Single Family HVAC Fault Detection and Diagnosis Research Report

Single Family HVAC

RESEARCH REPORT FOR FUTURE CODE CYCLES

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Prepared by Frontier Energy, Inc.

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Measure to be Considered in a Future Code Cycle

The single family fault detection and diagnosis (FDD) measure was removed as a proposed measure for the 2022 code cycle in April, 2020. The Statewide CASE Team is publishing the Draft CASE Report as a research report that contains analysis that may be used to put forth a future code change proposal and includes draft code language and recommended changes.

The single family FDD measure was considered for the 2022 code cycle because of the potential to ensure the persistence of performance of HVAC systems over time and because ongoing verification of HVAC performance is a critical part of realizing energy savings in the state of California. After initial research, including interviews with stakeholders, the Statewide CASE Team discontinued pursuing this code change proposal because of the uncertainty that identified faults would be remedied by the installation of FDD device, the difficulty in establishing specifications for manufacturer FDD certification processes, and the potential for burdensome HERS verification requirements. The emerging innovative tools that show promise to achieve the desired performance improvements function in widely diverging ways and accommodating variety in how different products function requires developing innovative verification procedures for both the manufacturer and the field installer or verifier.

While the following Draft CASE Report is no longer a 2022 code change proposal, the Statewide CASE Team is still interested in gathering additional input on appropriate and effective verification methods to help this measure's consideration for future code change proposals. Information collected may also be useful to utility program staff considering FDD systems from an incentive perspective. To support ongoing research, additional information on residential HVAC FDD can be submitted to the Statewide CASE Team through info@title24stakeholders.com.

Document Information

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Executive Summary

This is a research report containing analysis that may be used to put forth a future code change proposal and includes draft code language and recommended changes. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this research report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. For this report, the Statewide CASE Team is requesting input on the following:

1. *Methodology for manufacturers to demonstrate compliance with eligibility criteria,*
2. *Procedures for HERS verification, and*
3. *Ways to maximize persistence.*

Email comments and suggestions to info@title24stakeholders.com*. Comments will not be released for public review or will be anonymized if shared.*

Introduction

The Codes and Standards Enhancement (CASE) Initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update the California Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison – and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein are a part of the effort to develop technical and cost-effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The single family fault detection and diagnosis (FDD) measure was considered for the 2022 code cycle because of the potential to ensure the persistence of performance of HVAC systems over time and because ongoing verification of HVAC performance is a critical part of realizing energy savings in the state of California. After initial research, including interviews with stakeholders, the Statewide CASE Team discontinued pursuing this code change proposal because of the uncertainty that identified faults would be remedied by the installation of FDD device, the difficulty in establishing specifications for manufacturer FDD certification processes, and the potential for burdensome HERS verification requirements. The emerging innovative tools that show promise to achieve the desired performance improvements function in widely diverging ways and accommodating variety in how different products function requires developing innovative verification procedures for both the manufacturer and the field installer / verifier. Because of the significant resources necessary to develop a full code change proposal based on this measure, the Statewide CASE team chose to deprioritize this topic for the 2022 code change cycle.

The Statewide CASE Team is interested in gathering additional input on appropriate and effective verification methods to help this measure’s consideration for future code change proposals. To support ongoing research and future code cycle consideration, additional information on residential HVAC FDD can be submitted to the Statewide CASE Team through info@title24stakeholders.com.

Measure Description

Background Information

Although Title 24, Part 6 requires that efficient equipment be installed in buildings in California, it currently does little to ensure that performance persists over the life of the building. Heating, ventilation, and air conditioning (HVAC) systems in single family or multi-family buildings may not be properly installed. HERS verification of refrigerant charge is only required in the hotter climate zones, and it can fail to detect problems other than incorrect charge. More importantly, faults that affect long-term system performance can go undetected, leading to increased energy consumption. Defects can go unnoticed by the homeowner while significantly increasing energy use. Examples include low charge resulting from refrigerant leaks, contaminated refrigerant, reduced airflow due to clogged filters or coils or defective fan motors, refrigerant flow restrictions, and faulty expansion devices.

The Statewide CASE Team is pursuing this measure because there is a need to provide fault monitoring technologies to ensure that energy savings from efficient designs (encouraged by the code) persist over time. There is evidence that even when refrigerant charge is properly verified initially, many systems’ performance degrades over time after initial installation. There are a range of faults that can emerge over time due to poor maintenance and service practices, damage to the equipment in the attic or outside the home, or removal or damage of filters or coil fins. A recent American Council for an Energy Efficient Economy summer study paper (Fenaughty 2018) describes a four-year study that found the performance of residential HVAC systems in 56 Florida homes degraded on average about 3 percent per year. The study concluded that replacing defective systems could produce annual savings of 30 percent or more.

This code change proposal would add a compliance option to the performance path for installation of FDD systems on single family residential central split-system air conditioners and heat pumps[1]. This would enable a user (owner or service provider) to accomplish ongoing verification of the performance of the system, detect when performance has degraded, and initiate a service call to bring the system back to a suitable performance level. The designer would select an FDD system from a list of certified models, the installer would install the system and configure it to provide the necessary annunciation when a fault is detected, and the HERS Rater would verify that the correct model is installed and that it is installed correctly. This measure applies to any single family or low-rise multi-family building type. This measure would also allow installation of FDD systems to be used in lieu of the existing requirement for initial verification—either refrigerant charge verification or installation of a fault indicator display (FID)[2] –in certain climate zones.

The credit provided for this measure would be similar to the existing credit for initial verification. If refrigerant charge is initially verified or an FID is installed, CBECC-Res software calculates the efficiency of the compressor to be 96 percent of its rated efficiency, rather than applying a 90 percent multiplier when there is no FID or charge verification. The proposed change would utilize the full rated efficiency in compliance software if initial verification is provided, *and* an FDD is installed to ensure persistence of performance.

For this proposed measure, there would not be a defined list of faults that must be detected, but rather it would require that any individual faults or combination of faults that cause a significant degree of performance degradation shall be detected by the FDD system. The extent of a fault that leads to significant performance degradation

[1] The Energy Commission adopted a specific compliance option for mini-split heat pumps, or VCHPs, which are not included in this proposed measure (CEC 2019).

[2] At this time, no FID tools have been certified, but manufacturers could apply for a system to be both an FID and FDD. The proposed measure is not intended to fulfill the requirements of the FID tools and is an entirely separate credit.

would vary by fault type and even by system type, but the requirement would be tied to performance degradation.

The Statewide CASE Team proposed a similar measure for the 2019 Title 24, Part 6 rulemakings. After the residential quality HVAC Draft CASE Report was completed, the Energy Commission deemed there was insufficient data to support the proposal. The description of the FDD measure was not removed from the report but the proposed code language was redacted.

To support the FDD measure for the 2022 standards cycle, the Statewide CASE Team conducted field and laboratory testing. The objective of the field test was to gather sufficient data to characterize the extent of air conditioner and heat pump performance degradation over time. This information was used to develop a Compressor Efficiency Multiplier (CEM) similar to what is currently used by CBECC-Res to credit refrigerant charge verification. By installing monitoring systems in 40 homes over the summer of 2019 (in both Northern and Southern California), the Statewide CASE Team was able to verify an average baseline annual efficiency degradation of 3.6 percent. Through laboratory testing of one FDD tool, the Statewide CASE Team is obtaining data that is informing the methodology that will be required for manufacturer certification.

Proposed Code Change

This proposal adds a compliance option to the performance path. In this compliance option, the designer would select an FDD system from a list of certified models, the installer would install the system and configure it to provide the necessary annunciation when a fault is detected, and the HERS Rater would verify that the correct model is installed and that it is configured correctly.

This measure applies only to central split system or mini-split air conditioners or heat pumps in single family and multi-family buildings. As a compliance option, it can be applied to additions and alterations in existing homes only when the performance compliance method is used, but it is primarily aimed at the new construction market.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents that would be modified as a result of the proposed change(s).

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
Residential HVAC Fault Detection and Diagnosis	Compliance Option, Prescriptive Alternative	Section 150.1(b)3.B, 150.1(c)7Aic, 150.1(c)7Aii	Joint Appendix 6, Residential Appendix 3	ACM Section 2.4.5.1	New Forms: CF1R-PRF-01; CF2R-MCH-33; CF3R-MCH-33.

Market Analysis and Regulatory Assessment

To date, a limited number of FDD systems have been available for residential HVAC systems. Currently, at least two market ready residential FDD systems from Emerson are available to provide measurements and sophisticated diagnostics that can be used as FDD systems. Both systems can be used to assess as-installed performance (EER and COP) relative to manufacturer-rated performance or to a previously established, commissioned, baseline. There are other systems either on the market or soon to arrive in the market that may achieve the same objectives of this FDD system, such as the TruEnergy® system from Truveon[3] (a California company). Potentially applicable systems are emerging all the time, but their performance has not been standardized or verified. History informs us that including credits for technology in Title 24, Part 6 creates a market for technology known to be beneficial to stakeholders.

Cost Effectiveness

Since this is a compliance option, cost effectiveness was not evaluated. Per-site energy savings for this measure were evaluated and are presented in Section 4. Energy savings varied by climate zone and ranged from zero to 367 kWh per year.

Statewide Energy Impacts: Energy, Water, and Greenhouse Gas (GHG) Emissions Impacts

Since this code change proposal is not modifying the stringency of the standards, the measure would not have energy savings or water or greenhouse gas (GHG) emissions impacts. This assumes that any building that takes advantage of this optional credit would trade off other energy efficiency measures, and energy savings would remain the same. However, this measure is valuable for its significant non-energy benefits,

[3] http://truveon.com/

including the improved comfort, and extended equipment life that result from keeping equipment operational.

Water and Water Quality Impacts

The proposed measure is not expected to have any impacts on water use or water quality, excluding impacts that occur at power plants.

Compliance and Enforcement

Overview of Compliance Process

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process would have on various market actors. The compliance process is described in Section 2.5. Impacts that the proposed measure would have on market actors is described in Section 3 and Appendix A. The key issues related to compliance and enforcement are summarized below:

- This certification would be implemented by requiring manufacturers to provide evidence that their FDD systems can detect the required level of performance degradation, and to certify to that performance. Certified FDD systems would be listed on an Energy Commission website.
- To receive credit under this proposed measure, designer would select an FDD system from this list of certified models.
- Installers would be required to install the correct equipment, and to set it up according to manufacturer instructions. They would be required to configure the system to notify either the occupant or a service provider whenever a fault is detected.
- This correct installation and configuration would be verified by a Home Energy Rating System (HERS) Rater.

The compliance process is important for this measure because persistence of savings may depend on the building owner’s awareness of the FDD system and what any alarms mean. Additional information on the compliance process can be found in Section 2.5.

Field Verification and Diagnostic Testing

During the inspection phase, the HERS Rater would conduct a HERS verification to verify the following: the make and model of the FDD tool are correct, the FDD system is installed correctly, all Critical Field Adjusted Parameters (CFAPs) have been set correctly, is configured to alert the homeowner ~~or~~ and the service provider if one is identified. If a service provider is not identified when the system is configured, then information on service contractors who offer system monitoring as a service is left for the homeowner.

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The Codes and Standards Enhancement (CASE) initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update the California Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison– and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposal presented herein are a part of the effort to develop technical and cost-effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

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The Statewide CASE Team is interested in gathering additional input on appropriate and effective verification methods to help this measure's consideration for future code change proposals. To support ongoing research and future code cycle consideration, additional information on residential HVAC FDD can be submitted to the Statewide CASE Team through info@title24stakeholders.com.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshop that the Statewide CASE Team held on October 10, 2019 (Statewide CASE Team 2019).

The following is a brief summary of the contents of this report:

- Section 2 – Measure Description of this research report provides a description of the measure and its background. This section also presents a detailed description of how this code change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.
- Section 3 – Market Analysis presents the market analysis, including a review of the current market structure. Section 3 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards, such as fire, seismic, and other safety standards, and whether technical, compliance, or enforceability challenges exist.
- Section 4 – Energy Savings presents the per-unit energy, demand reduction, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate per-unit energy, demand reduction, and energy cost savings.
- Section 5 – Cost and Cost Effectiveness presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of the materials and labor

required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs, i.e., equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

- Section 6 – First-Year Statewide Impacts presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2022 code takes effect. This includes the amount of energy that would be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also reported in this section.
- Section 7 – Proposed Revisions to Code Language concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, compliance manual, and compliance documents.
- Section 8 – Bibliography presents the resources that the Statewide CASE Team used when developing this report.
- Appendix A: Statewide Savings Methodology presents the methodology and assumptions used to calculate statewide energy impacts.
- Appendix B: Embedded Electricity in Water Methodology presents the methodology and assumptions used to calculate the electricity embedded in water use (e.g., electricity used to draw, move, or treat water) and the energy savings resulting from reduced water use.
- Appendix C: Environmental Impacts Methodology presents the methodologies and assumptions used to calculate impacts on GHG emissions and water use and quality.
- Appendix D: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software (if any).
- Appendix E: Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.

2. Measure Description

Although Title 24, Part 6 requires that efficient equipment be installed in buildings in California, there is little the code can do to ensure performance meets expectations over the life of the building. HVAC systems in single family or multifamily buildings may not be properly installed. HERS verification of refrigerant charge is only required in the hotter climate zones, and it can fail to detect problems other than incorrect charge. More importantly, faults that affect long-term system performance can go undetected leading to increased energy consumption. Defects can go unnoticed by the homeowner while significantly increasing energy use. Examples include low charge resulting from refrigerant leaks, contaminated refrigerant, reduced airflow due to clogged filters or coils or defective fan motors, refrigerant flow restrictions, and faulty expansion devices.

Title 24, Part 6 already includes a prescriptive requirement for **initial** verification of refrigerant charge upon installation, through diagnostic testing or installation a fault indicator display (FID) in Climate Zones 2 and 8-15. The proposed measure would offer installation of FDD systems—which identify faults as they occur **over time**, enabling the owner to take remedial action and keep performance within initial expectations—as an alternative way to meet the prescriptive requirements in Climate Zones 2 and 8-15, and as a compliance option that can be used in addition to that initial verification in all Climate Zones.

2.1 Measure Overview

This code change proposal would add a compliance option to the performance path. In this compliance option, the designer would select an FDD system from a list of certified models, the installer would install the system and configure it to provide the necessary annunciation when a fault is detected, and the HERS Rater would verify that the correct model is installed and that it is configured correctly.

The credit provided for this measure would be equivalent in magnitude—and can be used in conjunction with—the credit provided for Refrigerant Charge Verification: rated compressor efficiency is reduced by 10 percent when neither is used, it is reduced by 4 percent when only one of these measures is used, and it is not reduced when both are used. It is also proposed that installation of a FDD system be offered as an alternate way to meet prescriptive requirements for refrigerant charge verification or installation of an FID device in Climate Zones 2 and 8-15. A simple change would be required to the software to specify the appropriate value for the Compressor Efficiency Multiplier (CEM).

This measure is proposed for any single family or multifamily buildings. The FDD technologies included are for residential split-system air conditioners and heat pumps, packaged air conditioners and heat pumps, and mini-split heat pumps. It is primarily designed for new construction, but it could be extended to include installation of new HVAC systems. The proposal would not add requirements for a system or technology that was not regulated previously.

There are a number of benefits to stakeholders, beyond energy savings. The potential benefits that FDD provides to contractors include elimination of service calls to correct problems with newly installed systems, and centralizing fault diagnosis responsibilities to a small number of well-trained technicians. With FDD, homeowners can be notified of potential problems before they occur, ensuring comfort and saving repair costs resulting from catastrophic equipment failure. Benefits to utilities include assurance of persistent air conditioner and heat pump performance resulting in improved load shapes.

2.2 Measure History

Currently, Title 24, Part 6 does not include a credit for verifying that a range of different types of installation faults are not present, nor to verify the system continues to perform adequately over its lifecycle. However, for some time it has included a prescriptive requirement for verifying that the refrigerant charge of a new system is correct when it is installed, and that credit serves as a useful template for the proposed measure. Because the proposed measure is structured in a similar way to the existing initial refrigerant charge verification measure, it is helpful to review how that measure works. This section describes that initial verification measure, as well as previously proposed measures for ongoing verification.

2.2.1 Initial Charge Verification

Section 2.4 of the Residential ACM Reference Manual currently includes a prescriptive requirement for initially verifying that charge is correct upon installation (via on-site diagnostic testing or installation of a FID tool) in Climate Zones 2 and 8-15. It estimates impacts by establishing a CEM which is used in calculations to degrade the efficiency of a compressor to 90 percent of the rated efficiency when charge is not verified as correct but is increased to 96 percent of the rated efficiency when it is verified as correct. To obtain this credit, charge must be verified as correct by using in-field diagnostic testing or installing an FID.

While it could be feasible for many FID tools to detect emerging faults, there is no requirement that they have this capability, nor is there a requirement that they actually be configured to be used in that way. At this time, no tools have emerged to obtain the FID credit. Note that the proposed measure is not intended to fulfill the requirements of the FID tools and is an entirely separate credit. One can envision, however, that systems that are certified to provide ongoing verification might also provide this initial verification functionality.

2.2.2 Previously Proposed Measure for Ongoing Verification

Verifying initial charge is only a part of the solution to HVAC system performance and there is still a need to provide technologies to ensure that savings sought in other measures within the code are realized and persist over time. There is evidence that even when a system is installed correctly and is properly verified initially, its performance degrades over time after initial installation. There are a range of faults that can emerge over time due to poor maintenance and service practices, damage to the equipment in the attic or outside the home, or removal or damage of filters or coil fins.

Installation of an FDD system—either as a feature on a new HVAC system or an after-market add-on with hardware and software components— would enable a user (owner or service provider) to monitor the performance of the system and detect when performance has degraded or when a specific fault has occurred. The user can then initiate a service call to bring the system back to a suitable performance level. Some of the types of faults that may be detected by an FDD system include:

- Low Refrigerant Charge
- High Refrigerant Charge
- Non-Condensables in Refrigeration System
- Restriction in Liquid Line
- Evaporator Airflow Restriction
- Condenser Airflow Restriction Damaged or Poorly Installed TXV

While these faults are all distinct, they have one thing in common: they cause degraded performance. In order to ensure that this performance degradation is detected promptly and addressed, the Statewide CASE Team proposed a measure for installation of FDD systems to verify ongoing residential HVAC system performance as part of the 2019 Title 24, Part 6 rulemakings. The 2019 proposal that was not adopted included elements of the currently proposed measure, but at that time, there was a lack of data to document energy savings and a lack of validated products. A recent ACEEE summer study paper that measured the performance of residential HVAC systems in 56 Florida homes over a four-year period determined that the systems degraded on average about 3 percent per year (Fenaughty 2018). Figure 1: Effect of annual degradation in efficiency on system efficiency over time. illustrates how a small annual degradation in efficiency accumulates over time. This indicates a serious problem.

