Western HVAC Performance Alliance Onboard and In-Field Fault Detection and Diagnostics (FDD) Committee

An Industry Roadmap
FDD Roadmap Update

A WHPA Work Product as of November 15, 2017

Roadmap Completed June 20, 2013
Approved July 10, 2013

Update Includes Revisions by WHPA FDD Committee Members
October 31, 2017

Prepared by:

WHPA FDD Committee Co-Chairs

1. Sean Gouw, Southern California Edison
2. Joe Schmutzler, Transformative Wave

WHPA Work Product Summary

DATE: October 31, 2017

INITIATING BODY: Onboard/In-Field Fault Detection and Diagnostics (FDD) Committee

WORK PRODUCT NAME: FDD Roadmap Update

TYPE OF ACTION REQUESTED: ☒ **VOTE** ☐ **GUIDANCE** ☐**OTHER**: Click here to enter text.

APPROVAL HISTORY

COMMITTEE: Onboard/In-Field Fault Detection and Diagnostics (FDD) Committee

☐ **BY CONSENSUS** ☒ **BY VOTE**

TALLY: Motion was made by Pete Jacobs (BMI) and seconded by Rob Falke (NCI). The Email votes were cast as follows:

1. AYEs: Glenn Hourahan (ACCA), Jeff Gamble (Bes-Tech, Inc.), Dick Lord (Carrier Corporation), Jim Hanna (Energy Solutions), Benjamin Kelderman (Ezenics, Inc.), Dale Rossi (FDSI), Wayne Guelfo (JCI), Alexi Miller (NBI), Sean Gouw (SCE), Joe Schmutzler (Transformative Wave), Farhad Farahmand (TRC), Robert Mowris (Verified, Inc.)
2. NAYs: Skip Ernst (Daikin Applied), Aniruddh Roy (Goodman Mfg.)
3. ABSTENTIONS: Caleb Joiner (Trane-Ingersoll Rand, Inc.), Janet Peterson (XCSpec)
4. Unavailable to Vote: Abram Conant (Proctor Engineering)

Motion Passed

DATE: November 3, 2017

WORK PRODUCT OBJECTIVES: O

CA ENERGY EFFICIENCY PLAN STRATEGIC GOAL ALIGNMENT:
☐ GOAL 1 ☐ GOAL 2 ☐ GOAL 3 ☒ GOAL 4

CEESP HVAC GOAL STRATEGIES: Increasing the percent of shipments of HVAC equipment that is optimized for the California climate) by focusing on Strategies 4.5 (onboard FDD) and 4.6 (in-field FDD).

BENEFITS: Increase the number of technologies used in the program(s) to improve participation and reduce customer costs. Also, by increasing the number of actors in the market, it would improve competition and potentially product quality.

OUTSTANDING ISSUES / DEBATES / MINORITY VIEWS: None

POTENTIAL AUDIENCE: Utility Quality Maintenance program implementers and managers, FDD technology manufacturers, and QM program maintenance contractors.

EXECUTIVE COMMITTEE MOTION: At the November 15, 2017, Executive Committee Meeting, the Fault Detection and Diagnostics (FDD) Committee “FDD Roadmap Update” Work Product Summary and Updated Roadmap were presented by Committee Chairs Joe Schmutzler (Transformative Wave) and Sean Gouw (SCE). Don Tanaka (UA) made the motion and Scott Higa (SCE) seconded the motion to adopt this Work Product

VOTE TALLY: There were 10 out of 13 voting members represented. 10 Aye votes were cast by CEC, HARDI, IHACI, JCEEP-by-proxy, NCI, PG&E, SCE, SDG&E, SoCalGas, and UA. There were no Nay votes.

