refine these estimates and to disseminate information about cost-effectiveness.

Program Pilot Test. Before launching an IOU Energy Efficiency incentive program, the technology must be piloted. This will require some program design, and implementation in a limited number of buildings. This may or may not fall under the requirements of the TRC test.

Case Studies. Providing information to end users in the form of case studies has been shown to be an effective way of encouraging technology uptake. These case studies must be carefully considered and be done in buildings that are similar to the target audience for the case studies. These should be polished looking and provide measured pre-post retrofit performance data.

Research into Market Acceptability . Market research is needed, looking into issues such as deployment models, customer awareness, behavior, change management, cost/benefits, and non-energy benefits.

Design IOU FDD Program. An IOU energy efficiency incentive program will be designed with results from the pilot test. The design must include factors such as marketing, deployment, implementation strategies, and measurement and verification. A work paper would be written as a part of this task.

Launch IOU FDD Program. An IOU energy efficiency Incentive program should be launched.

ACTION ITEMS FOR STRATEGY 4-6

Table 3 lays out the timeline for the Action Items required to address the gaps to Strategy 4-6. The Action Items are described below in more detail, organized by gap.

Table 3: Action Items Required to Meet Strategy 4-6 of the CLTEESP.

		Q3 2011	Q4 2011	Q1 2012	Q2 2012	Q3 2012	Q4 2012	Q1 2013	Q2 2013	Q3 2013	Q4 2013	Mid-Term	Long-Term
Lack of Validated Protocols	Results from PIER Purdue Diagnostic Protocol Evaluator Project							☑	X	X	X		
	Collect and Disseminate Field Data							X	X	X	X	X	
	Benchmark and Assess Existing Protocols									X	X		
	Create Gap Analysis of Existing Protocols											X	
Lack of Customer Pull	Develop Program for Commercial Buildings											X	X
	Develop Program for Residential Buildings											X	X
	Conduct Human Behavior Projects									X	X		
Lack of Integration with Existing Systems	Work with Manufacturers to Enhance Maintainability							X	X	X	X	X	X
	Institute Voluntary Industry Agreement to Deliver Changes								X	X	X		
	In-Field FDD and Maintenance Study											X	X
	Work with OEMS to Develop Products											X	

Lack of Validated Protocols

There are several protocols available for doing in-field diagnostics of HVAC systems. Most of these protocols have shown promise and have been effectively used. However, they have not been validated in a way that will allow them to be used universally.

Results from Diagnostic Protocol Evaluator Project. Researchers at Purdue University's Herrick Lab developed an "evaluator" that will allow testing of the validity of various in-field diagnostic tools, using computer modeling techniques. Results from the Diagnostic Protocol Evaluator Project should lead to a national protocol to test refrigeration and airflow diagnostic tools.

Collect and Disseminate Field Data. One additional action item that is needed to validate protocols is the collection and dissemination of more field data. These data will be invaluable in conducting an evaluation of tools in modeling, lab, and field environments.

Benchmark and Assess Existing Protocols. There are tools available, but they must be validated to be useful for utility programs or code compliance. The tools must be "Benchmarked" against one another and against laboratory and field data. Their appropriateness and accuracy should be assessed (including savings and cost-benefit/effectiveness).

Create Gap Analysis of Existing Protocols. Once the existing protocols have been evaluated, a gap analysis can be carried out to identify where additional protocol development is necessary. This will include comparison with both current needs and future needs.

Lack of Customer Pull

Develop Program for Commercial Buildings. An IOU Energy Efficiency incentive program will be designed to deliver maintenance services to commercial buildings based upon in-field FDD tools. This type of program will help spur the market by reducing the cost of the tool deployment.

Develop Program for Residential Buildings. An IOU Energy Efficiency incentive program will be designed to deliver maintenance services to homes based upon in-field FDD tools. This type of program will help spur the market by reducing the cost of the tool deployment.

Continue Human Behavior Field Work. Human behavior is critical in using FDD tools: human beings install the tools, respond to fault s detected by the tools, and provide services to remediate problems that led to the fault detection. A good understanding of these human factors is important in developing tools that will actually be useful and generate energy savings.

Lack of Integration with Existing Systems

Work with Manufacturers to Enhance Maintainability. Many systems today are not convenient to maintain. Work with HVAC manufacturers is needed to enhance HVAC system maintainability. Examples of innovations that could enhance maintainability include integrated pressure and temperature sensors and power measurement.

Institute Voluntary Industry Agreement to Deliver Changes. Rather than rely on appliance or building standards, it is desirable to Institute voluntary industry agreement to deliver the highest priority of these changes. This will require working closely with industry to understand their business drivers as well as technical hurdles.

In-Field FDD and Maintenance Study. A second field study should be conducted to test in-field FDD tools in the context of a maintenance program. Special emphasis should be placed on accuracy of diagnostics, reliability and ease of use.

Work with OEMS to Develop Products. Original Equipment Manufacturers can provide stand-alone in-field diagnostic devices, as well as HVAC systems that are "FDD-friendly." This will require working with OEMs to develop appropriate products and ensure product availability.