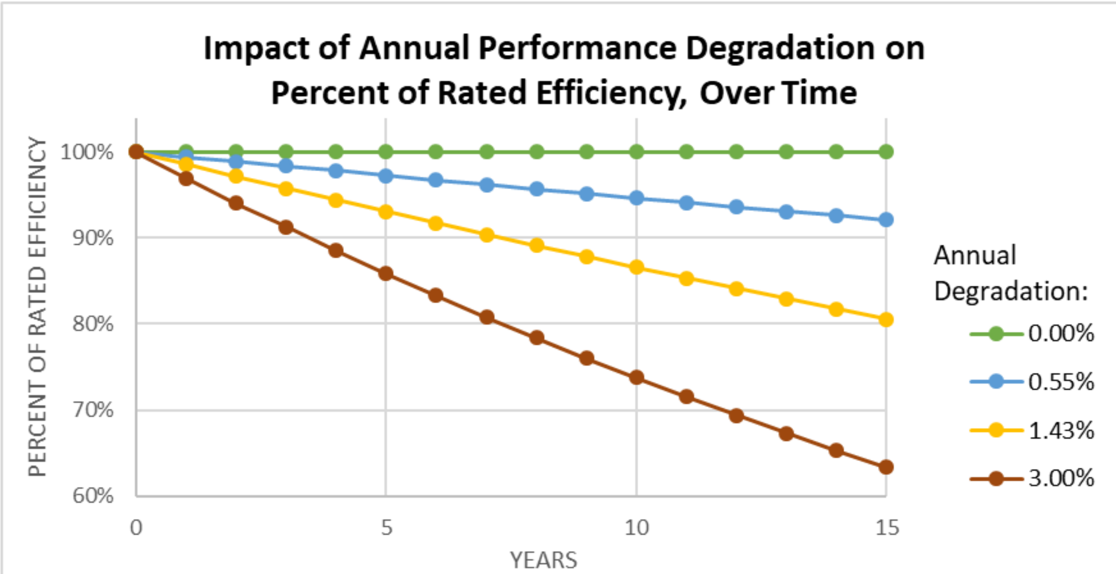

Figure 1: Effect of annual degradation in efficiency on system efficiency over time.

In support of the proposed measure for 2022 and to address the lack of data, the Statewide CASE Team has conducted field and laboratory testing.

- The objectives of the field test were to gather sufficient field data to characterize the extent of air conditioner and heat pump performance degradation over time in California households in order to establish appropriate CEM. By installing monitoring systems in 40 homes over the summer of 2019 (in both Northern and Southern California), the team was able to verify an average baseline efficiency degradation of 3.6 percent annually.
- Through laboratory testing of one FDD system, the Statewide CASE Team obtained data to inform the methodology that would be required for manufacturer certification. In this testing, a standard air conditioning unit was installed in a laboratory and subjected to a number of different simulated faults (liquid line restriction, low airflow, and non-condensables). A single FDD system was also installed, and the alerts generated by the FDD system were compared with the detailed measurements of the severity and impacts of the simulated faults.

With this information in hand, the Statewide CASE Team now recommends adoption of a measure for Residential HVAC FDD for Title 24, Part 6.

2.2.3 Status of Technology

To date, a limited number of FDD systems have been available for residential HVAC systems. In 2010, a Building America expert meeting on fault detection was unable to identify any existing products. Three years later, a Building America study conducted by

Davis Energy Group identified only one product, Emerson's ComfortGuard. A 2016 survey by Southern California Edison lists two systems produced by Emerson Climate Technologies, one (by Lennox) with limited capability, and one by Smart Home that appears to be no longer available. A 2017 Revised Study by the CASE Initiative team exploring the Residential Quality HVAC Measures identified only one FDD product designed for residential units: Emerson's CoreSense. While the Western HVAC Performance Alliance (WHPA) listed the ComfortGuard also by Emerson, and the iComfort by Lennox (Springer 2017).

Currently, at least two market ready residential FDD systems from Emerson are available to provide measurements and sophisticated diagnostics that can be used as FDD systems. Both systems can be used to assess as-installed performance (EER and COP) relative to manufacturer-rated performance or to a previously established, commissioned, baseline:

- Emerson Comfort Solutions offers an aftermarket diagnostic system called Sensi Predict which uses ten sensors to detect non-optimal operation and system failures. The system senses thermostat signals, refrigerant temperatures, and indoor, outdoor, supply, and return air temperatures, and fan and compressor current. It can be used with any brand of air conditioner or heat pump. Data are stored in the cloud and alerts are displayed to homeowners and sent to service contractors. Messages ("Caution, "Warning, and "Urgent") can be viewed by homeowners using Emerson's Sensi display.
- Emerson also provides a software package called FaultFinder that, along with their CoreSense and ComfortAlert systems, is designed to help contractors troubleshoot air conditioning systems. Fault Finder software extracts valuable fault history information directly from the installed modules to help guide the contractor to the root cause of system issues.

There are other systems either on the market or soon to arrive in the market that may achieve the same objectives of this FDD system, such as the TruEnergy® system from Truveon (a California company). Potentially applicable systems are emerging all the time, but their performance has not been standardized or verified. History informs us that including credits for technology in Title 24, Part 6 creates a market for technology known to be beneficial to stakeholders.

The Statewide CASE Team will remain vigilant to determine whether there is a need to assess other emerging systems. This is a rapidly evolving market, and there is a clear need to lab test more than one product and continue market research on all existing FDD products.

2.3 Summary of Proposed Changes to Code Documents

For this proposed measure, compliance credit would be provided upon installation and verification of a system to ensure the performance of a residential FDD system. Additionally, installation of an FDD system can be used as an alternate to carrying out initial refrigerant charge verification or installing an FID to meet prescriptive requirements in Climate Zones 2 and 8-15. There is not a defined list of faults that must be detected, but the measure requires faults that cause a “significant” performance degradation must be detected. For the purposes of this standard:

- The FDD system must report any fault that causes a performance impact (reducing either the efficiency or the capacity of an air conditioning system below its normal value) of 15 percent or greater. This number was chosen as a value that is clearly and unambiguously a fault. It is also clearly significant enough to warrant sending a technician to remedy.
- The FDD system must NOT report as a fault any situation that causes a performance impact (reducing both the efficiency and the capacity of an air conditioning system below its normal value) of 5 percent or less. This number was chosen as a value that clearly does not warrant sending a technician to remedy. If an FDD system were to report this as a fault, it would be considered a false alarm.
- Any performance impacts between 5 and 15 percent represent a gray zone where the standard makes no judgments about whether a fault should be detected or not.
- Similarly, there are other legitimate faults that are not related to system efficiency or capacity, and this Standard makes no judgments about whether these faults should be detected or not. For example, if there is no performance impact on efficiency or capacity, but there is an impact on equipment lifecycle, generating an alarm would not constitute a false alarm.
- The *severity* of a fault (for example, 15 percent low on charge) that leads to this impact on *performance* will vary by fault and even by system type, but the requirement will be tied to impacts on performance.

To receive credit under this proposed measure, the energy consultant would select one of the following choices from the “AC Verification” drop-down menu (previously named “AC Charge”) on the Cooling System Data screen:

- Not Verified
- Initial (Charge Verified/FID)
- Ongoing (FDD)
- Initial + Ongoing

The third and fourth selections indicate the installation of a certified FDD system.

The designer would select an FDD system from a list of certified models. This certification would be implemented by requiring manufacturers to provide evidence that their systems can detect this level of performance degradation and to certify to that ability. Certified systems would be listed on an Energy Commission website. Manufacturers would also provide a list of up to five Critical Field-Adjusted Parameters (CFAPs). CFAPs would be static values required for the configuration of the FDD system. For example, CFAPs might include factors such as the installed location's zip code, the capacity of the HVAC system, the system airflow rate, or system static pressure. Having manufacturers select a few such critical factors and HERS raters verify that they have been set correctly would help to ensure that the system is actually configured and not left unconfigured at default values.

Installers would be required to install the correct equipment, and to set it up according to manufacturer instructions, including correctly setting all CFAPs and recording their values. They would also be required to configure the system to notify the occupant and a service provider whenever a fault is detected. Correct installation and configuration would be verified by a HERS Rater, who would verify that all CFAPs are set as noted in the CF2R.

The sections below summarize how the standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents would be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of the California Energy Code as shown below. See Section 7.2 of this report for marked-up code language.

This code change proposal would modify Sections 150.1(c)7Ai c, and 150.2(b)1Fii b to indicate that Ongoing Verification (FDD) is an alternative to refrigerant charge verification or installation of an FID to meet the prescriptive requirements in Climate Zones 2 and 8-15. This also includes an addition to Tables 150.1-A and B (Component Package – Single Family/Multifamily Standard Building Design).

It would also list residential HVAC FDD as one of the systems requiring field verification, in Section 150.1(b)3.B.

2.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the sections of the Reference Appendices identified below. See Section 7.3 of this report for the detailed proposed revisions to the text of the reference appendices.

— **JOINT APPENDIX 6 – HVAC SYSTEM FAULT DETECTION AND DIAGNOSTIC TECHNOLOGY.**

- **Section JA6.4:** The proposed requirements would add a new section that describes the requirements for manufacturer certification of FDD systems.

— **RA2.2 MEASURES THAT REQUIRE FIELD VERIFICATION AND DIAGNOSTIC TESTING**

- Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing would be changed to include Residential HVAC FDD as a measure requiring verification.

— **RESIDENTIAL APPENDIX 3.4 — FIELD VERIFICATION OF INSTALLED HVAC SYSTEM COMPONENTS AND DEVICES**

- **Section RA3.4.4.3: Residential HVAC Fault Detection and Diagnosis (FDD) Verification Procedures:** The proposed requirements would add a new section that describes field verification methods to confirm that FDD systems are installed correctly and configured to detect and annunciate faults correctly. This includes construction inspection requirements as well as functional testing requirements.

2.3.3 Summary of Changes to the Residential ACM Reference Manual

This proposal would modify the following sections of the Residential ACM Reference Manual as shown below. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

— **SECTION 2.4.5 COOLING SUBSYSTEMS**

- **Section 2.4.5.1 Verified Refrigerant Charge or Fault Indicator Display:** Subsection would be renamed "2.4.5.1 Verified Refrigerant Charge, Fault Indicator Display, or Residential HVAC FDD," and the section would be modified to establish a separate FDD CEM to be used in calculations to give appropriate credit for ongoing FDD that detects faults as they occur.

2.3.4 Summary of Changes to the Residential Compliance Manual

The proposed code change would modify the Residential Compliance Manual by adding a section 4.3.3.5 that describes how to apply the measure.

2.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 7.6.

— **CF1R – PRF-01 CERTIFICATE OF COMPLIANCE FORM**

- An additional column would be added to the existing HVAC Cooling – HERS Verification table on the existing CF1R form.

— **CF2R-MCH-35-HVAC FDD CERTIFICATE OF INSTALLATION FORM**

- A new form would be created, to record the FDD make and model installed, the number of required Critical Field-Adjusted Parameters (CFAPs), and the name and actual configured value of each.

— **CF3R-MCH-35-HVAC FDD CERTIFICATE OF VERIFICATION FORM**

- A new form would be created, to record the FDD make and model verified by the HERS Rater, and the actual verified value of each CFAP.

2.4 Regulatory Context

2.4.1 Existing Requirements in the California Energy Code

There are no relevant requirements in the California Energy Code.

2.4.2 Relationship to Requirements in Other Parts of the California Building Code

There are no relevant requirements in other parts of the California Building Code.

2.4.3 Relationship to Local, State, or Federal Laws

There are no relevant local, state, or federal laws.

2.4.4 Relationship to Industry Standards

There are no relevant industry standards.

2.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** During the design phase, the energy consultant and designer would decide if the FDD credit is recommended to make the proposed building comply with the code. The energy consultant would select one of the following choices from the “AC Verification” drop-down menu (previously named “AC Charge”) on the Cooling System Data screen:

  - Not Verified
  - Initial (Charge Verified/FID)
  - Ongoing (FDD)
  - Initial + Ongoing

  The third and fourth selections indicate the installation of a certified FDD system.

- **Permit Application Phase:** During the permit application phase, the plans examiner would verify that the information indicated on the CF1R is also documented on the plans (notes on electrical or mechanical schematics).
- **Construction Phase:** During the construction phase, the HVAC installer would identify a suitable FDD system from the Energy Commission website and identify the required CFAPs for that model, include make and model of FDD on plans and specifications, indicate the FDD make and model on a CF2R-MECH-35, and enter the number of CFAPs, and list their names and the required values of each. The installer would install and configure the equipment according to manufacturer instructions, by setting all CFAPs and setting up the system to alert the homeowner and service provider when an alarm is generated. If a service provider would be receiving the alert, the installer would ensure that information is left for the homeowner to help identify service contractors who provide performance monitoring as a service. The information would also provide the instructions to the homeowner on what to do if there is an alert.
- **Inspection Phase:** During the inspection phase, the HERS Rater would conduct a HERS verification, verifying that:
  - The make and model of the FDD system are as indicated on the CF2R-MCH-35,
  - It is installed correctly,
  - The list of CFAPs matches the list provided by the manufacturer on the Energy Commission website,
  - The value of each CFAP matches the value indicated on the CF2R-MCH-35,
  - It is configured to alert the homeowner and service provider (if applicable), and
  - Information to help identify service contractors and what to do in the event

of a fault is left for the homeowner.

The HERS Rater would complete CF3R-MCH-35, documenting these verifications, and the building inspector would verify that the appropriate forms have been completed by the HERS Rater.

This process is somewhat more involved than the standard compliance process. The designer would have to look up on the Energy Commission website for certified FDD systems. Required CFAPs must be clearly listed and described by FDD manufacturers in their certification submission to the Energy Commission. Their desired values must be:

- Determined by the installer,
- Communicated between installer and HERS Rater via the CF2R form,
- Adjusted by the installer, and
- Verified by the HERS Rater.

The installer must select a mechanism for alerting the homeowner and a service contractor, the FDD system must be configured accordingly, and the HERS Rater must confirm that it has been configured accordingly. There are no new burdens added on building officials, beyond checking for coordination between plans and specifications.

All compliance during the design stage would be accomplished by the mechanical system designer, so little or no additional coordination with other designers would be required. All field installation would be done by the mechanical subcontractor, so little or no coordination with other installers would be required. There would be new compliance documents required, but no changes would be made to existing forms. No new HERS verifications would need to occur during the construction phase, but additional factors would have to be verified.

The Statewide CASE Team has mitigated any potential compliance and enforcement challenges by providing recommended changes to compliance manuals and compliance documents. The Statewide CASE Team is committed to work with industry stakeholders to help them prepare for the code change before it takes effect. With suitable mechanism to provide expected values of CFAPs on the forms, this compliance procedure should not be burdensome.

There are no known potential loopholes to compliance. However, the reliability of this measure depends to a great extent on increasing the likelihood that detected faults would be communicated adequately and that someone responds to any identified faults. This is reinforced by the requirements for verification of correct configuration for FDD and for routing alerts that would facilitate detection and response.

3. Market Analysis

3.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team then considered how the proposed standard may impact the market in general as well as individual market actors. Information was solicited about the incremental cost of complying with the proposed measure, market size, and measure applicability through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during a public stakeholder meeting that the Statewide CASE Team held on October 10, 2019 (Statewide CASE Team 2019).

Fault Detection and Diagnosis (FDD) manufacturers provide products that aim to reduce the costs of HVAC maintenance while improving operational efficiency through prescriptive and reactive data analytics. These products generally consist of hardware added onboard to the HVAC units, which uses software that employ predictive algorithms to monitored data and identify faults or recommend preventative maintenance (NIST 2019). One main market supply chain delineation for FDDs exists between Original Equipment Manufacturers (OEMs) and FDD product manufacturers. OEMs have typically included FDD onboard systems either as an option or automatically built into their products, while FDD manufacturers typically add on their products to existing or newly installed HVAC equipment (Springer 2017).

OEMs provide FDD products and services through their existing residential HVAC unit supply chain, and work with contractors to install the HVAC equipment. In contrast, standalone FDD products require much more interaction between the contractors and FDD manufacturers; FDD vendors rely heavily on the contractors as a critical entry point into the market. The contractors can offer an FDD manufacturers product whom they have an agreement with, as an add-on equipment option to the consumer during HVAC unit installations. With standalone FDD products being relatively new to the residential HVAC market, market presence is low but growing. This new and growing presence in the market was noted during the vendor interviews conducted by the Statewide CASE team (CASE Team Manufacturer Interviews 2020). Many of these companies appear to reside in a “tech start-up” sector where overhead costs are high, profits are low, and contractor agreements and interfacing will be crucial to many aspects of the companies projected outlook. The interviews identified that manufacturers are in different stages of developing solutions to market barriers, refining their business models, validating their products, and identifying avenues of entry into the market through funding sources and market participation.

There are fewer FDD products on the market for residential HVAC units than commercial units, though the applications and fault detection approach are similar. There are overarching characteristics to fault detection that are common among most products. Defining characteristics of the residential FDD products include, but are not limited to:

- FDD Product Method
    - Data-driven
    - Model-based
    - Rule-based
- Hardware- or software-based
- Proprietary or open source
- Subscription-based vs one-time fees
- Detection of failures and speed of detection
- Distinguish between multiple faults
- Detect unidentifiable faults
- Generate alarms

A 2016 survey by Southern California Edison lists two systems produced by Emerson Climate Technologies, one (by Lennox) with limited capability, and one by Smart Home that appears to be no longer available. A 2017 Revised Study by the CASE Initiative team exploring the Residential Quality HVAC Measures identified only one FDD product designed for residential units: Emerson's CoreSense. While the Western HVAC Performance Alliance (WHPA) listed the ComfortGuard also by Emerson, and the iComfort by Lennox (Springer 2017).

Currently, at least two market ready residential FDD systems from Emerson are available to provide measurements and sophisticated diagnostics that can be used as FDD systems. Both systems can be used to assess as-installed performance (EER and COP) relative to manufacturer-rated performance or to a previously established, commissioned, baseline:

- Emerson Comfort Solutions offers an aftermarket diagnostic system called Sensi Predict which uses ten sensors to detect non-optimal operation and system failures. The system senses thermostat signals, refrigerant temperatures, and indoor, outdoor, supply, and return air temperatures, and fan and compressor current. It can be used with any brand of air conditioner or heat pump. Data are stored in the cloud and alerts are displayed to homeowners and sent to service contractors. Messages ("Caution, "Warning, and "Urgent") can be viewed by homeowners using Emerson's Sensi display.

- Emerson also provides a software package called FaultFinder that, along with their CoreSense and ComfortAlert systems, is designed to help contractors troubleshoot air conditioning systems. Fault Finder software extracts valuable fault history information directly from the installed modules to help guide the contractor to the root cause of system issues.

3.2 Technical Feasibility, Market Availability, and Current Practices

The Statewide CASE Team assessed the FDD market for technical feasibility, availability of products in the market and observed practices with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team then considered how the market actors currently navigate the supply chain and what foreseeable needs in the market might arise to promote market growth and increased market penetration for FDD products. Information was solicited about the current state of the market, products and services provided, and avenues which market players are using to progress their business and product implementation, as well as what these stakeholders see is needed to promote development in this market.