FURTHER ACTIONS REQUIRED: WHPA Staff will ensure the combined Work Product Summary and the FDD Roadmap Update are properly posted and distributed in accordance with established marketing protocol for approved WHPA Work Products

NEXT STEPS: None

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

Completed June 20, 2013
Approved July 10, 2013

Updated October 31, 2017
Approved November 15, 2017

WESTERN HVAC PERFORMANCE ALLIANCE

ACKNOWLEGEMENTS

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

Abdullah Ahmed, Sempra Utilities
Abram Conanat, Proctor Engineering
Adrienne, Thomle, Adrienne Thomle Consuulting
Alberto Cordova, Xcel Energy
Alexi Miller, New Buildings Institute
Aniruddh Roy, Goodman Manufacturing
Anthony Hernandez, Southern California Edison
Benjamin Kelderman, Ezenics, Inc.
Bob Cross, Xencom, Inc.
Brent Eubanks, Taylor Engineering, LLC
Brian Thompson, Ezenics, Inc.
Caleb Joiner, Trane-Ingersoll Rand, Inc.
Cathy Chappell, Heschong Mahone Group
Chris Scruton, California Energy Commission
Christian Weber, Pacific Gas and Electric Company
Craig Fulgum, Virtjoule, Inc.
Daihong Yu, University of Nebraska/Omaha
Dale Gustavson, Better Buildings Inc./Western HVAC Performance Alliance
Dale Rossi, Field Diagnostic Services, Inc.
Daniel Sullivan, Target Corporation
Darryl DeAngelis, BELIMO Aircontrols, Inc.
David Yuill, Purdue University
Denis O'Connor, Constellation Energy
Dick Lord, Carrier Corporation
Farhad, Farahmand, TRC, Inc.
Glenn Hourahan, Air Conditioning Contractors of America
Jan Peterson, XCSPec
Jeff Aalfs, XCSPec
Jeff Gamble, Bes-Tech Inc.
Jeff Miller, CEC
Jerine Ahmed, Southern California Edison
Jim Braun, Purdue University
Jim Hanna, Energy Solutions
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Joe Shiau, Sempra Utilities
Jon Douglas, Lennox Industries
Keith Spivey, Pacific Gas and Electric Company
Klas Bergloff, ClimaCheck Sweden AB
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Paul Thomas, San Diego Gas & Electric
Robert Mowris, Verified, Inc.
Sean Gouw, Southern California Edison
Sherry Hu, Pacific Gas and Electric Company
Skip Ernst, Daikin McQuay/Daikin Applied
Tim England, Varidigm Corporation
Vance Payne, National Institute of Standards and Technology
Warren Lupson, Air-Conditioning, Heating, and Refrigeration Institute
Wayne Guelfo, Johnson Controls, Inc..

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 Utilities Commission (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's Emerging Technology Program and its Codes and Standards Enhancement Program in collaboration with the California Energy Commission (CEC). 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 HVAC efficiency and performance 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

Original Equipment Manufacturers (OEMs) 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.

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

Short-Term Milestones:

- Work with industry-wide task force to develop and disseminate national standard diagnostic protocols.
- Continue to work with 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.

Mid-Term Milestones:

- Commercialize onboard diagnostic systems that include communication protocols that meet CA requirements

Long-Term Milestones:

- Incorporate mandatory onboard diagnostic systems in California Building Codes for built up and residential systems.

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, GreenFan® Inc., Verified® Inc., 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 HARDI (Heating, Air-conditioning & Refrigeration Distributors International), contractors represented nationally by ACCA (Air Conditioning Contractors of America), the SMACNA (Sheet Metal and Air Conditioning Contractor's National Association), and in California by IHACI (Institute of Heating and Air Conditioning Industries) and labor represented by SMWIA (Sheet Metal Workers International Association).

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 Center, and the University of Nebraska.

Research Institutions and Research Companies: 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, CLEAResult, GreenFan® Inc., Robert Mowris & Associates Inc., Verified® Inc., 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 is for high performance buildings and 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 Buildings Alliance and the Better Buildings 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 Buildings 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 FDD option 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.

Utilities

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

Lack of Availability: Existing residential 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 few tools that can detect multiple faults which are much more common than individual faults. See Appendix B (page 15) for some current options. 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: Code changes in California mandate communication at the thermostat or other method. FDD Committee should keep up on research into the effectiveness of this method and which processes achieve the best results.