3.2.1 Vendor Engagement

The Statewide CASE Team contacted five residential FDD system manufacturers. Four manufacturers provided responses via survey questionnaire, and three participated in an additional 1-hour phone interview. The participants are shown below along with a brief description on their product(s) and capabilities.

- **Truveon – TruEnergy:** An after-market unit that can be installed to measure all variables and parameters needed to calculate system capacity and compare to a performance benchmark. The product estimates the capacity as the difference in enthalpy of the circulated air before and after the evaporator coil, which is then compared against internal performance benchmarks. The System detects failures and sends these as notifications to the owner through a smart phone app known as the TrueEE score.
- **Emerson Comfort Solutions – Sensi Predict:** A kit of 10 sensors that is installed on board the HVAC unit and connects to the cloud via a homeowner's Wi-Fi network and diagnoses both through trend data and instantaneous performance. Once a fault is detected an actionable alert is sent to the homeowner via email with an explanation and recommended actions.
- **Carrier – TruVu:** A multi-purpose control (MPC) platform for monitoring and control of residential HVAC equipment. The controller is expandable to support embedded fault detection diagnosis (FDD) capabilities. TruVu integrates the onboard system in a subset of their products as an option, along with the mandatory economizer fault detection and diagnosis requirements outlined in

Title 24, Part 6 Section 120.2(I) for air-cooled unitary conditioning systems over 4.5 tons cooling capacity (Carrier 2019).

- **GeenNet IoT:** GreenNet has a patent pending FDD technology. GreenNet technologies and methods are based on verifiable on-going monitoring of HVAC and other energy-consuming systems. Most GreenNet monitoring technologies utilize ANSI approved electrical meters. The latency of the internet-based monitoring system is 3 to 5 seconds, or whatever parameters are set. The length of time to detect a fault depends on the type of fault and the benchmarked parameters of the individual systems.

3.2.2 Technical Feasibility

While FDD technologies are mostly hardware and software-oriented products, any code measure must specify compliance metrics to ensure that each system can accommodate the code requirements. All vendors indicated their systems could be added onto standard HVAC equipment and install in new construction projects. Table 2 summarizes the FDD product compatibility with different HVAC equipment types. Further details are provided below.

- Emerson's Sensi Predict was noted as specifically being compatible with all single phase 24V split systems, including heat pumps, and some variable speed systems, and dual fuel systems. Sensi Predict can serve HVAC units ranging from 1.5 to 5 tons in capacity. They noted their system did not include fully communicating (non 24V) systems, nor does it work on mini splits, PTACS, or packaged systems.
- GreenNet IoT and Carrier products are compatible with residential HVAC split systems, heat pumps, mini splits, packaged units, variable speed systems, and products with or without thermostatic expansion valves (TXVs).
- Truveon's TruEnergy ™ has product compatibility with heat pumps and variable speed systems.

Table 2: Compatibility of FDD Systems to Different HVAC System Types, by Manufacturer

HVAC Equipment	24V Split Systems	Typical Split System	Heat Pumps	Variable Speed Systems	Duel Fuel Systems	Mini Split Systems	Packaged Systems
Emerson Sensi Predict	•		•	•	•		
GreenNet IoT		•	•	•		•	•
Truveon		•	•	•			

Statewide CASE Team identified multiple products from market vendors, but an inconsistent level of large-scale deployment and installations. Emerging FDD manufacturers are dependent on relationships with HVAC contractors as an avenue for installation, and consequently baseline data sets by which algorithms performance can be benchmarked and improved upon. Emerson Comfort Solution’s Sensi Predict and GreenNet IoT have partnered with HVAC contractors to deploy their systems in new construction and existing retrofit cases in addition to offering installation and troubleshooting trainings to the contractors and technicians (CASE Team Manufacturer Interviews 2020). While, the Statewide CASE Team did not have access to market presence data, manufacturers did confirm they had systems deployed in California, and either sales reps or offices located in California. Carrier and all the other major OEMs are present in the CA market.

Emerson indicated that their system deployment was approaching 10,000 installations nationwide across several climate zones, including in California. Emerson was able to establish their installations through an agreement with a contractor whom also provided Emerson access to their existing customer in-situ data sets. These in-situ data sets enable the companies to better assess the stock of buildings for which they will deploy the FDD product and generate a baseline with which to measure improvement. This baseline is a crucial part to many of these FDD products and is a major aspect in which most are lacking. As was the case for Emerson, the contractor-vendor relationship is a major gateway into the market, and a catalyst to aid progress towards an economy of scale for this market (CASE Team Manufacturer Interviews 2020). With most of the FDD vendors being relatively new to the market, the lack of access to these data, or rather the relationships with parties to obtain said data can stunt deployment.

This lack of in-situ FDD performance data was noted by many manufacturers as a prominent barrier. Statewide CASE Team identified multiple products from market vendors, but an inconsistent level of large-scale deployment and installations. Emerging FDD manufacturers are dependent on relationships with HVAC contractors as an avenue for installation, and consequently baseline data sets by which algorithms performance can be benchmarked and improved upon (Proctor 2013). Emerson Comfort Solution’s Sensi Predict and GreenNet IoT have partnered with HVAC contractors to deploy their systems in new construction and existing retrofit cases in addition to offering installation and troubleshooting trainings to the contractors and technicians. Emerson noted that establishing a baseline data was an initial barrier they overcame by building new relationships with contractors. The Statewide CASE Team solicited for but did not receive any manufacturer reported energy savings associated with current FDD products, ostensibly because of limited market penetration and associated data.

Many interviewees noted little-to-no profit on hardware-based products, and although software-based products have a slightly higher profit margin they do not always have the same contractor relationships to leverage. This dependency on a contractor relationship coupled with the low profit margins of hardware and software results in the need for outside market stimulation (CASE Team Manufacturer Interviews 2020). This stimulation could be in the form of incentives, programs or rebates which could aid in fostering the development of an economy of scale, which could directly drive down hardware costs and improve profit margins. FDD products have generally limited avenues for market entry and are not supported by program incentives to drive down costs. Vendors stated the following:

- **Emerson -** "We are planning to commit to making this a key technology for the HVAC industry in the long term. We've yet to solve the hardware side of things -- we have a very low gross margin, which needs to be rectified before any scale can happen."
- **Truveon - "**We are a start-up, but we will have volume installs soon. Once you have done a couple of generations, the supply chain issues become less and less of an issue. It's a fully vertically integrated system."

FDD manufacturers stated that building maintenance technicians are generally not concerned about the risk of automation displacing their work diagnosing HVAC systems. FDD manufacturers indicated that HVAC technicians and maintenance staff will, in an ideal scenario, have reduced time spent troubleshooting and the same or potentially less time performing the required maintenance. Because FDD systems typically provide alerts that indicate the severity of the detected fault(s), technicians can prioritize site visits by severity and be more prepared ahead of time with tools and equipment to address the designated issue.

Three of the four FDD vendors surveyed offer trainings to contractors and technicians before they are cleared to install and operate their products. Emerson has developed an online learning center for contractors and technicians to learn proper installation and troubleshooting at their own convenience. It is very likely that as new FDD vendors scale, they would need to offer similar trainings to their contracting partners in order to increase the efficiency of knowledge transfer and quality of installations (CASE Team Manufacturer Interviews 2020).

Code allowances for compliance credits or prescriptive pathways may further expand the market share of FDD products, and vendors appear to be well suited to scale. However, FDD vendors are depending on contractors for installations, and significant training and relationship-building would be required before products become mainstream. The proposed credit would make possible the ramping up of product capability and availability in advance of the likely January 2023 effective date of the 2022 Title 24.

One remaining market barrier is reluctance to consider life-cycle-costs when evaluating first-costs. Homeowners need to be aware of FDD tech and be willing to shoulder the additional tech costs (possibly including both product and recurring subscription costs). Furthermore, they would also have to be willing and able to pay for remediation activities, which may be necessary to realize any life-cycle-cost savings.

3.2.3 Cost Models

Some FDD vendors combine services into installation packages, while others separate costs into hardware, installation, and subscriptions. Sensi Predict hardware costs $250 with 1 year of monitoring free, and each additional year of monitoring costs $49. Installation cost can vary by contractors. GreenNet IoT products are offered as part of service (and installation package), and the customers are not charged for on-going monitoring. Monitoring includes alarming and alerts, and energy bill projections (CASE Team Manufacturer Interviews 2020).

4. Energy Savings

The code change proposal would not modify the stringency of the existing California Energy Code, so there would be no savings on a per-unit basis. Section 4 of the research reports, which typically presents the methodology, assumptions, and results of the per-unit energy impacts, has been truncated for this measure. However, this measure would provide non-energy benefits such as extending the life of residential HVAC systems by addressing equipment faults before they degrade the system's condition and by improving comfort and system-uptime by addressing problems before they result in a system shutdown.

4.1 Key Assumptions for Energy Savings Analysis

The key assumptions that went into the estimate of savings include:

- Baseline: CEM = 0.90 for Climate Zones 1, 3-7, and 16; 0.96 for Climate Zones 2 and 8-15
- With Ongoing Verification (FDD): CEM = 0.96
- With Initial + Ongoing Verification: CEM = 1.00

These new CEM values are conservative estimates, validated using a field study, described in Appendix G. The field study found that homes experience about 3.6 percent performance degradation per year of system age. This translates to a baseline performance averaging about 75 percent of rated efficiency over 15 years—well below the baseline for this measure. If the system is brought up to full efficiency every time the performance goes below 85 percent (with an FDD system resulting in a service call and remediation), the average loss of performance would only be 93 percent. The incremental improvement is about 18 percent. Assuming only 50 percent of this improvement is likely to occur (because the fault detection doesn't result in a service call and remediation in every case), it is an improvement of about 9.0 percent. This is well above the assumed performance improvement of 6 percent for Refrigerant Charge Verification, and the 4 percent assumed for adding FDD on top of RCV.

Since the intent for proposed code changes to Title 24, Part 6 in the 2022 code cycle is to not make the baseline more stringent for single family buildings, it is not proposed to reduce the baseline to the level found in the field study. For now, since the baseline CEM is 0.90, and the multiplier for systems that have had refrigerant charge verification is 0.96, the Statewide CASE Team has selected a very conservative CEM of 0.96 also for systems that have FDD installed. For systems that have both refrigerant charge verification and FDD installed, a CEM of 1.00 is proposed, since the combination of initial verification and ongoing verification should enable the performance to be closer to the original rated efficiency.

For the 2025 Title 24, Part 6 code cycle, the Statewide CASE Team may consider proposing to reduce the baseline compressor efficiency multiplier to a more realistic value of 0.80 and reassessing the CEMs for refrigerant charge verification and FDD.

4.2 Energy Savings Methodology

4.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 3. This measure applies to only to new construction. The measure may also apply to midrise multifamily buildings, but these were not analyzed in this report.

Table 3: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
SF 2100	1	2,100	single story house with attached garage, pitched roof, attic. 9-ft ceilings, 1 ft overhang, front door, garage door.
SF 2700	2	2,700	2-story home with attached 2-car garage. 9-ft ceilings, 1-ft between floors, 1-ft overhang.
LowRiseGarden	2	6,960	2-story, 8-unit apartment building. Average dwelling unit size: 960 ft2. Individual HVAC & DHW systems.

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of the California Building Energy Code Compliance (CBECC) software for residential buildings (California Energy Commission 2019).

CBECC-Res generates two models based on user inputs: the Standard Design and the Proposed Design.[4] The Standard Design represents the geometry of the design that the

[4] CBECC-Res creates a third model, the Reference Design, that represents a building similar to the Proposed Design, but with construction and equipment parameters that are minimally compliant with the 2006 International Energy Conservation Code (IECC). The Statewide CASE Team did not use the Reference Design for energy impacts evaluations.

builder would like to build and inserts a defined set of features that result in an energy budget that is minimally compliant with 2019 Title 24, Part 6 code requirements. Features used in the Standard Design are described in the 2019 Residential ACM Reference Manual. The Proposed Design represents the same geometry as the Standard Design, but it assumes the energy features that the software user describes with user inputs. To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design, and two Proposed Designs for each prototypical building.

Two scenarios were evaluated, depending on the designer's selections made for the "Performance Verification" variable.

Refrigerant charge verification is a prescriptive requirement in Climate Zones 2 and 8-15, so the Standard Design uses a CEM of 0.96 in those Climate Zones. In Climate Zones 1, 3-7, and 16, refrigerant charge verification is not required, so the Standard Design uses a CEM of 0.90 in those Climate Zones.

The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes to the code. The proposed conditions assume different values for the Compressor Efficiency Multiplier. Table 4 presents precisely which parameters were modified and what values were used in the Standard Design and Proposed Design, for each scenario.

Table 4: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value	Model Scenario
SF 2100, SF 2700, LowRiseGarden	1, 3-7, 16	CEM	0.90	0.96	Ongoing Verification
	1, 3-7, 16	CEM	0.90	1.00	Initial + Ongoing Verification
	2, 8-15	CEM	0.96	1.00	Initial + Ongoing Verification

Comparing the energy impacts of the Standard Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

CBECC- Res calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). It then applies the 2022 time dependent valuation (TDV) factors to calculate annual energy use in kilo British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Com/Res also generates TDV energy cost savings values measured in 2023 present value dollars (2023 PV$) and nominal dollars.

The energy impacts of the proposed code change vary by climate zone. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the climate-zone specific TDV factors when calculating energy and energy cost impacts.

Per unit energy impacts are presented in savings per prototype building. Savings are presented for both single family prototypes and the low-rise multifamily prototype. As described in Section 6, the Statewide CASE Team developed a weighted average savings of the two prototypes to calculate statewide savings.

4.2.2 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the Energy Commission provided. The Statewide Construction Forecasts estimate new construction that will occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Res, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 5 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Table 5 presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 5: Residential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Single Family	SF2100	50%
	SF2700	50%
Multi Family	LowRiseGarden	100%

4.3 Per-Unit Energy Impacts Results

Energy savings and peak demand reductions per unit for new construction are presented in Table 6 through Table 8 for the “Ongoing Verification” scenario, and in Table 9 through Table 11: , for the “Initial + Ongoing Verification” scenario. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates.

For the “Ongoing Verification” scenario, there are no savings shown for Climate Zones 2 and 8-15, since initial verification (refrigerant charge verification or installing an FID device) is a prescriptive requirement. In those Climate Zones, if FDD is installed in lieu of carrying out initial verification, there is no additional credit provided. In Climate Zones 1, 3-7 and 16—where initial verification is not required—however, compliance option credit is provided, and the estimated savings are shown. These savings are quite small in these climate zones.

Table 6: First-Year Energy Impacts Per Home – SF2100 Prototype Building, “Ongoing Verification” Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A	N/A	N/A	N/A
3	(17.9)	N/A	N/A	(525)
4	0.5	0.010	N/A	861
5	N/A	N/A	N/A	N/A
6	(0.8)	0.009	N/A	525
7	1.5	0.007	N/A	273
16	7.2	0.011	N/A	252

Table 7: First-Year Energy Impacts Per Home – SF2700 Prototype Building, “Ongoing Verification” Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A	N/A	N/A	N/A
3	(9.9)	N/A	N/A	(162)
4	10.7	0.019	N/A	2,214
5	0.1	N/A	N/A	N/A
6	4.9	0.015	N/A	1,134
7	5.7	0.012	N/A	648
16	19.1	0.028	0.000	648

Table 8: First-Year Energy Impacts Per Home – LowRiseGarden Prototype Building, "Ongoing Verification" Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	1.1	0.000	N/A	70
3	15.0	0.012	N/A	2,645
4	74.0	0.071	N/A	6,055
5	12.8	0.010	N/A	1,183
6	60.6	0.070	N/A	5,081
7	66.6	0.093	N/A	4,106
16	94.4	0.076	N/A	2,993

For the "Initial + Ongoing Verification" scenario, shown in Table 9 through Table 11, per-unit energy savings for the first year are expected to range from slightly negative savings in a few climate zones to 223 kWh/yr, in single family homes, and 636 kWh/yr in multifamily, depending upon climate zone. Demand reductions are expected to range from 0.000 to 0.149 kW in single family homes and 0.386 kW in multifamily, depending on climate zone. TDV impacts range from slightly negative in a few climate zones to 8,700 TDV kBtu/yr in single family homes, and 24,000 kBtu/yr in multifamily.

No natural gas savings are modeled.

Table 9: First-Year Energy Impacts Per Home – SF2100 Prototype Building, "Initial + Ongoing Verification" Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A	N/A	N/A	N/A
2	(34.1)	0.001	N/A	(357)
3	(4.9)	N/A	N/A	(147)
4	(3.3)	0.007	N/A	588
5	N/A	N/A	N/A	N/A
6	1.4	0.007	N/A	462
7	(0.4)	0.003	N/A	105
8	17.4	0.028	N/A	1,008
9	16.3	0.026	N/A	1,134
10	28.0	0.046	N/A	2,058
11	46.6	0.052	N/A	2,310
12	9.1	0.011	N/A	1,365
13	68.0	0.060	N/A	3,213
14	22.9	0.050	N/A	1,701
15	186.2	0.128	N/A	7,476
16	4.3	0.007	N/A	147

Table 10: First-Year Energy Impacts Per Home – SF2700 Prototype Building, "Initial + Ongoing Verification" Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A	N/A	N/A	N/A
2	(4.0)	0.003	N/A	945
3	(2.9)	N/A	N/A	N/A
4	7.2	0.007	N/A	675
5	N/A	N/A	N/A	N/A
6	2.8	0.010	N/A	648
7	1.7	0.005	N/A	270
8	25.6	0.038	N/A	1,863
9	25.2	0.042	N/A	2,133
10	40.2	0.049	N/A	2,214
11	63.8	0.069	N/A	3,753
12	18.6	0.019	N/A	1,836
13	93.0	0.084	N/A	4,509
14	49.4	0.052	N/A	2,484
15	222.5	0.149	N/A	8,694
16	11.6	0.017	N/A	405

Table 11: First-Year Energy Impacts Per Home – LowRiseGarden Prototype Building, "Initial + Ongoing Verification" Scenario

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	1.7	0.001	N/A	70
2	23.6	0.022	N/A	2,714
3	24.0	0.019	N/A	4,315
4	118.9	0.114	N/A	10,162
5	20.6	0.017	N/A	1,879
6	96.2	0.111	N/A	8,004
7	106.5	0.147	N/A	6,473
8	123.1	0.138	N/A	6,055
9	112.7	0.130	N/A	6,055
10	155.3	0.169	N/A	7,447
11	214.6	0.212	N/A	10,092
12	81.2	0.074	N/A	5,498
13	279.0	0.229	N/A	11,971
14	195.3	0.197	N/A	9,674
15	635.5	0.386	N/A	24,012
16	134.6	0.123	N/A	4,037

When FDD is used in lieu of initial verification (in those Climate Zones where credit is provided), savings are generally quite small. If both initial and ongoing verification are used (with initial charge verification or FID device, *and* FDD installation), kWh and TDV savings are typically one to two percent, and kW savings are three to four percent. In Climate Zone 15, however, because of its extremely high cooling loads coupled with high PV availability, the energy savings are on the order of ten percent, and TDV savings are on the order of five percent.

5. Cost and Cost Effectiveness

The code change proposal would not modify the stringency of the existing California Energy Code, so the Energy Commission does not need a complete cost-effectiveness analysis to approve the proposed change. Section 5 of the research reports typically presents a detailed cost-effectiveness analysis. For this proposed change, the Statewide CASE Team is presenting information on the cost implications in lieu of a full cost-effectiveness analysis.

Based upon the energy and demand reductions estimated in the last section, significant energy cost savings would be achieved. These savings may or may not be cost effective in a particular case, depending on the cost of the FDD system chosen. Costs for FDD vary, and they include several elements, including:

- Sensors: some FDD systems would require a sophisticated suite of sensors, while others are based upon only simple indicators.
- Electronics: some FDD systems would be embedded in the electronics of the HVAC system, while others would be added hardware.
- Software: the algorithms for FDD can be embedded in the FDD system, but in many cases the analysis is done on a remote server for a cloud-based solution.
- Communications hardware: if diagnostic algorithms are implemented on the cloud, there would likely be a need for communications hardware, such as gateways and routers.
- Communications service: in some cases, internet service would be required. This can make use of existing home Wi-Fi connectivity, but in many cases, additional service is added for the FDD system, in order to ensure no interruptions in service.

There should not be an increase in maintenance costs for implementing FDD, but it is likely that the findings may result in added calls for equipment service or maintenance. This should not be a net increase, however, as periodic preventive maintenance should be less costly than sporadic service calls and expensive equipment repair and replacement.

6. First-Year Statewide Impacts

The code change proposal would not modify the stringency of the existing California Energy Code, so the savings associated with this proposed change are minimal. Typically, the Statewide CASE Team presents a detailed analysis of statewide energy and cost savings associated with the proposed change in Section 6 of the research report. As discussed in Section 4, although the energy savings are limited, the measure would provide non-energy benefits such as extending the life of residential HVAC systems by addressing equipment faults before they degrade the system's condition and by improving comfort and system-uptime by addressing problems before they result in a system shutdown.

7. Proposed Revisions to Code Language

7.1 Guide to Markup Language

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2019 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

7.2 Standards

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW RISE RESIDENTIAL BUILDINGS

Section 150.1(b)3.B: Field Verification.

x. Residential HVAC FDD. When performance compliance requires field verification of the installation of Residential HVAC FDD, the FDD system shall be field verified in accordance with the procedures in Reference Residential Appendix RA3.4.4.3.

Section 150.1(c) Prescriptive Standards/Component Package.

7. Space Heating and Space Cooling.

All space heating and space cooling equipment shall comply with minimum Appliance Efficiency Regulations as specified in Sections 110.0 through 110.2 and meet all applicable requirements of Sections 150.0 and 150.1(c)7A.

A. Refrigerant Charge.

When refrigerant charge verification or fault indicator display is shown as required by TABLE 150.1-A or B, the system shall comply with either 150.1(c)7Ai or 150.1(c)7Aii:

i. …

c. The installer shall charge the system according to manufacturer's specifications. Refrigerant charge shall be verified according to one of the following options, as applicable:

I. The installer and rater shall perform the standard charge procedure as specified by Reference Residential Appendix Section RA3.2.2 or an approved alternative procedure as specified by RA1; or

II. The system shall be equipped with a fault indicator display (FID) device that meets the specifications of Reference Joint Appendix JA6. The installer shall verify the refrigerant charge and FID device in accordance with the procedures in Reference Residential Appendix Section Residential Appendix Section RA3.4.2. The HERS Rater shall verify FID device in accordance with the procedures in Section RA3.4.2; or

III. The installer shall perform the weigh-in charging procedure as specified by Reference Residential Appendix Section RA3.2.3.1 provided the system is of a type that can be verified using the RA3.2.2 standard charge verification procedure and RA3.3 airflow rate verification procedure or approved alternatives in RA1. The HERS Rater shall verify the charge using RA3.2.2 and RA3.3 or approved alternatives in RA1.; or

IV. The installer shall install a certified Residential HVAC FDD System that meets the specifications of Reference Joint Appendix JA6.4. The HERS Rater shall verify the installation and configuration of the FDD system in accordance with the procedures in Section RA3.4.4.3.

TABLES 150.1-A and B COMPONENT PACKAGE – Single Family/Multifamily Standard Building Design

TABLE 150.1-A COMPONENT PACKAGE – Single Family Standard Building Design (continued)

				Climate Zone											
				1	2	3	4	5	6	7	8	9	10	11	…
HVAC SYSTEM	Space Heating 9	Electric-Resistance Allowed		No	No	No	No	No	No	No	No	No	No	No	…
		If gas, AFUE		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	…
		If Heat Pump, HSPF 7		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	…
	Space Cooling	SEER		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	…
		Refrigerant Charge Verification or Fault Indicator Display or Residential HVAC FDD		NR	REQ	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	…
		Whole House Fan8		NR	NR	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	…
	Central System Air Handlers	Central Fan Integrated Ventilation System Fan Efficacy		REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	…
	Ducts10	Roof/Ceiling Options B	Duct Insulation	R-8	R-8	R- 6	R-8	R- 6	R- 6	R- 6	R-8	R-8	R-8	…	
			§150.1(c)9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	…	
		Roof/Ceiling Option C	Duct Insulation	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	…	
			§150.1(c)9B	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	…	

SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING LOW-RISE RESIDENTIAL BUILDINGS

150.2(b)1F: Altered Space-Conditioning Systems – Mechanical Cooling

ii. In Climate Zones 2, 8, 9, 10, 11, 12, 13, 14, and 15, air-cooled air conditioners and air-source heat pumps, including but not limited to ducted split systems, ducted package systems, small duct high velocity air systems, and minisplit systems, shall comply with subsections a and b, unless the system is of a type that cannot be verified using the specified procedures. Systems that cannot comply with the requirements of 150.2(b)1Fii shall comply with 150.2(b)1Fiii.

…

b. The installer shall charge the system according to manufacturer's specifications. Refrigerant charge shall be verified according to one of the following options, as applicable.

I. The installer and rater shall perform the standard charge verification procedure as specified in Reference Residential Appendix Section RA3.2.2, or an approved alternative procedure as specified in Section RA1; or

II. The system shall be equipped with a fault indicator display (FID) device that meets the specifications of Reference Joint Appendix JA6. The installer shall verify the refrigerant charge and FID device in accordance with the procedures in Reference Residential Appendix Section RA3.4.2. The HERS Rater shall verify FID device in accordance with the procedures in Section RA3.4.2; or

III. The installer shall perform the weigh-in charging procedure as specified by Reference Residential Appendix Section RA3.2.3.1 provided the system is of a type that can be verified using the RA3.2.2 standard charge verification procedure and RA3.3 airflow rate verification procedure or approved alternatives in RA1. The HERS Rater shall verify the charge using RA3.2.2 and RA3.3 or approved alternatives in RA1; or

IV. The installer shall install a certified Residential HVAC FDD System that meets the specifications of Reference Joint Appendix JA6.4. The HERS Rater shall verify the installation and configuration of the FDD system in accordance with the procedures in Section RA3.4.4.3.

7.3 Reference Appendices

JA6.4 RESIDENTIAL HVAC FAULT DETECTION AND DIAGNOSIS CERTIFICATION SUBMITTAL REQUIREMENTS

According to Title 24, Part 6, ACM Section 2.4.5, credit may be provided for installation of a Residential HVAC Fault Detection and Diagnosis (FDD) system. Each air conditioning system manufacturer, controls supplier, or FDD supplier wishing to certify that their FDD system conforms to JA6.4.1 - 6.4.3 and certified by written declaration to the Energy Commission according to Section 6.4.4.

JA6.4.1 Information that shall be included with the Declaration

The air conditioning system manufacturer, controls supplier, or FDD system supplier provides evidence as shown below:

(a) The FDD system is capable of detecting that either the rated efficiency or the capacity of the HVAC system is reduced by more than 15 percent.
Evidence: per Section JA6.4.3.

(b) The FDD system does not indicate a fault when both the efficiency and the capacity of the HVAC system are within 5 percent of normal.
Evidence: per Section JA6.43.

(c) All required Critical Field-Adjusted Parameters (CFAPs) are identified in the submission, Each FDD system shall have at least two CFAPs. The submission must include the name of the CFAP, a brief description of how it the appropriate value should be determined, and a description of the process for verifying its value.
Evidence: per Section JA6.4.4 in the Certification Submittal, along with a .description for each of how the appropriate value should be determined, and a description of the process for verifying its value.

(d) The FDD system is capable of reporting faults one of the following ways:

A. Annunciated locally on one or more zone thermostats, or on a device within five (5) feet of zone thermostat(s), clearly visible, at eye level. On the thermostat or device, instructions must be displayed to contact an HVAC technician.

B. To a Home Automation System, or other application that automatically provides notification of the fault to the occupant and a remote HVAC service provider.

Evidence: per Section JA6.4.4

JA6.4.2 Specification of Fault Detection Performance

(1) The FDD system is capable of detecting that either the efficiency or the capacity of the HVAC system is reduced by more than 15 percent at a given operating condition, compared to the un-faulted value.

(2) The FDD system does not indicate a fault when both the efficiency and the capacity of the HVAC system are within 5 percent of the un-faulted value.

JA6.4.3 Specification of Fault Detection Performance Demonstration

(1) The Executive Director may approve certification of specific FDD systems, subject to a manufacturer providing sufficient evidence to the Executive Director that the FDD system will meet the performance criteria laid out in JA6.4.2. This approval shall be subject to the requirements for Exceptional Methods contained in Title 24 Part 6 Sections 10-109 and 10-110.

(2) To request approval, the manufacturer shall propose, conduct, and document a study that demonstrates—using data collected either in a laboratory or field setting—that their FDD system meets the performance criteria laid out in JA6.4.2. This study may be proposed, conducted, and documented in conjunction with a third party. This shall consist of the following activities:

   (a) In preparation for their study, the manufacturer shall submit to the energy commission an *FDD Performance Assessment Methodology Proposal* describing the study it intends to conduct. In this document, the manufacturer shall describe in detail how it proposes to:

   - Demonstrate that the FDD system's performance meets the specification in JA6.4.2 in response to at least two of the following faults:
     - Low evaporator airflow or heat transfer
     - Low refrigerant charge
     - Liquid line restrictions
     - Non-condensable gas in the refrigerant
     - Low condenser airflow or heat transfer
     - Duct leakage.
   - Simulate or field-verify faults.
   - Collect, analyze, and present data.
   - Conduct an uncertainty analysis—including analysis of issues such as sample size and significance—of the expected results.

(b) The Energy Commission will review the proposal, verify that it is compliant with the requirements above, and provide comments that identify any opportunities for improvement. The Energy Commission may then grant the manufacturer approval to conduct a study conforming to the proposal as a means of demonstrating compliance with the requirements of JA6.4.

(c) The manufacturer shall proceed to conduct a study, based upon its approved *FDD Performance Assessment Methodology Proposal*.

(d) Upon completion of the study, the manufacturer shall submit to the Energy Commission an *FDD Performance Certification Report* that fully documents its study and justifies its claim that its FDD system meets the performance criteria laid out in JA6.4.2. This report shall address issues raised in the proposal and include all raw data used to calculate performance.

(e) The Energy Commission will review the study, and grant approval to an FDD system so long as the following are found to be true:

- the manufacturer faithfully carried out the study for which approval was granted by the Energy Commission, and
- the study concluded that the performance criteria laid out in JA6.4.2 were met.

JA 6.4.4 Declaration

Consistent with the requirements of Title 24, Part 6, Joint Appendix 6.4, companies wishing to certify to the Energy Commission shall execute a declaration under penalty of perjury attesting that all information provided is true, complete, accurate, and in compliance with the applicable provisions of Part 6. Companies may fulfill this requirement by providing the information, signing the declaration below and submitting to the Energy Commission as specified by the instructions in JA6.4.5.

Manufacturer, Model Name and Number of all systems being certified

Manufacturer / Model Name / Model Number

When providing the information below, be sure to enter complete mailing addresses, including postal/zip codes.

Certifying Company

Contact Person Name *	Phone 1
Certifying Company Name **	Phone 2

Address	Fax
(Address)	E-mail
(Address)	Company Website (URL)

* If the contact person named above is NOT the person whose signature is on the Declaration, then the full contact information for the person whose signature is on the Declaration must also be provided on a separate page.

** If the company named above is: A) a parent entity filing on behalf of a subsidiary entity; B) a subsidiary entity filing on behalf of a parent entity; or C) an affiliate entity filing on behalf of an affiliate entity, the above contact information must be provided for any additional entities on a separate page.

Manufacturer (if different from Certifying Company)

Contact Person Name *	Phone 1
Certifying Company Name **	Phone 2
Address	Fax
(Address)	E-mail
(Address)	Company Website (URL)

Declaration

I declare under penalty of perjury under the laws of the State of California that:

(1) All the information in this statement is true, complete, accurate, and in compliance with all applicable provisions of Joint Appendix JA6.4 of the reference Appendix to Title 24, Part 6 of the California Code of Regulations.

(2) Each Residential HVAC Fault Detection and Diagnosis (FDD) system has been tested in accordance with all applicable requirements of JA6.4 of the reference Appendix to Title 24, Part 6 of the California Code of Regulations.

(3) [If the party submitting this statement is a corporation, partnership, or other business entity] I am authorized to make this declaration, and to file this statement, on behalf of the company named below.

Certifying Company Name Date

Name/Title (please print) Signature

JA6.4.5 Certification

Send declarations and evidence of functionality or test reports to the addresses below. Electronic submittals are preferred.

(1) Electronic submittal: CertifiedtoCEC@energy.ca.gov Attn: Residential FDD Certification

(2) Mail: Attn: Residential FDD Certification/Building Standards Development Office California Energy Commission/1516 Ninth St., MS 37/Sacramento, CA 95814

RA2.2 MEASURES THAT REQUIRE FIELD VERIFICATION AND DIAGNOSTIC TESTING

Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing

Measure Title	Description	Procedure(s)
Air Conditioning Measures		
Residential HVAC FDD	When a Residential HVAC FDD system is installed and verification of the FDD system's installation is required by Section 150.1(b)3B, the installed system equipment shall be verified according to the procedure specified in this section.	RA 3.4.4.3

RA3.4.4.3 Residential HVAC FDD Verification Procedure

When a Residential HVAC FDD system is installed and verification of the FDD system's installation is required by Section 150.1(b)3B, the installed system equipment shall be verified according to the procedure specified in this section.

The procedure shall consist of the visual verification of installation of the following system components and confirmation that the installed equipment is certified to the Energy Commission:

(a) Verify fault detection and diagnosis (FDD) system is installed on HVAC unit.

(b) Verify the FDD system matches the make and model listed on the Energy Commissions database of certified residential FDDs and on the CF2R-MCH-35.

(c) Verify that all the Critical Field-Adjusted Parameters (CFAPs) required by the manufacturer are indicated on the CF2R.

(d) Verify that the values of all required CFAPs indicated on the CF2R match the observed values.

(e) Verify that the FDD system has been configured to report faults one of the following ways:

1. Annunciated locally on one or more zone thermostats, or on a device within five (5) feet of zone thermostat(s), clearly visible, at eye level. Verify that on the thermostat or device, instructions are displayed to contact an HVAC technician.
2. To a Home Automation System, or other application that automatically provides notification of the fault to the occupant and a remote HVAC service provider.
    - If this method is used, verify that information is made available to the homeowner on how to identify a service contractor who provides fault monitoring as a service.

7.4 ACM Reference Manual

2.4.5.1 VERIFIED REFRIGERANT CHARGE, ~~OR~~ FAULT INDICATOR DISPLAY, OR RESIDENTIAL HVAC FDD

Proper refrigerant charge is necessary for electrically driven compressor air-conditioning systems to operate at full capacity and efficiency, and ongoing verification is needed to keep it operating at full capacity and efficiency. Software calculations set the compressor efficiency multiplier to ~~0.90 to account for the effect of improper refrigerant charge or 0.96 for proper charge.~~:

- 0.90 when there is no initial verification/FID and no ongoing FDD; or
- 0.96 when there is initial verification/FID installed, but no ongoing FDD; or
- 0.96 when there is ongoing FDD but no initial verification/FID; or
- 1.00 when there is both initial verification/FID and ongoing FDD.

Proposed Design

The software allows the user to indicate if systems will have diagnostically tested refrigerant charge (or~~, or~~ field-verified FID), or a residential HVAC fault detection and diagnosis (FDD) system, or both. Refrigerant charge verification applies only to ducted split-systems and packaged air-conditioners and heat pumps.

Standard Design

The standard design building is modeled with either diagnostically tested refrigerant charge or a field-verified FID if the building is in Climate Zone 2 or 8-15, and refrigerant charge verification is required by Section 150.1(c) and Table 150.1-A or 150.1-B for the proposed cooling system type, and with no verification in Climate Zones 1, 3-7, and 16.

Table 10: Summary of Space Conditioning Measures Requiring Verification

Measure	Description	Procedures
Verified Residential HVAC FDD	A Residential Fault Detection and Diagnosis system can be installed as a compliance option. If installed, its proper installation and configuration must be verified.	RA3.4.4.3

7.5 Compliance Manuals

RESIDENTIAL COMPLIANCE MANUAL, 4.3.3. PERFORMANCE COMPLIANCE OPTIONS FOR COOLING EQUIPMENT

4.3.3.5 Residential HVAC FDD

Performance compliance option credit is provided for installation of a certified Fault Detection and Diagnosis (FDD) system to be used in conjunction with the cooling system.

- Credit is only provided for FDD systems used with conventional split systems, including heat pumps and variable-capacity systems.
- FDD systems that meet eligibility criteria will be certified by the Energy Commission and listed on their website. These listings will include a unique identifier, make, model, and a list of Critical Field-Adjusted Parameters (CFAPs), along with a description of their importance and instructions on how to set and verify them.
- Installers will have to take care to set these CFAPs correctly, and HERS verification of their values is required.
- Credit is equivalent in magnitude—and can be used in conjunction with—the credit provided for Refrigerant Charge Verification: rated compressor efficiency is reduced by 10 percent when neither is used, it is reduced by 6 percent when only one of these measures is used, and it is not reduced when both are used.

7.6 Compliance Documents

CF1R – PRF-01 CERTIFICATE OF COMPLIANCE

The following column will be included in the existing HVAC Cooling – HERS Verification table on the existing CF1R form.