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

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 are only limited methods 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. See Appendix C (page 16) for third-party test references researching this topic.

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 Standards: The CEC approved a code change proposal to include mandatory requirements for FDD in the 2013 version of Title 24 for commercial packaged air handlers 4.5 tons and larger. Based on this California initiative, the International Code Council adopted a similar mandatory measure for its 2015 International Energy Conservation Code. The Title 24 Code has been updated twice to include built-up air handlers and for clarifying requirements for notifying the appropriate personnel.

Research Laboratory Methods of Test: Methods are needed to test an 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. Third-party companies are developing test methods as well. See Appendix A (page 14) for reference.

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 Standards 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.

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. SCE completed a study in 2012 to evaluate 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 efficient 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: (1) instantaneous *prevalence* and (2) 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.

FDD Program Pilot Test: Utilities are looking to review FDD systems and how better to incorporate FDD and remote monitoring into existing programs to claim energy savings starting with the 2018 program cycle. 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 must 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 in looking into issues such as deployment models, customer awareness, behavior, change management, cost/benefits, and non-energy benefits.

Design of IOU FDD Programs: Incorporate knowledge from previous research into existing FDD elements in IOU programs. This would incorporate understanding of technological requirements of FDD, behavioral issues related to contractor sales and management, and customer oversight of faults and incorporating these systems into their management of HVAC units.

ACTION ITEMS FOR STRATEGY 4-6

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 faults 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 to ensure product availability.

Appendix A: FDD Related Research

Utility Reports

- Energy Market Innovations, Inc., California HVAC Contractor & Technician Behavior Study, Western Cooling Efficiency Center, UC Davis, Verified®, Inc., Better Buildings, Inc., CALMAC Study ID SCE0323.01, http://www.calmac.org/publications/CA_HVAC_Behavior_Study_FinalReport_2012Sept14_FINAL.pdf

Government Research Lab Reports

- David Springer, Expert Meeting Report: HVAC Fault Detection, Diagnosis, and Repair/Replacement, May 2016, https://www.nrel.gov/docs/fy16osti/60987.pdf

Third-Party Reports

- R. Mowris, E. Jones, R. Eshom, K. Carlson, J. Hill, P. Jacobs, J. Stoops, Laboratory Test Results of Commercial Packaged HVAC Maintenance Faults, 2015, Prepared for the California Public Utilities Commission. http://www.calmac.org/publications/RMA_Laboratory_Test_Report_2012-15_v3ES.pdf
- Meyer, J, DNV GL, 2017 Impact Evaluation of 2015 Upstream HVAC Programs (HVAC 1), http://www.calmac.org/publications/HVAC1_2015_ImpactReport_FinalES.pdf
- R. Mowris. 2015. HVAC.03 Appendix I. Pilot Memorandum: RMA Master Technician HVAC.03 Pilot Study Observations of PG&E SW Program.
- Heinemeier, K. 2014. "Free Cooling: At What Cost." ACEEE Summer Study on Energy Efficiency in Buildings. http://aceee.org/files/prjrvboceedings/2014/data/papers/3-1007.pdf.
- California Utilities Statewide Codes and Standards Team. 2011. Residential Refrigerant Charge Testing and Related Issues. http://www.energy.ca.gov/title24/2008standards/special_case_appliance/refrigerant/2013_CASE_R_Refrigerant_Charge_Testing_Dec_2011.pdf