HVAC COOLING – HERS VERIFICATION						
01	02	03	04	05	06	07
Name	Verified Airflow	Airflow Target	Verified EER	Verified SEER	Verified Refrigerant Charge	Verified HVAC FDD

CF2R-MCH-35-HVACFDD CERTIFICATE OF INSTALLATION

A. HVAC Fault Detection and Diagnosis (FDD) Procedures for the HVAC FDD verification are detailed in RA3.4.4.3. "CFAPs" are Critical Field Adjusted Parameters		
01	FDD Manufacturer Name	
02	FDD Model Number	
03	FDD Unique CEC ID	

04	Number of Required CFAPs	
05	CFAP1 Name	
06	CFAP1 Configured Value	
07	CFAP2 Name	
08	CFAP2 Configured Value	
09	CFAP3 Name	
10	CFAP3 Configured Value	
11	CFAP4 Name	
12	CFAP4 Configured Value	
13	CFAP5 Name	
14	CFAP5 Configured Value	

CF3R-MCH-35-HVACFDD CERTIFICATE OF VERIFICATION

A. HVAC Fault Detection and Diagnosis (FDD) Procedures for the HVAC FDD verification are detailed in RA3.4.4.3. "CFAPs" are Critical Field Adjusted Parameters		
01	FDD Manufacturer Name	
02	FDD Model Number	
03	FDD Unique CEC ID	
04	Number of Required CFAPs	
05	CFAP1 Name	
06	CFAP1 Verified Value	
07	CFAP2 Name	
08	CFAP2 Verified Value	
09	CFAP3 Name	
10	CFAP3 Verified Value	
11	CFAP4 Name	
12	CFAP4 Verified Value	
13	CFAP5 Name	
14	CFAP5 Verified Value	

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Appendix A: Statewide Savings Methodology

The code change proposal would not modify the stringency of the existing California Energy Code, so there would be no energy savings on a per-unit basis, so there is no description of Savings Methodology.

Appendix B: Embedded Electricity in Water Methodology

There are no on-site water savings associated with the proposed code change.

Appendix C: Environmental Impacts Methodology

Greenhouse Gas (GHG) Emissions Factors

As directed by Energy Commission staff, GHG emissions were calculated making use of the average emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion (United States Environmental Protection Agency 2018). This ensures consistency between state and federal estimations of potential environmental impacts. The electricity emissions factor calculated from the eGRID data is 240.4 MMTCO2e per GWh. The Summary Table from eGrid 2016 reports an average emission rate of 529.9 pounds CO2e/MWh for the WECC CAMX subregion. This value was converted to metric tons/GWh.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in Chapter 1.4 of the U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (United States Environmental Protection Agency 1995). The U.S. EPA's estimates of GHG pollutants that are emitted during combustion of one million standard cubic feet of natural gas are: 120,000 pounds of CO_2 (Carbon Dioxide), 0.64 pounds of N_2O (Nitrous Oxide) and 2.3 pounds of CH_4 (Methane). The emission value for N_2O assumed that low NOx burners are used in accordance with California air pollution control requirements. The carbon equivalent values of N_2O and CH_4 were calculated by multiplying by the global warming potentials (GWP) that the California Air Resources Board used for the 2000-2016 GHG emission inventory, which are consistent with the 100-year GWPs that the Intergovernmental Panel on Climate Change used in the fourth assessment report (AR4). The GWP for N_2O and CH_4 are 298 and 25, respectively. Using a nominal value of 1,000 Btu per standard cubic foot of natural gas, the carbon equivalent emission factor for natural gas consumption is 5,454.4 metric tons per million therms.

GHG Emissions Monetization Methodology

The 2022 TDV energy cost factors used in the lifecycle cost-effectiveness analysis include the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs). To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the other economic impacts. The authors used the same monetary values that are used in the TDV factors – \$106/$MTCO_2$e.

Water Use and Water Quality Impacts Methodology

There are no expected impacts to water quality or water use.

Appendix D: California Building Energy Code Compliance (CBECC) Software Specification

CASE Authors will follow the steps below to provide the necessary information to CBECC software developers:

1. Describe the CASE measure and the technical basis for the proposed change(s) to CBECC-Com/Res, referencing other sections of this report or other reports as necessary.
2. Determine CBECC-Com/Res user inputs.
3. Determine EnergyPlus/California Simulation Engine (CSE) inputs.
4. Identify section(s) of the Alternative Calculation Method (ACM) Reference Manual pertaining to the proposed software change.
5. Identify any relevant inconsistencies between code language in the standards and Reference Appendices, ACM Reference Manual, and the CBECC software implementation.
6. Propose any revisions to the ACM Reference Manual that may be required.
7. Identify the limitation(s) of the CBECC software preventing adequate modeling of the proposed measure (e.g., missing input fields, unsupported technology, inaccurate schedule values).
8. Identify if new algorithms, models, files, or other must be added to EnergyPlus/California Simulation Engine (CSE) to conduct the needed calculations. This step is only needed if the underlying simulation engines do not have the required capabilities.
9. Identify related objects/inputs in the simulation input file (EnergyPlus IDF file for CBECC-Com or CSE file for CBECC-Res) that may need to be corrected or included.
10. Identify output variables or meters that may be needed to verify feature implementation.
11. Propose updates or revisions to the software's user interface that may be needed to expose new features or clarify input descriptions.
12. Propose updates or revisions to the software's output reports that may be needed for compliance documentation.

CBECC-Com/Res software developers will use the information from this document to implement the proposed software change. Once the software change is implemented, the software will be tested and verified using the test procedure and reference results provided in the Simulation Engine Inputs section of this appendix.

The Energy Commission requires a beta version of CBECC software to be released at least one year prior to the effective date of the California Energy Code. The 2022 code will take effect January 1, 2023. Therefore, the beta version of the CBECC software must be released no later than January 1, 2022. The Statewide CASE Team will provide this appendix to the CBECC development teams at least 20 months prior to the anticipated effective date of the 2022 code to allow sufficient time for the development and testing of the software changes. Therefore, the Statewide CASE Team will provide this document to the CBECC development teams no later than May 1, 2021.

Introduction

The purpose of this appendix is to present proposed revisions to CBECC for residential buildings (CBECCRes) along with the supporting documentation that the Energy Commission staff, and the technical support contractors would need to approve and implement the software revisions.

Technical Basis for Software Change

The software needs to be changed in order to calculate impacts of increasing the Compressor Efficiency Multiplier (CEM) when FDD is implemented. Field research was done to provide the basis for the change in CEM.

Description of Software Change

Background Information for Software Change

During the design phase, the energy consultant and designer will decide if the FDD credit is recommended to make the proposed building comply with the code. The energy consultant will select one of the following choices from the “AC Verification” drop-down menu (previously named “AC Charge”) on the Cooling System Data screen:

Performance Verification Selection	CEM
Not Verified	0.90
Initial (Charge Verified/FID)	0.96
Ongoing (FDD)	0.96

Initial + Ongoing	1.00

The third and fourth selections indicate the installation of a certified FDD system. Based on this selection, a different CEM will be used in the software to calculate energy use.

Existing CBECC- Res Modeling Capabilities

CBECC-Res currently includes a way for the designer to select whether the AC Charge is verified:

AC Charge Selection	CEM
Verified	0.96
Not Verified	0.90
FID (Fault Indicator)	0.96

This software needs to be modified in order to provide credit for the FDD measure.

Summary of Proposed Revisions to CBECC-Res

In order to model the FDD measure, the CEM will be changed. Existing calculations are sufficient.

User Inputs to CBECC-Res

The only new inputs required are additional options provided in the drop-down list for "AC Charge" on the Cooling System Data Screen. The label provided for this selection should be renamed "AC Verification".

Simulation Engine Inputs

EnergyPlus/California Simulation Engine Inputs

Based on the selection for the AC Verification field, the CEM will be changed, as indicated above.

Calculated Values, Fixed Values, and Limitations

There will be no new calculated values.

Alternate Configurations

There will be no alternate configurations.

Simulation Engine Output Variables

There will be no new simulation engine output variables.

Compliance Report

There will be no changes made to the compliance report.

Compliance Verification

Compliance verification will include:

- Verifying that the installed FDD system is listed in an online database of certified products, compiled by the Energy Commission.
- Verifying that the values of the Critical Field-Adjusted Parameters (CFAPs) match those on the compliance documents.
- Verifying that the installer has left behind educational information.

Testing and Confirming CBECC-Res Modeling

There will be no new tests required to confirm CBECC-Res modeling.

Description of Changes to ACM Reference Manual

Changes will be required in the ACM Reference Manual, to describe the different values of CEM used for different selections of the AC Verification variable.

Refer to Section 7 of the research report for marked up language.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. Table 12 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. The information contained in Table 12 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes. Appendix F summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the code change proposal, including gathering information on the compliance process.

The proposed compliance process would affect the current compliance and enforcement process in the following ways:

- It would not require a significant change to the design process.
- In the installation phase, the installer would have to select appropriate products from the Energy Commission online database, and enter its make, model, and a list of Critical Field Adjusted Parameters (CFAPs) and their values. The installer would fill out an additional CF2R. The installer would figure out how system would communicate alarms to customer or service provider and provide instruction to end-user.
- It would require additional HERS verification, and one additional CF3R to verify.
- It would not require market actors to coordinate or collaborate with actors they do not coordinate/collaborate with currently.
- It would not require specialized training to increase knowledge or skill.
- It would not require additional resources to implement.
- It would require new documentation practices, including a new CF2R and CF3R.

Table 12: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
FDD Manufacturer	• Propose to the Energy Commission a study to conduct lab testing, field testing, or modeling (TBD) to verify performance. • Conduct the study and submit the report to the Energy Commission and obtain approval. • Submit required certifications to Energy Commission, including list and description of any Critical Field-Adjusted Parameters (CFAPs). • Provide support and documentation to ensure correct installation, configuration, verification, and operation.	• Expand market for their products. • Have successful products that lead to future sales and future code credits.	Have to create additional materials for end user, installer, and HERS rater.	Energy Commission should provide sample materials.

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Energy Consultant/ Modeler	• Decide if the FDD credit is recommended to make project comply. • Include FDD in the table of requirements on the CF1R-PRF-01, indicating that HERS verification is required.	Identify measures that can meet compliance targets.	• Another tool in toolbox to make projects comply. • New opportunity to consider installing FDD instead of refrigerant charge verification (earning the same credit), especially for winter installations. • Possible and likely negative workflow impact when the installed CFAPs don't match what's indicated on the CF1R, requiring the HERS rater to coordinate getting the CF1R changed to match installed values.	Very few compliance credits left for Res, so this is helpful to have more options to offer clients to comply & doesn’t significantly change design.
Designer/ Responsible Person	Same as Energy Consultant / Modeler.	Create a compliant design that ensures a happy customer and no complaints.	Another tool in toolbox to make projects comply.	N/A

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Plans Examiner	Verify what's indicated on CF1R is also documented on plans. (notes on electrical or mechanical schematics).	Verify that compliance documents match plans.	No new responsibilities.	N/A
HVAC Equipment Supplier	• Be up to date on the Energy Commission's list of what qualifies, and supply systems that are certified. • Be able to answer contractor questions and refer them to compliant equipment upon request.	• Provide solutions for their clients. • Have knowledge of available products to retain customers.	No impact.	Provide guidance on product label or some other way for consumers to easily identify it's certified without having to go to Energy Commission list.
HVAC Contractor/ Maintenance Technician	• Identify a suitable FDD system from the Energy Commission website and identify the required CFAPs for that model. • Include make and model of FDD on plans and specifications. • Indicate the FDD make and model on a CF2R-MECH-35, and enter	• Want equipment to work to reduce call backs • Clearly be able to see the requirement on the construction docs. • Have clear direction on how to install and configure FDD systems.	• Requires installer to: ○ Lookup models and CFAPs ○ Install and configure FDD system correctly. ○ Fill out an additional CF2R. ○ Figure out how system would communicate alarms to	Ensure contractor knows of this requirement & that it's connected and works before they leave site.

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
	the number of CFAPs, and list their names and the required values of each. • Install the equipment according to manufacturer instructions. • Configure the equipment according to manufacturer instructions, by setting all CFAPs and setting up the system to alert the homeowner or service provider when an alarm is generated. • If a service provider would be receiving the alert, ensure that information to help identify a suitable service contractor is left for the homeowner. • Educate the homeowner on what to do if there is an alert.	• Possibly expand service customer base. • Manufacturer's list of CFAPs and instructions on how to configure their system are important because the Contractor needs to understand the requirement.	customer or service provider and provide instruction to end-user.	

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
HERS Rater	• Conduct a HERS verification, verifying that: ○ the make and model of the FDD system match the CF2R-MCH-35, ○ it is installed correctly, ○ the list of CFAPs matches the list provided by the manufacturer on the the Energy Commission website, ○ the value of each CFAP matches the value indicated on the CF2R-MCH-35, ○ it is configured to alert the homeowner or service provider, and ○ information to help identify a suitable service contractor is	Have clear direction on how to verify installation and configuration of FDD systems.	• Additional HERS verification required. • Possible and likely negative workflow impact when the installed CFAPs don't match what's indicated on the CF1R, requiring the HERS rater to coordinate getting the CF1R changed to match installed values.	Manufacturer including a test mode to facilitate HERS verification. (nothing like that right now)

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
	left for the homeowner. • Complete CF3R-MCH-35, documenting these verifications.			
Building Inspector	Verify all required forms are completed by HERS Rater.	Have clear requirements for compliance documents.	One additional CF3R to verify.	N/A
Energy Commission	• Maintain directory of certified products. • Verify systems meet certification criteria. • Add FDD credit to compliance software. Reflect credit on CF1R & HERS Verification feature.	Have a clear certification process that is easy to administer, not requiring a lot of support to manufacturers or contractors.	Review study proposals, study reports, and other certification submittals from manufacturers.	N/A

Appendix F: Summary of Stakeholder Engagement

Collaborating with stakeholders that might be impacted by proposed changes is a critical aspect of the Statewide CASE Team's efforts. The Statewide CASE Team aims to work with interested parties to identify and address issues associated with the proposed code changes so that the proposals presented to the Energy Commission in Draft research reports are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including: cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

This appendix summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the recommendations presented in this report.

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2022 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

- Proposed code changes
- Draft code language
- Draft assumptions and results for analyses
- Data to support assumptions
- Compliance and enforcement, and
- Technical and market feasibility

The Statewide CASE Team hosted one stakeholder meeting for Residential HVAC FDD via webinar. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting. Such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography section of this report. (Statewide CASE Team 2019).

Appendix G: Field Study of Performance Degradation in California Homes

Objectives

In this study, Frontier Energy installed instrumentation at 40 sites in Northern and Southern California with HVAC systems of varying ages, in order to estimate their efficiency and identify the degree of performance degradation that can occur over the life-cycle of a residential air conditioner. This would determine the baseline for performance improvements available from installing FDD in new systems.

Methodology

This study consisted of the following steps:

- Recruit participants and install monitoring instruments to measure system capacity, energy use, and efficiency.
- During this installation visit, record observations of any obvious issues with performance.
- Monitor each site for approximately two weeks during the summer.
- Return to sites to commission the system and carry out conventional check-ups and diagnostic tests to identify probable faults.
- Analyze the monitored data to:
    - Calculate each system's *current* efficiency at *observed* conditions.
    - Estimate what each system's *current* efficiency would be at *standard* AHRI conditions.
    - Look up what each system's *rated* efficiency was (when new) at *standard* AHRI conditions.
    - Calculate the percent degradation (difference between *current* and *rated* efficiency at *standard* conditions) for each system.
    - Calculate the percent degradation as a function of system age, and the overall annual percent degradation.

Analysis

There were four distinct stages in analyzing the measured data:

- Identifying periods that represent steady state performance
- Adjusting measured efficiency at non-standard conditions to estimate what the efficiency would be at standard (AHRI) conditions
- Comparing efficiency of the degraded unit at AHRI conditions with the rated efficiency (for the unit when it was new and running as expected)

- Calculating the annual degradation as a function of system age

Identifying Steady State Performance

Frontier Energy filtered out data when the system was not operating, was operating at lower capacity, or was not yet at steady state. Frontier Energy only used data when the air conditioning unit was deemed to be at steady state, defined as a period when air conditioner power was not changing significantly over at least 15 minutes (for 7 sites, Frontier Energy also included points that were steady for between 10 and 15 minutes, since there were too few points with 15 minutes of steady state operation). Each of the datapoints used in the analysis then represented the average of the value for the last 5 minutes of a steady-state period.

Adjusting Measured Efficiency for Standard Conditions

In order to estimate the degradation in efficiency, Frontier Energy adjusted the measured data to estimate what the performance of the degraded unit would be at AHRI conditions. This analysis conducted for each site included the following steps:

- Calculate the total (sensible and latent) net EER for each measured steady-state period:
    - This was based upon the measurements (over 5 minutes) of energy consumed by the indoor and outdoor units (average kW converted to Btu/hr), average supply and return duct dry-bulb temperature and relative humidity (°F and percent RH), one-time measurements of indoor unit airflow (cfm).
- Identify the most representative datapoint for each site:
    - Regress the measured EER vs outdoor air temperature for each steady state period; record the regression coefficients
    - Calculate the residuals for each data point (absolute value of difference between measured and regressed EER values)
    - Calculate the difference between the measured outdoor air temperature and the standard condition of 95°F (absolute value of difference between outdoor air temperature and 95°F)
    - Select a single measured datapoint for each site to represent the performance: the datapoint with the smallest residual and the smallest difference from 95°F (minimum sum of percent residual and percent difference).
    - This point is considered the most representative measured EER at off-standard conditions, which will be adjusted in the next step (the Red Circle in Figure 2 is an example for one unit).

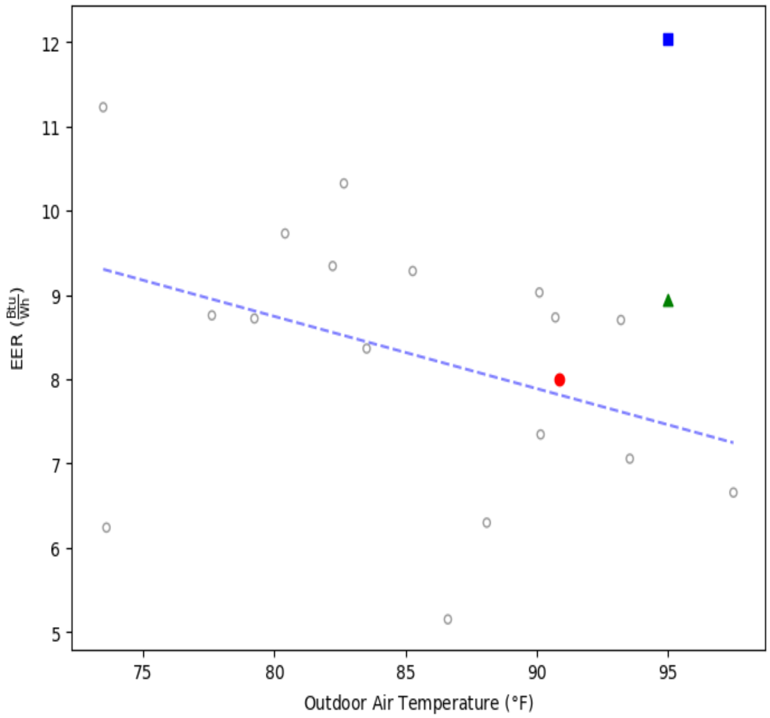


Figure 2: Example of Adjustments to Measured Data for One Unit

(Gray open circles are individual measurements (5-min steady state averages) and the Blue Line shows the trendline of all these points. The Red Circle is an individual measurement selected as the most representative because it is close to the line and close to 95°F. The Green Triangle is the adjusted EER (unit's estimated performance at AHRI conditions), and the Blue Square is the AHRI rating point).

- Adjust this measurement to estimate the EER at AHRI conditions:
  - Use DOE-AC routines[5] iteratively to find the EER of the degraded unit at AHRI conditions:
    - calculate the gross EER at the off-standard measured conditions (EER using the gross capacity, by adding the energy of the fan to the measured load removed),
    - input the off-standard measured conditions, and a "guess" of the EER at AHRI conditions,
    - observe the DOE-AC routines output estimate of EER at those off-standard conditions based on the guess of EER at AHRI conditions,
    - revise the input EER at AHRI conditions and re-run the DOE-AC algorithm,
    - repeat until the DOE-AC routines' output estimate of EER at those off-standard conditions match the measured gross EER,
    - the input EER at AHRI conditions that resulted in a match is an estimate of how that degraded unit would perform at AHRI conditions,

[5] DOE-AC routines developed by Hugh Henderson, which simulate the performance of an air conditioning unit using default functions from DOE2. It uses the rated size, EER and SHR at the AHRI point (95/80/67) to develop a map for all conditions.

- convert that back to net EER again by subtracting out the energy of the fan,
- this is the value that will be compared with the manufacturer's reported net EER at AHRI conditions to estimate the amount of performance degradation (it is shown as the Green Triangle in the example shown in Figure 2).

Estimating the percent degradation

To estimate the percent degradation for each site, Frontier Energy identified the rated net EER (at AHRI conditions) for each site by looking at manufacturers' cutsheets. Of all the data provided by manufacturers, Frontier Energy located the EER (or capacity and power) at AHRI rating conditions (95°F outdoor dry-bulb temperature, 67°F return wet-bulb temperature, and 80°F return dry-bulb temperature). In most cases, these ratings were specified for an airflow rate of 450 cfm per ton. Frontier Energy confirmed that each of the ratings was for *net efficiency* (power including only the compressor and condenser fan, and capacity not including the evaporator fan heat gain). When cutsheets were not available Frontier Energy utilized the Energy Commission's MAEDbS database[6]. (This value is shown in the Blue Square in the example shown in Figure 2).

For each site, the efficiency degradation was calculated as a percentage, using the following equation:

(Rated EER – Measured EER) / Rated EER

where Rated EER is from manufacturers' tables and Measured EER is at AHRI conditions—the result of the DOE-AC algorithm analysis.

Calculating the average annual degradation for all units

The desired metric for this analysis is the average percent efficiency degradation per year of system age (assumed to be the age of the condensing unit). This metric was calculated for each site and averaged across sites.

Findings

Table 13 shows the results of the measurement and analysis. It includes:

- SITE ID: includes location (Southern California and Northern California),
- AGE: age of Condensing Unit,
- CFM: measured or assumed airflow rate, and TONS: nominal unit size, in tons,

[6] Modernized Appliance Efficiency Database System, https://cacertappliances.energy.ca.gov/

- EER-NOW-MEAS: current net EER measured at observed conditions,
- EER-NOW-AHRI: current net EER at standard AHRI conditions (adjusted efficiency),
- EER-NEW-AHRI: rated net EER at standard AHRI conditions,
- DEGRAD%: percent efficiency degradation, and DEGRAD%/YR: percent degradation per year.

Table 13: Results of Measurements and Analysis

SITE ID	AGE	CFM	TONS	EER-NOW-MEAS	EER-NOW-AHRI	EER-NEW-AHRI	DEGRAD %	DEGRAD %/YR
SC-18	3	1500	5	7.7	7.4	12.9	43.1%	14.4%
SC-20	3	1200	4	8.6	7.1	13.0	45.3%	15.1%
NC-04	4	1220	3.5	10.1	10.8	12.0	10.20%	2.6%
SC-19	5	1500	5	9.6	10.1	13.0	22.4%	4.5%
SC-05	6	900	3	8.4	9.2	14.5	36.6%	6.1%
SC-22	6	900	3	6.3	6.6	10.7	37.7%	6.3%
SC-21	7	1200	4	8.8	9.8	10.3	5.3%	0.8%
SC-03	7	1500	5	8.3	9.5	11.0	13.4%	1.9%
SC-04	7	1200	4	11.0	10.7	12.4	13.5%	1.9%
NC-09	7	750	2.5	6.0	6.3	11.0	42.6%	6.1%
NC-07	8	1000	3	9.4	8.9	10.7	16.6%	2.1%
NC-01	10	715	2.5	7.4	8.0	10.4	22.7%	2.3%
SC-07	10	1500	5	3.0	3.2	11.0	71.1%	7.1%
NC-13	12	1140	4	5.6	5.3	13.0	59.5%	5.0%
SC-02	13	1963	5	9.5	9.7	10.5	7.3%	0.6%
NC-05	13	775	4	7.4	8.0	12.0	33.5%	2.6%
NC-08	15	1180	3.5	8.2	8.8	10.5	16.4%	1.1%
SC-09	16	1200	4	9.7	9.7	12.0	19.0%	1.2%
SC-12	16	900	3	8.5	8.0	10.8	26.4%	1.6%
SC-01	16	1008	3.5	5.1	5.9	8.7	32.5%	2.0%
SC-11	16	900	3	7.2	7.5	14.5	48.3%	3.0%
NC-02	20	560	2	8.7	9.0	12.0	25.7%	1.3%
NC-06	20	1100	3.5	4.5	4.9	9.1	46.6%	2.3%
SC-13	22	900	3	4.6	4.1	10.5	61.1%	2.8%
SC-10	26	900	3	8.1	8.0	12.0	33.6%	1.3%
NC-10	27	1360	3.5	8.8	8.7	8.8	0.8%	0.0%
SC-16	43	900	3	6.6	6.2	13.1	52.4%	1.2%
AVERAGE								**3.6%**
TOO NEW TO INCLUDE IN DEGRADATION RATE:								
SC-06	1	1200	4	11.33	12.11	12.5	3.1%	3.1%
NC-03	1	1450	3.5	10.77	11.63	12.5	6.9%	6.9%
SC-24	1	1500	5	11.15	10.72	12.5	14.2%	14.2%
SC-17	1	900	3	8.49	8.49	13.0	34.7%	34.7%
SC-08	1	1500	5	7.56	8.02	13.0	38.3%	38.3%
SC-23	1	1500	5	7.19	7.09	12.5	43.3%	43.3%
NC-12	2	1140	3.5	9.76	9.64	12.2	21.0%	10.5%
NEGATIVE DEGRADATION:								
SC-14	16	900	3	9.16	10.12	9.0	-12.4%	-0.8%
NC-11	17	1070	3	8.62	9.26	9.2	-0.7%	-0.04%

This table shows the percent degradation per year of age for all 36 sites with complete data. Only 27 were used in calculating the average percent degradation: seven sites were too new to calculate a meaningful degradation per year, and two sites had negative degradation (which is not a reasonable result). The average percent degradation per year of age for the remaining 27 sites was 3.6 percent per year.

Discussion

There are several issues that came up during the study:

- There is a potential for bias in the results, because most sites were current maintenance customers of the contractors, and therefore had presumably higher quality installation and more regular maintenance. This should tend to *under*estimate the average savings due to avoiding degradation.
- The project started later than it should have, and recruitment took longer than expected. Therefore, the project continued beyond the hottest part of the summer, and ultimately cooler weather limited the sample size Frontier Energy was able to obtain. Some sites were installed too late in the summer to obtain any significant cooling data.
- Frontier Energy was unable to identify the rated EER for some units. Altogether, adequate data were available for only 36 of the 40 sites.
- Many one-time evaporator airflow measurements were not reliable. Data were deemed unreliable at 17 sites, where Frontier Energy assumed an average value of 300 cfm/ton.
- For redundancy, Frontier Energy used two types of instruments for supply air temperature:
  - A highly accurate solid-state temperature/RH sensor (Vaisala) placed in the supply plenum (with a slower response, more accurate readings, located in only one location so potentially subject to error due to placement), and
  - Thermocouples placed in each take-off duct (with a faster response, allowing calculation of an area-weighted average that should be more indicative of overall temperatures, but with concerns due to potential for transposing reported duct diameters).

  The two were not well correlated, so Frontier Energy used the Vaisala in most cases, but in one case where the Vaisala temperatures were not reasonable, Frontier Energy used the thermocouples with an area-weighted average. At that site Frontier Energy also had to calculate the wet bulb temperature from an estimate of the supply relative humidity.
- Return wet-bulb temperatures in California homes are consistently below that included in EER ratings, a trend that was borne out by the measured data.

Nevertheless, Frontier Energy adjusted the measured EER to the AHRI conditions with their high wet bulb return temperature.

Conclusions

Average Annual Performance Degradation Rate

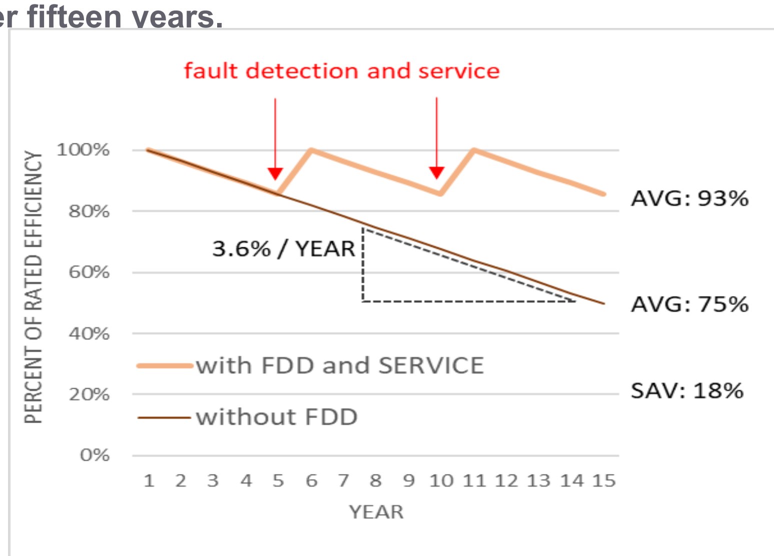
Through field testing of HVAC system performance in older systems in California homes, Frontier Energy was able to measure the tendency of older units to have degraded performance. The average percent degradation in system efficiency per year of age was found to be 3.6 percent per year.

Quantifying the Benefit of FDD

An FDD tool that can detect faults that are impacting efficiency by 15 percent should lead to a service call and performance upgrade whenever performance has degraded by 15 percent. The field study found that on average, HVAC performance degrades by about 3.6 percent per year. Table 14 shows the performance each year over fifteen years (considered as the lifetime of the measure), assuming 3.6 percent degradation per year (Column 2), and assuming 3.6 percent degradation but with FDD and service whenever performance goes below 85 percent (Column 3). This is also illustrated in the figure accompanying the table.

Table 14: Illustration of impact of FDD Fault Detection and Service on average percent of rated efficiency, over fifteen years.

YEAR	BASELINE	WITH FDD
1	100%	100%
2	96%	96%
3	93%	93%
4	89%	89%
5	86%	86%
6	82%	100%
7	78%	96%
8	75%	93%
9	71%	89%
10	68%	86%
11	64%	100%
12	60%	96%
13	57%	93%
14	53%	89%
15	50%	86%
AVG	75%	93%
	SAVINGS:	18%



Source: Statewide CASE Team Analysis

Note that the 3.6 percent annual degradation was the average observed in the field, and thus it already takes into account the prevalence of faults, the impacts of faults, and the probability of detecting and addressing faults *without* FDD—all of which should be taken into account when analyzing the impacts of FDD. It does not, however, take into account the probability that any identified faults will result in service and remediation. Frontier Energy assumed this probability to be only on the order of 50 percent for this analysis. (Note that this factor can be influenced by the design of the measure). Table 15 summarizes these factors and the analysis of the impacts of FDD.

Table 15: Probability Analysis of Impacts of FDD

(a)	Performance degradation rate per year	3.6%	*findings from field test*
(b)	Average performance over 15 years without fault detection	75%	*from Table 14, column 2*
(c)	Average performance over 15 years with fault detection and service	93%	*from Table 14, column 3*
(d)	Probability of service	50%	*assumption*
(e)	Average performance over 15 years with fault detection and assumed probability of service	84%	*b + d (c-b)*
(f)	Overall prevention of reduction in performance	9.0%	*e - b*

This analysis shows that the baseline for performance is 75 percent of rated efficiency (this is less than the 90 percent assumed when there is no verification). With FDD, this is increased to 84 percent. The expected impact of FDD in preventing a reduction in performance is 9.0 percent—well above the 6 percent value assumed in the research report's savings analysis for Ongoing Verification (as an alternative to Initial—refrigerant charge—Verification), and the 4 percent value assumed as the incremental impact above Initial Verification.

Another finding that was interesting—although not relevant to the FDD research report—was that even the units that were too new to be included in the annual degradation analysis had significant performance shortfalls. The seven units that were only one or two years old had an average EER shortfall of 23 percent. This suggests that FDD tools that can be used for initial performance verification—in addition to ongoing performance verification—would be quite valuable.

Appendix H: Lab Study to Inform Manufacturer Certification

Background

The Statewide CASE Team has developed a proposal to provide optional compliance credit for homes that install a residential HVAC Fault Detection and Diagnosis (FDD) system. The measure proposed by the Statewide CASE Team would require the following performance of an FDD system that receives credit through Title 24, Part 6:

- Fault Present (FP): The FDD system is capable of detecting that either the efficiency or the capacity of the HVAC system is reduced by more than 20 percent at a given operating condition, compared to the un-faulted value.
- Fault Not Present (FNP): The FDD system does not indicate a fault when both the efficiency and the capacity of the HVAC system are within 5 percent of the un-faulted value.

For their FDD system to be eligible for this credit, a manufacturer would have to certify that their device meets these performance criteria and provide sufficient evidence. As part of this evidence, it is expected that a manufacturer would conduct a study that demonstrates—using data collected either in a laboratory or field setting—that their FDD system meets these performance criteria. At a minimum, this study would be required to do the following:

- Demonstrate that the FDD system's performance meets the FP and FNP performance criteria in response to at least two of the following faults:
    - Low evaporator airflow or heat transfer
    - Low refrigerant charge
    - Liquid line restrictions
    - Non-condensable gas in the refrigerant
    - Low condenser airflow or heat transfer
    - Duct leakage.
- Simulate or field-verify faults.
- Collect, analyze, and present data.
- Conduct an uncertainty analysis—including analysis of issues such as sample size and significance—of the expected results.

As part of the preparation of that proposal, the Statewide CASE Team engaged the Western Cooling Efficiency Center (WCEC) of the University of California, Davis to conduct some trial laboratory testing to help guide the development of these requirements,

Lab Test Objectives

Laboratory testing was completed between October 2019 and February 2020 at the WCEC laboratory on a standard three-ton split system air conditioning unit equipped with an Emerson Sensi Predict FDD system. Through this testing the Statewide CASE Team obtained data to identify the ability of this device to detect faults of various types and magnitudes, to determine the performance degradation threshold at which this FDD device could reliably determine when service should be provided, and most importantly, to inform methodology that would be required for manufacturer certification.

Test Plan

Systems Tested and Conditions

Testing was conducted using a three-ton Goodman condenser unit (GSX140361, R410a) connected to Goodman single speed air handler air handler (ARUF37C14). The condenser unit shipped charged with refrigerant. The air handler came with a fixed orifice plate and that was converted to a thermostatic expansion valve (TXV) using a Goodman 2.5 to 3-ton thermostatic expansion valve kit.

Testing was performed in WCEC's Environmental Test Chambers. For all tests, the outdoor air condition was 95°F and the indoor air condition was 80°F/67°F (dry-bulb/wet-bulb), per AHRI 210/240 test specifications. All tests, except for low evaporator airflow, were conducted at the indoor fan speed that that delivered 1100 cfm. To represent a typical installation for the Goodman system, both the condenser unit and the air handler were installed in the outdoor air chamber.

To represent a typical split system installation with an attic-mounted air handler, both the condenser unit and the air handler were installed in the outdoor air chamber.

The FDD system was installed on the condenser unit and air handler based on the instructional videos on Emerson's website for installation technicians. The FDD system's ability to detect the following three faults was tested:

- Reduced evaporator airflow
- Liquid-line restriction
- Presence of non-condensables in the refrigerant lines

System Installation Procedures

The condensing unit and air handler were installed the outdoor chamber and connected using a 30-foot-long line set (3/8" liquid & 7/8" suction). A filter-dryer was factory7 installed in the liquid line. A needle valve was also installed in the liquid line between the condensing unit and the TXV to allow for fine adjustments to the degree of restriction of refrigerant flow.

The condenser unit was pre-charged with refrigerant. The lineset was purged with nitrogen, leak tested, and vacuum tested to 500 microns. Then while under vacuum the refrigerant charge in the condenser is released to fill the system. Frontier Energy then adjusted refrigerant charge and set the TXV per manufacturer specifications (for sub-cooling and superheat). The weight of refrigerant was measured along with extracted nitrogen added during the non-condensable fault testing, weighted, and calculated by subtracting the added non-condensables weight from the total.

The air handler was ducted to a nozzle box for precise airflow measurements. All sensors required for accurately measuring the parameters listed below were installed.

Measurements

In addition to monitoring test chamber conditions, the following measurements were made at 1-minute intervals or less: air handler airflow, indoor and outdoor unit power (measure independently), entering and leaving dry bulb and dew point temperature, and liquid line pressure at the condenser discharge and upstream of the TXV. Sensible and total capacity, power, and EER were calculated using the test instrumentation (LabVIEW) and plotted over the test period.

Test Procedure

All testing was completed at AHRI rating conditions. For each test, the system was operated for at least 30 minutes or until the EER varies by less than 1.5 percent over each subsequent 5-minute period, after which data were taken for at least 15 minutes and averaged. An initial test to establish performance at baseline conditions was completed. The faults were imposed and adjusted to determine one operating point where the impact of the given fault was clearly significant ("Fault Present" (FP), defined as a fault impact greater than 20 percent). and another operating point where the impact of the given fault was clearly not significant ("Fault Not Present" (FNP), defined as a fault impact less than 5 percent). The intent of the test is to confirm that an alarm is generated at the FP condition, and not at the FNP condition.

Step-by-step procedures used for each fault condition are as follows:

1. Establish the lowest fault intensity setting using the figure and table below for guidance.
2. Measure the EER and capacity and calculate the EER and capacity Fault Impacts.
3. Increase the Fault Intensity incrementally until a fault impact of 5 percent is

reached for either EER or capacity, noting the intensity at each increment and observing whether the FDD system detects a fault and how it is diagnosed.