Appendix B: FDD Related Technology Patents

- Patent number: 8583384, Method for calculating target temperature split, target superheat, target enthalpy, and energy efficiency ratio improvements for air conditioners and heat pumps in cooling mode, Date of Patent: November 12, 2013, Inventor: Robert J. Mowris
- Patent number: 9207007, Method for calculating target temperature split, target superheat, target enthalpy, and energy efficiency ratio improvements for air conditioners and heat pumps in cooling mode, Date of Patent: December 8, 2015, Inventor: Robert J. Mowris
- Patent number: US7500368B2. System and Method for Verifying Proper Refrigerant Charge and Airflow for Air Conditioners and Heat Pumps, Date of Patent: March 10, 2009, Inventor: Robert J. Mowris
- Patent number: US8583384B2. Method for Calculating Target Temperature Split, Target Superheat, Target Enthalpy, and Energy Efficiency Ratio Improvements for Air Conditioners and Heat Pumps, Date of Patent: November 12, 2013. Inventor: Robert J. Mowris
- Patent number: US9207007B1. Method for distinguishing non-condensables from refrigerant over-charge and restrictions from refrigerant under-charge and calculating the amount of refrigerant to be added or removed to the cooling system for optimal performance. Date of Patent: December 08, 2015. Inventor: Robert J. Mowris
- Patent number: US 9671125 B2. Method for controlling an HVAC ventilation fan in heating or cooling mode and varying the fan-off time delay as a function of heat source or cool source operational time. Method for increasing heater ventilation fan speed from the low speed used for heating to the high speed used for cooling. Method for maintaining the heat pump reversing valve signal at the same position throughout the cool or heat source operational and extended variable fan-off time delay. Method for closing economizer dampers at the end of the cool or heat source operational time while continuing to operate the ventilation fan for an extended variable fan-off time delay. Date of Patent: June 06, 2017, Inventor: Robert J. Mowris, John Walsh
- Patent number: US 7500368B2. An apparatus for the diagnosis of a cooling system which receives inputs in the form of data about a cooling system, and measurements made from the cooling system, and which then calculates the amount of refrigerant to be removed or added to the cooling system for optimal performance. In addition, methods for ensuring correct setup of a cooling system are disclosed. The methods may apply to FXV (fixed expansion valve) systems and may include making and displaying a prediction of a refrigerant adjustment based upon measurements such as return air wet bulb temperature, condenser air entering temperature, refrigerant superheat vapor line temperature, and refrigerant superheat vapor line pressure. A method for ensuring correct setup of a cooling system is disclosed. The method may apply to TXV (thermostatic expansion valve) systems and may include making and displaying a prediction of a refrigerant adjustment based upon measurements such as refrigerant subcooling liquid line temperature and refrigerant subcooling liquid line pressure. A method for ensuring correct setup of a cooling system is disclosed. The method may include making and displaying a prediction of a refrigerant adjustment or of an airflow adjustment based upon measurements such as return air wet bulb temperature, return air dry bulb temperature and supply air dry bulb temperature. Recommendations may also be based upon evaporator coil temperature splits. Methods for visual identification, archiving of associated measurement and verification data, and viewing of data for a correct setup of a cooling system are disclosed. Methods of maintaining correct setup of a cooling system through use of labels and locking, double-sealing, color-coded, and laser etched Schrader caps are disclosed. Date of Patent: March 10, 2009, Inventor: Robert J. Mowris
- Patent number: US 9797405. A method for controlling heater ventilation fan operation increases fan speed from low to high after a short delay after turn-on, and continues fan operation for a period of time based on duration of operation, after tum-off. The higher fan speed improves heat transfer and efficiency while the heating system is operating. Continuing fan operation after turn-off maximizes recovery of additional heat from the heat exchanger. Known methods do not provide sufficient air flow to efficiently transfer heat from the heat exchanger to the air, and leave high temperature air (i.e., 110 to 200° F.) in the heat exchanger after tum-off. Date of Patent October 24, 2017. Inventor: Robert J. Mowris, John Walsh.

Appendix C: Organizations Involved in FDD

Third Party Groups

- List of Economizer Fault Detection and Diagnostics Certified to the Energy Commission: http://www.energy.ca.gov/title24/equipment_cert/fdd/
- ASHRAE Guideline Project Committee 36: High Performance Sequences of Operation for HVAC Systems
- ASHRAE Guideline Project Committee SPC-207: Laboratory Method of Test of Fault Detection and Diagnostics Applied Commercial Air-Cooled Packaged Systems