4. If no fault has been detected, continue to increase the Fault Intensity until an impact of 20 percent (EER or capacity) has been detected and note the intensity level at which the FDD system reports a fault condition. If no fault is detected at 20 percent, intensity, continue testing until either the Fault Intensity reaches 30 percent or the FDD system reports a fault.
5. Record all observations and continue to the next fault type.

Details of Fault Introduction

In each case the baseline was the system as originally installed and commissioned with the airflow set at approximately 1200 cfm, correct refrigerant charge, and no added liquid line restriction. Faults were artificially introduced and adjusted to obtain the desired Fault Impact. After each test the system was returned to this baseline condition. The following procedures were used:

Low Airflow (LAF)

Incrementally reduce airflow by restricting either the return air or supply air ducts. Fault intensity is measured as (mass flow(baseline) – mass flow(faulted)/mass flow(baseline)).

Liquid Line Restriction (LLR)

Close needle valve by a small increment at each step while monitoring and recording the pressure differential. It may require several adjustments to determine valve settings that yield reasonably consistent settings over the desired range of differential pressures. The fault intensity is measured using $1 - \frac{P_{Liquid\ Line,Test} - P_{Suction\ Line,Test}}{P_{Liquid\ Line,Baseline} - P_{Suction\ Line,Baseline}}$.

Non-Condensables (NC)

Introduce incremental volumes of dry nitrogen by weighing the cylinder. It is not necessary to remove equal amounts of refrigerant since overcharging has a minor impact on EER and capacity. To avoid wasting contaminated refrigerant, this must be the last test completed. The fault intensity is the mass of $\frac{N_{2,injected}}{N_{2,NTP}}$, where $N_{2,NTP}$ is the weight of the nitrogen to fill the refrigeration circuit at standard conditions.

For Context

Figure 3 plots measured fault impacts as a function of fault intensity and is a compilation of numerous field and laboratory studies (Mehrabi and Yuill 2017). It provides general guidance for approximately where the 5 percent FNP and 20 percent FP conditions may be found, though results may vary by system type and test location.

Table 16 lists fault intensities and impacts from testing completed by Southern California Edison (Southern California Edison 2012). Negative values reflect performance below baseline. Values in parentheses were obtained using refrigerant side measurements (mass flow); all others are from air side measurements.

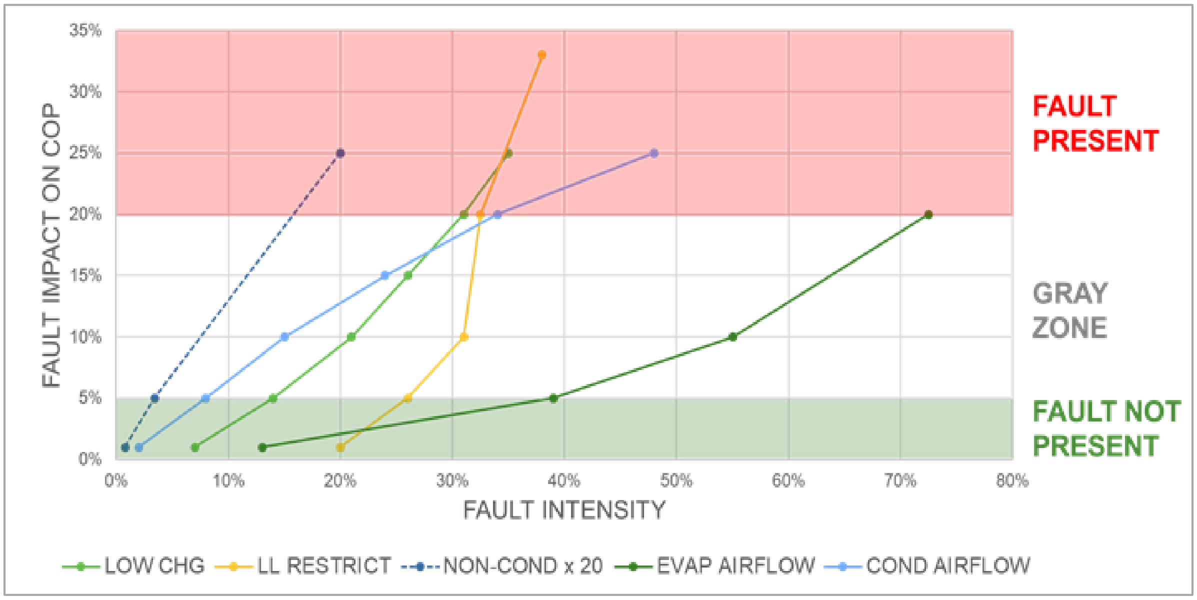


Figure 3: Fault impacts as a function of fault intensity

Table 16: Fault Results from Southern California Edison Lab Tests

Fault Type	Fault Intensity	Fault Impact EER	Fault Impact Capacity
Low Charge	-13%	-2%	-3%
Low Charge	-27%	-52%	-54%
Low Charge	-40%	-61%	-65%
Liquid Line Restriction	32 psi	1%	2%
Liquid Line Restriction	66 psi	2%	3%
Liquid Line Restriction	98 psi	-33%	-34%
Non-condensables	0.2 oz N_2	-1%	3%
Non-condensables	0.8 oz. N_2	-12%	-2%

Evap. Airflow Reduction	-33%	-3%	-13% (-9%)
Evap. Airflow Reduction	-49%	-7%	-5% (-15%)
Evap. Airflow Reduction	-57%	-10%	-10% (-20%)

Methodology

The HVAC system listed in the test plan was acquired and set up in the WCEC lab. Because the air handler ordered was for a heat pump it was necessary to replace the "flowrater" heat pump expansion valve with a typical thermostatic expansion valve. A needle valve was installed in the liquid line to simulate a liquid line restriction. Otherwise, refrigerant lines were installed, and the system was charged in accordance with the manufacturer's instructions.

The condensing unit was placed in a chamber that was maintained at 95°F (±0.4%). The air handler was installed in another chamber where the dry bulb temperature was maintained at 80°F (±0.5%). Air handler airflow was measured using calibrated nozzles and pitot tubes. Sensors were connected to a LabVIEW data acquisition system to enable the following measurements:

- Outdoor air dry bulb temperature
- Evaporator entering air dry bulb and wet bulb temperature
- Evaporator leaving dry bulb and wet bulb temperature
- Condenser entering and leaving air temperature
- Suction line temperature
- Liquid line temperature entering TXV
- Suction line pressure
- Liquid line pressure
- Liquid line differential pressure (across imposed restriction)
- Air handler fan power
- Condenser power
- Evaporator airflow

The FDD system was installed according to manufacturer's instructions. It includes the following sensors representing ten measurement points:

- Liquid line temperature
- Suction line temperature
- Return air wet and dry bulb temperature
- Supply air wet and dry bulb temperature
- Air hander and condenser volts and amps

The FDD system does not directly measure outdoor temperature but uses the system location entered at setup to obtain temperature data from a local weather station. In order to fix the outdoor temperature at the AHRI 210/240 rating point of 95°F Emerson provided a work-around using a dummy zip code.

For each set of tests, the system's performance (capacity and COP) were measured at an un-faulted condition, and then the fault intensity was gradually increased. The goal was to obtain at least one valid test at a FNP condition (defined in the test specification as having a fault impact on capacity or COP of less than 5 percent), and then to gradually increase the fault intensity until it reached a FP condition (defined in the test specification as having a fault impact on capacity or COP of more than 20 percent). Unfortunately, this test specification was vague about what was meant by "capacity or COP". The testers reasonably interpreted this as allowing either the capacity or the COP to be used as the limit. It was determined after testing, however, that the appropriate limits should have been:

- FNP is defined as a condition that results in an impact of ≤ 5 percent on BOTH capacity AND COP
- FP is defined as a condition that results in an impact of ≥ 20 percent on EITHER capacity OR COP.

This invalidated several of the tests but did help to refine the specified requirements in the proposed code language.

Results

Key outputs from the FDD system's web display are provided in Table 17. The tests included were low airflow (LAF), liquid line restriction (LLR), and noncondensables (NC).

Table 17: FDD System Outputs and Alarms

Test Name and Fault Impact Limit	FDD System Result	Temperature Split	Outdoor Unit Current	Approach Temp	Evaporator Airflow
LAF-Base	Pass (18hr)	-20.87F - Good	11.58Amps - Good	6F - Good	301.46CFM/Ton - Good

LAF-FNP	Pass(4min)	-19.69F - Good	12.06Amps - Good	-10F - Poor	304.8CFM/Ton - Good
LAF-FP	Caution - Approach Temperature, Temperature Split	-15.07F - Poor	13.09Amps - Good	-21F - Poor	299.74CFM/Ton - Low
LLR-Base	Pass (3min)	-20.69F - Good	11.01Amps - Good	10F - Good	308.48CFM/Ton - Good
LLR-FNP	Pass(3min)	-21.63F - Good	11.14Amps - Good	6F - Good	291.26CFM/Ton - Low
LLR-FP	Caution - Temperature Split	-26F - Poor	11.43Amps - Good	6F - Good	243.36CFM/Ton - Low
NC-Base	Pass (4min)	-20.88F - Good	12.48Amps - Good	5F - Good	301.64CFM/Ton - Good
NC-FNP	Caution - Capacity, Outdoor Current (3min)	-19.87F - Good	19.07Amps - Bad	2F - Good	294.6CFM/Ton - Low
NC-FP	Caution - Capacity, Outdoor Current (10min)	-19.69F - Good	25.15Amps - Bad	2F - Good	290.52CFM/Ton - Low

The evaporator airflows reported by the FDD system are all below the 400 cfm per ton used in testing (except for the airflow reduction tests). It is not known how the FDD system determines airflow. Though the reported values are lower than the test airflows, they do correlate to faulted conditions. Except for the faulted cases, the temperature splits are within 1.7°F or less of the 19.9°F temperature split from temperature split tables for 95°F outdoor, 80°F indoor dry bulb and 67°F indoor wet bulb. Temperature split and compressor amps appear to be good fault indicators for any FDD device. It is not known how "approach temperature" is measured, but as in the 4 percent evaporator airflow reduction test, it could trigger unnecessary service calls.

Table 18 compares the fault impact measured by laboratory equipment to the FDD diagnosis.

Table 18: Comparison of Measured Fault Impact and FDD Diagnosis

Induced Fault	Test	Fault Intensity	Capacity Impact	COP Impact	Lab Diagnosis	FDD Diagnosis	Valid?	Pass?
Airflow Reduction	LAF - Base	Baseline	0.0%	0.0%			N/A	N/A

	LAF - FNP	3% reduction	3.2%	3.6%	FNP	FNP	☑	☑
	LAF -FP	29% reduction	20.1%	17.7 %	FP	FP	☑	☑
Liquid Line Restricti on	LLR - Bas e	Baseline	0.0%	0.0%			N/A	N/A
	LLR - FNP	40% restriction	4.8%	7.9%	FNP	FNP	☐	
	LLR -FP	56% restriction	21.9%	28.6 %	FP	FP	☑	☑
Non-Condens -ables	NC-Bas e	Baseline	0.0%	0.0%			N/A	N/A
	NC-FNP	1.2% non-condensabl es	5.3%	37.3 %	FP	FP	☐	
	NC-FP	1.6% non-condensabl es	n/a	n/a	FP	FP	☑	☑

Note that for the NC-FNP and NC-FP tests, the compressor tripped off on high pressure before these tests were completed. The ambiguous test specifications and challenges in testing resulted in three of the six tests being invalid, although the FDD system passed all the valid tests (and, in fact, all the invalid tests as well).

Lessons Learned from Laboratory Testing

While the technical results of the effectiveness of this FDD system at detecting faults is interesting and important, one of the primary objectives of the lab testing was to gain intelligence about some of the challenges and opportunities in doing a reliable and authoritative test of the performance of an FDD system. These lessons learned help to guide the mechanism that is proposed to require of manufacturers attempting to certify their FDD systems as eligible for the proposed Residential HVAC FDD compliance option.

The Lessons Learned were documented in three ways: in an interview with the lab managers and technicians involved with the testing, in a report submitted by the testing team, and in a discussion of the costs, time, and personnel required. These are described below, followed by a summary of the lessons learned.

Interview with Lab Managers and Technicians

The lab managers and technicians were interviewed to determine whether they felt the testing had the following characteristics:

- Accuracy: Test results seemed to be accurate and generally came up with a reliable answer.
- Feasibility: Tests took a lot of time and were expensive. Researching the procedure took more time than doing it. For example, coming up with how to measure the original refrigerant charge, adjusting the TXV, and doing the non-condensables test. More detailed specifications would have reduced this cost. Could do sensitivity testing less expensively on a bench top. Might be done in a less-controlled environment like the field.
- Repeatability: Airflow and liquid-line restriction testing seemed repeatable, but the non-condensables tests did not. With changes to the test procedures, the non-condensable tests would have been more repeatable.
- Resistance to cheating: A specified test report format would help but there is nothing to PROVE that the reported results are accurate (a concern if not done by a neutral third-party).
- Necessity: If they're getting compliance credit, they should have to do it.
- Plausibility: The method of imposing the fault appeared to be simulating the actual fault. For the airflow tests, the restriction was put on the input side to replicate clogged filter. For refrigerant flow, Frontier Energy believe that where the restriction was placed (especially in relation to the TXV) would have affected the results.
- Adequacy of specification: A more detailed test plan specification would have reduced time and provided more valid results. For example, if it had required taking reports at every adjustment, the non-condensables test would have given better results.

Lessons Learned Report from Test Team

HVAC System Setup

8.1.1.1.1 Instrumentation and Sealing

Testing the three faults required several refrigerant pressure sensors to be installed on the circuit. T-valves were installed so the testing team could access to the line-set Schrader valve ports during the testing process. During initial charging, the technician could not maintain a proper vacuum and it took an extra day to find and fix all the leaks. All the threaded connections proved to be harder to seal and more finicky than the brazed ones. Care must be taken when attaching new equipment to threaded connections as it has potential to loosen one of the connections and introduce a new leak. For future work, it would be recommended to add additional Schrader ports to the line-set through braised components.

8.1.1.1.2 Accurate Refrigerant Charge

The technician who charged the split system was unable to determine the correct refrigerant charge because the testing team could not provide the manufacturer's rated load. The outdoor chamber configuration had not yet been completed (so that the technician would have adequate space to do the complicated line-set brazing and commissioning). This meant the test team had to adjust the charge themselves, requiring knowledge of how to use a technician's refrigerant tools to how to add and /or recover refrigerant correctly. Additionally, the testing team determined that the TXV valve was not shipped in the correct position for the split system, and additional adjustment were required to get the recommended super-heat and sub-cooling.

FDD System Setup

8.1.1.1.3 Internet Connection

The FDD system requires a wireless internet connection to connect to the cloud. It can be challenging to provide an appropriate wireless signal because of site specific IT procedures and laboratory materials that can attenuate the signal.

8.1.1.1.4 Local Outside Air Temperature Reading

At the beginning of testing, it was determined that the FDD system references a local weather station in lieu of an outdoor air temperature measurement. Although Frontier Energy was testing at a constant temperature of 95°F, the FDD system thought it was 55°F. This was fixed by asking the manufacture to set up a special set of zip codes (99900 – 99999) so the last two digits would represent the desired outdoor air temperature. For the remaining tests, the zip code 99995 was used.

Imposing Faults

8.1.1.1.5 Interpreting Specification for Target Capacity "or" Efficiency

The original test plan required that the Fault Present and Fault Not Present tests be done at conditions where **efficiency or capacity** were impacted by more than 20 percent, or less than 5 percent, respectively. It turned out that that highlighted phrase was ambiguous. The test team interpreted that it was their choice, and they selected to target capacity reductions. The Statewide CASE Team realized the ambiguity of their specification, and clarified it to mean:

- Fault Present: If EITHER capacity OR efficiency are reduced >20 percent, it should generate an alarm

- Fault Not Present: If BOTH capacity AND efficiency are reduced <5 percent, it should NOT generate an alarm

8.1.1.1.6 Fine-Tuning Fault Intensity

It is difficult to fine-tune the fault intensity to obtain the desired fault impact. Airflow restriction was significantly easier than the other tests. The other two tests were “like driving a bit blind”. The transient nature of the TXV with the refrigerant flow restrictions and time needed to settle into a steady state takes time. It got faster as the researchers learned the positions of the needle valve and how much effect changes tend to have.

The noncondensable testing would need much more discrete details as to how it should be done as the team attempted to measure in tiny amounts of nitrogen, but in retrospect should have used even smaller increments. The approach taken was to implement the fault, and then run the system and see if the fault is in the right neighborhood. If it looks like a valid datapoint, then let the system sit for a while and measure the fault impact accurately. This would be expensive to do if you had to go up in tiny increments. It is more efficient if it can be done by trial-and-error, which adds uncertainty to the estimation of testing time. Also, it is problematic to specify taking a measurement at the “last point before reaching a 5 percent fault impact”. This is particularly problematic for faults, such as non-condensables, that are effectively irreversible, and one cannot simply lessen the fault slightly to get the desired condition. Another thing that makes accurately imposing accurate fault levels difficult is that there are few available data on what levels become problematic, making it difficult to fine tune the test.

In order to practically meet the test specification, Frontier Energy attempted to take one measurement where the fault intensity was “close to but below” 5 percent, and another that was “close to but above” 20 percent. This leaves it ambiguous as to whether, for example, a test with a fault impact of 1 percent is a valid FNP test, or whether a fault impact of 50 percent is a valid FP test. For a commercial lab test, a tighter specification would be needed.

8.1.1.1.7 Different Conditions Impact COP and Capacity Very Differently

Testing for the three faults showed that the impact on power and capacity changed at different rates. For example, during the non-condensable Fault Not Present testing, the condenser unit shut off because the high-pressure limit switch was tripped. Immediately prior to shutting off, the split-system’s capacity was reduced by 11 percent, while the COP was already reduced by 54 percent. Since it is not feasible to remove non-condensables (“go backwards”), this led to an unusable test point. During future testing, it would be important to measure capacity and efficiency impacts and record FDD system outputs at each small increment—particularly for testing non-condensables.

8.1.1.1.8 Challenges of Adding Non-Condensables

In retrospect, the targets set for addition of non-condensables were too high to develop a good relationship between fault intensity and fault impact. At 1.6 percent (2.12 oz. of N_2) the compressor tripped off on high head pressure. N_2 was added incrementally while the system was running, and data showed that at 0.1 oz. (0.1 percent) the capacity and COP impact were under 5 percent. Tests by Southern California Edison showed a 2 percent decrease in capacity and a 12 percent decrease in EER following the addition of 0.8 oz. N_2 (0.6 percent). Subcooling rose from 13°F to 42°F with the addition of 1.2 percent N_2, so devices that measure liquid line temperature may be capable of detecting this fault.

It was challenging to find a gas cylinder and scale that would allow such small masses to be accurately measured. When adding gas to the pressurized system, it must be at a higher pressure, but not so high it is hard to control. The team ended up using a pair of refrigerant gauges and a regulator to down-regulate. For their testing, Frontier Energy used a cylinder that weighed 14 lbs., 10.32 oz., a pressure regulator set at 150 PSI, and a refrigerant manifold/meter to add the nitrogen to the split-system. The refrigerant manifold/meter was used to slowly add nitrogen in fractions of an ounce increments. For future testing, another more expensive way to accomplish this would be through use of a mass flow controller or measurement which would also need to be rated for such pressures. Frontier Energy also recommend using larger tanks and/or more accurate scales. The tank was connected through tubes to the valves leading to the AC refrigerant system, and if the tank was bumped even slightly it affected the scale measurement. A hands-free valve operation would reduce this difficulty.

8.1.1.1.9 Non Condensables Line Purging

Based on the method of adding non-condensable gas, a procedure must be made to purge the lines of the refrigerant manifold/meter so that only known amounts of nitrogen could be accurately added into the system. This challenge took a bit of research and time to figure out the appropriate sequence of operations.

Testing Operation

8.1.1.1.10 Challenges and Time Requirement for Maintaining a Steady State Condition as Equipment Capacity Changes

Each tested fault had a negative impact on the cooling capacity of the evaporator. These changes had a secondary impact on the control systems for both environmental chambers. Because of that, extra time was needed after each change to confirm that the desired test point had been reached and that performance remained steady. It was determined that it took 5-10 minutes to see if the change reached the test point and another 30 to ensure the system had reached a steady state. 30 minutes should have been sufficient to meet all specified test control requirements and result in a constant

Capacity and COP for most cases. However, it took significantly longer than 30 minutes for a few cases. Additionally, it is possible that after the 30 minutes, the split-system would settle outside the desired range for the test point, requiring restarting of the entire process.

8.1.1.1.11 Humidity Control as a Coil Transitions from Wet to Dry

The control system for the indoor air chamber expected the split-system's evaporator to dehumidify the circulating air. During the reduced evaporator airflow tests, it was determined that the transition between a wet and a dry evaporator coil happened more quickly than the control system could account for, and the wet-bulb temperature increased slightly. This should not impact performance of the coil, as the primary change was the air density. In some cases, the test team could wait this impact out if the absolute humidity of the ambient air was lower than the 80°F/67°F test condition. In the future this situation could be avoided through improved control design or through additional dehumidification capabilities in the test chamber design.

After Testing

8.1.1.1.12 Accurate Refrigerant Recovery

To get an accurate measurement of the of the refrigerant charge, special care must be taken to properly recover the refrigerant. It is recommended that whoever preforms the recovery takes the extra time necessary to recover refrigerant and purge the recovery pump to get the maximum amount of recovered refrigerant into the recovery tank. This can never be perfect, using typical refrigerant recovery methodology and tools, as the hose between the recovery pump and tank will have a small amount of refrigerant. This could be improved if a valve were added to the line and the original tare weight was measured.

8.1.1.1.13 Refrigerant Void Measurement

To quantify the fault intensity of the non-condensable testing, the volume of nitrogen that would fit in the refrigerant circuit under normal temperature and pressure conditions (1atm, 20°C) is required to be known. To measure the volume of the refrigerant void, the nitrogen must be measured accurately as it flows into the void under a vacuum. It takes special care to purge properly while maintaining the vacuum in the refrigerant system. It took the test team three times to get this right. After the successful attempt, the temperature and pressure of the nitrogen were measured and used to calculate the volume under normal temperature and pressure conditions.

8.1.1.1.14 Accessing Test Results

There was no easy way to download the FDD system's performance report. Accessing it required logging into a portal, viewing a report, and then capturing the screen display into a PDF document. Exporting data from this PDF into a machine-readable format turned out to be difficult, since there was a problem with the fonts.

Cost, Time and Personnel Required

Frontier Energy did not closely track costs specific to the testing or time required for each task, but the sections below identify the areas in which expenses were incurred and time and personnel were used. It should be kept in mind that this was a research test, and most testing conducted by manufacturers could be less expensive. On the other hand, the laboratory chambers and instruments and infrastructure were already in place, and if a manufacturer did not have this infrastructure it might be more expensive.

Cost

This lab already had most of the materials and instruments required. The following additional items had to be purchased:

- HVAC system and TXV kit
- HVAC technician to install system and adjust charge
- Electrician to connect FDD transformer to HVAC unit's power supply (240 and 120 V)
- Nitrogen tanks and regulators
- Needle-valves for LLR tests
- Several T's for providing measurement access to refrigerant pressure.

Time

- Acquire HVAC system and FDD system: weeks
- Install and commission HVAC system, instrumentation, and data collection controls: 2 weeks
- Install and setup mechanisms to impose faults: weeks
- Install FDD system: less than half a day
- Getting FDD system up and running (including weather adaptation): weeks
- Running through tests: time to get to steady state each day, then an unknown number of tests to get to the appropriate Fault Impact level. Overall, this required about 1.5-2 hours per test, total of about a half day for each of the three faults
- Reporting: a day.

Personnel

- Engineering manager to oversee testing.
- Several engineers and technicians to install systems, instruments, and mechanisms to impose faults.

- One lab technician for most testing.
- Electrician to connect FDD transformer to HVAC unit's supply power
- HVAC technician to install system and adjust charge.

Summary of Laboratory Testing

On the whole, the lab tests were ultimately fairly successful. The testing for liquid line restrictions and low airflow were felt to be accurate and repeatable, and to accurately simulate actual faults. For several reasons, the testing of non-condensables were not successful. Because of ambiguity in the test specifications, three of the six tests were not valid. Some detailed conclusions are:

- FDD tools are designed to be implemented in the field and may be difficult to implement in a lab setting. For example, this FDD system was designed to provide results in a format useful for the service contractor, making the process for accessing data from FDD during testing difficult. Also, this FDD system accessed weather data from an online-weather service in lieu of using outdoor air sensors. Since all testing was done at a standard (and constant) AHRI test condition, there was not a ready source of this measurement. It took a significant amount of time to find a work-around for this problem. This FDD system was designed to communicate with the cloud using Wi-Fi. Accessing a Wi-Fi signal from within the chamber was problematic, as was navigating the university's security restrictions.
- Fine-tuning fault intensity in order to dial-in the targeted fault impact was very challenging. Fault intensity is a measured *output* of the test rather than a test setting *input* to the test. The relationship between the fault intensity and the fault impact will vary by manufacturer, technology and even unit size. Without knowing this relationship ahead of time, doing a test at a given fault impact requires either a trial-and-error approach—which is problematic for faults such as non-condensables that are effectively irreversible—or a stepwise approach to increase the fault intensity in tiny increments—which is problematic because of the large and unpredictable number of tests that would be required. For a commercial lab test, a tighter specification would be needed.
- Installing and charging the HVAC system, installing and configuring the FDD system, determining and implementing the method for precisely imposing the fault, instrumenting the system and programming the data collection controls all required considerable effort. Since this is a very specialized kind of test, the personnel had to figure out how to do many tasks, which took more time. The testing might be streamlined if very detailed instructions were provided, but this would limit adaptability.

- Controlling the system effectively and efficiently as the conditions were changed from one test to another was difficult and not as straight forward as expected.
- Overall, testing of non-condensables was very challenging. Determining how to precisely inject a controlled amount of nitrogen took considerable ingenuity and iteration, requiring changes in the test apparatus. Since little data are available on the performance of systems with this fault, it was difficult to predict how the system would respond. As it turned out, the impacts on the system's performance appeared more quickly than expected, and before Fault Present and Fault Not Present conditions were observed and recorded, the system suddenly shut down on a safety. Because it would be prohibitively difficult to remove a controlled amount of nitrogen, there was no going back. It is unrealistic to expect that labs across the country will be able to do successful and repeatable tests without very detailed instruction on how to gradually approach the target conditions.
- The test plan provided to the university lab was intentionally loosely specified, to allow them to determine the best way for them to implement the tests. This is also in line with the attempt to allow FDD manufacturers to define for themselves the most appropriate way to do the testing. It was concluded, however, that if the tests were better specified, they would be easier and less expensive to accomplish, and the results would be more repeatable. The down-side to more tightly specified testing is that it is quite challenging to develop generalized test specifications that are appropriate to all types of HVAC system or FDD system.
- The testing that was done may not be reasonable to expect of FDD manufacturers. The time and cost required were considerable. It took several months from start to finish. This was not full time as it would be in a commercial lab, but it still required many hours. Lab time in a commercial laboratory is expensive, and even in a dedicated lab, this testing would tie up the resources for a considerable amount of time.
- Based on results from lab tests and fault indications from the FDD system, temperature split, condensing unit current or power, and subcooling are affected by the imposed faults and both should be required measurements for any FDD devices to be certified for compliance credits under Title 24, Part 6. The FDD system did not report subcooling, but this can be estimated using the measured liquid line temperature and refrigerant tables and is normally 10-15°F. Given the magnitude of the fault impacts, reasonable limits that would justify a "truck roll" would be a temperature split that varies more than 5°F from initial readings, a 15 percent or greater deviation from nameplate current, and more than 30°F of subcooling.

Conclusions

Based on the results of this laboratory testing, the Statewide CASE Team does not believe that it is reasonable to specify a specific laboratory test for manufactures to use in providing evidence that their FDD systems meet eligibility criteria. Nor is it feasible to expect manufacturers to specify their own test and maintain consistency across manufacturers. It may be possible that a suitable test plan that is based on measurements taken in the field or using statistical methods to evaluate data collected in prior lab testing could be more feasible. The Statewide CASE Team recommends that future work should go into the most reliable and feasible ways to ensure that only FDD tools that provide the required benefits are given credit for Title 24, Part 6. Significant engagement with FDD manufacturers would be essential in such a development.

Appendix I: Unresolved Issues

This measure was considered for the 2022 code cycle because of the potential to ensure the persistence of performance of HVAC systems over time and ongoing verification of HVAC performance is a critical part of realizing energy savings in the State of California. After initial research, including interviews with stakeholders, the Statewide CASE Team discontinued pursuing this code change proposal because of the uncertainty that identified faults would be remedied, the difficulty in establishing specifications for manufacturer FDD certification processes, and the potential for burdensome HERS verification requirements. The emerging innovative tools that show promise to achieve the desired performance improvements function in widely diverging ways and accommodating variety in how different products function requires developing innovative verification procedures for both the manufacturer and the field installer / verifier. Given the limited resources available in this code cycle, this significant development effort does not have as high a priority as other measures.

The Statewide CASE Team is interested in gathering additional input on appropriate and effective verification methods. To support ongoing research and future code cycle consideration, additional information on residential HVAC FDD is welcome. In the course of reviewing the research report, a number of comments were made, addressing a number of overarching issues. This Appendix categorizes the comments, provides a response to the overarching issues, provides a few responses to specific comments, then then proposes a general response. If and when this measure is reconsidered at a future date, this section should help to guide follow-on development efforts.

In each section below, a list of the individual comments in that general category is listed (bullets in italics), and then discussion of the general issue and some specific responses is provided. Then (in bold) general responses are suggested. These proposed general responses are repeated again at the end of this section.

Does the Proposed Measure Guarantee Savings Will Occur?

- *Verification is provided 96% of its rated efficiency because in theory any issues with the refrigerant charge have been addressed. If FDD is installed it may identify an error but does not guarantee that this error was addressed before occupancy of the building. (p. 6)*
- *Fault monitoring may not actually ensure or guarantee energy savings over time. Action needs to be taken for the fix to realize savings (that usually come with service cost). Elaborate/add language. (p. 6)*
- *Initial verification will ensure that the equipment is working at the start. FDD may identify a problem, but there is no way to compel a homeowner to ensure that the problem is addressed. While the service provider will also be notified will there be an issue if the homeowner does not buy into the process? (p. 6)*
- *If the occupant is notified but they do not own the building than they might not be allowed to*

authorize any fixes to the system. Would the owner also need to be notified if the owner is not the occupant? (p. 9)

- *Homeowners may not add in a service provider at a later date. What is the process for programming in contacts into the system? Is it relatively simple? (p. 9)*
- *Is there confidence that the next homeowner 5-10 years down the road will utilize the system? (p. 12)*
- *What is an example of potential problems? Will homeowners ignore this if they feel cold / hot air and not call a technician if they feel it works fine? (p. 12)*
- *I see this notification component as a big piece to FDD measure. This is only done one time at the point of installation. Any way to ensure this notification is in place in the future? (p. 16)*

Ensuring that not only is a fault generated reliably, but that someone takes action to fix the fault is the biggest challenge for this measure, as has been accurately identified. This can be made more reliable with the following elements:

- Ensure that information is provided for owner on what to do if an alarm is generated and how to figure out who to call. This should include encouragement to enter into a service contract and information on why/how to do so.
- Part of this is also making sure that when an alarm is responded to by a homeowner, it has sufficient *urgency* to compel them to do something.
- Ensure that the performance degradation is *worth* responding to…this is why 20 percent was selected (changing it to 15 percent): something all agree is worth sending out a truck for.
- Ensure they don't get nuisance alarms: if they sometimes get alerts at levels < 5 percent, they will definitely be nuisance alarms, and they will learn not to respond to alarms (even when they are larger).

1.	Add more detail to the current requirement about what information must be left behind: It may describe the benefits of having some sort of service contract, and might possibly describe how to go about finding one, but it will not under any circumstances suggest an individual or provide any contact information. ("you have an XYZ FDD system installed, in order to make best use of it you are encouraged to identify a contractor to monitor alarms. You can find a suitable contractor by…")
2.	Require that when an alarm is presented to an occupant, it conveys a sense of urgency. Or include instructions that explain the urgency.

Should the Owner or Service Provider be Notified?

- *I think this, whether owner or service provider, will be quite significant on how effective FDD is over. Probably should not be considered equivalent. (p. 6)*
- *Initial verification will ensure that the equipment is working at the start. FDD may identify a problem, but there is no way to compel a homeowner to ensure that the problem is addressed. While the service provider will also be notified will there be an issue if the homeowner does not buy into the process? (p. 6)*

- *If the occupant is notified but they do not own the building than they might not be allowed to authorize any fixes to the system. Would the owner also need to be notified if the owner is not the occupant? (p. 9)*
- *Is this an "either, or" option or do both need to be notified? [notify occupant or service provider] There is no way to require that additional action is taken to address the faults. (p. 9)*
- *Homeowners may not add in a service provider at a later date. What is the process for programming in contacts into the system? Is it relatively simple? (p. 9)*
- *So this will rely on a service agreement? (p. 12)*
- *Why wouldn't this be required? [configured to alert the homeowner and service provider (if applicable)"] Or is it required to alert home owner, but the service provider is only if applicable? (p. 19)*
- *Does this [mechanism for alerting homeowner and service contractor] need to be standardized or have some type of minimum so that the HERS rater can easily verify this? (p. 20)*
- *Can we eliminate this? [currently A. Annunciated locally, or B. To home automation system or other app that notified occupant and service provider. Suggesting removing B] I'd much prefer in-house indicator as minimum required. I feel it's much more reliable method than to depend only on a software app or cloud based system. (p. 39)*

Disadvantages to alert going to homeowner:

- If alerts are only provided to homeowners, they may have some interest in following up on alerts, but this will require a lot of education about what alerts mean and the impact on costs, and what to do when an alert is generated (who to call).
- It is difficult to imagine any way we can require notifying the owner (vs. occupant).

Disadvantages to alert going to service contractor:

- There are two types of contracts that could be envisioned (without getting in the middle of how these are structured). Follow-up calls can be:
  a) billed as normal service calls, or
  b) covered in the cost of the contract.

  In case a, the contractor would have an incentive to follow up on all alerts, and in case b, the contractor would not. In case a, we can rely on contractors to help facilitate this market and make sure that customers install the measure and sign up for the follow-up service. In case b, contractors will be a lot more risk averse and concerned about nuisance calls.
- It cannot be required that the owner stay on a contract or that the next owner is on a contract. In that case, if they DON'T have an indicator in-home, all benefit will be lost.
- Relying on the service contractor means relying on internet connections, etc. (without getting in the business of specifying how the product communicates to the service provider, which would overly constrain the market.)

- A contract can’t be required, especially in those cases where the new homeowner is not known.

What is currently proposed is the best compromise: allow either alerting the homeowner or a service contractor but attempt to improve probability of a response in either case (see comments on previous question). After discussion, there was general agreement that notifications should be annunciated via a local display (possibly the thermostat, but not via a cloud connection), and to *optionally* make the alarm available to third parties (service contractor, owner, other…).

3.	Modify language to require that notification of any alarms shall be—at a minimum—annunciated to the home’s occupant via a display (possibly the thermostat, but not via a cloud connection; review FID language for potential applicability), and optionally also made available to third parties (service contractor, owner, others…).
4.	Provide requirements for where device interface is to be located in the body of the Research report, not just in the proposed code language section.
5.	Clarify that the occupant, not the owner, must be notified.
6.	There is a general concern about relying on cloud connections, although this will be required for many tools. Perhaps over time this concern will be resolved as internet connectivity becomes more reliable.

How will Products be Certified?

- *What is the certification process? (p. 6)*

Many manufacturers already have data to demonstrate effectiveness, but they don’t do it all in the same way. Defining a standardized test is quite difficult and fraught with controversy. An approach similar to that taken for ENERGY STAR smart thermostats is proposed. The proposed approach is that the Energy Commission would approve any reasonable studies that demonstrate the tool meets performance criteria (alarms >15% fault, does not alarm <5% fault). The Energy Commission will approve the *methodology* for the study before the study is conducted, to avoid manufacturers conducting a study only to be told that their approach wasn’t adequate.

In preparation for the following cycle, the Energy Commission can review the current cycle’s studies, and ultimately develop a method that is suitable for the most manufacturers (lab or field?) … in time for manufacturers to conduct a (potentially 12 month) study before the effective date of the following cycle.

7.	Provide criteria to objectively assess whether or not a manufacturer’s proposal or study is “good enough.” This might include something like requiring a level of significance or confidence.

Is the HERS Verification Process Unduly Burdensome?

- *This will be an additional load on raters. (p. 6)*
- *Can a HERS rater be expected to verify that the system is installed correctly? Are components, sensors and such, readily accessible by the HERS rater? Will HERS rater be able to test fault detection? (p. 6)*
- *This seems like it could be a large test for HERS verification. I'm assuming these systems have sensors, wiring, hardware, and software and the rater is expected to check all the wiring diagram, sensor locations, settings, etc. (p. 9)*
- *This may not be sufficient enough to determine the system will detect faults that occur over time. [HERS rater verify configured correctly] I think comprehensive testing will need to be done to make sure the FDD is working properly. (p. 12)*
- *In this case [Initial + Ongoing] if the FDD also meets the requirements of the FID does this mean that only the installer will verify the charge and that the HERS rater will verify the FID/FDD? (p. 16)*
- *Will a larger list [up to five CFAPS] be identified in code and the manufacturer chooses from this list? Or will this be completely left up to the manufacturer to determine CFAPs? (p. 16)*
- *Can a HERS rater perform test to see if faults are detected? How would one know FDD is working? Do these systems need calibration? (p. 19)*
- *Does this [mechanism for alerting homeowner and service contractor] need to be standardized or have some type of minimum so that the HERS rater can easily verify this? (p. 20)*
- *How will system configuration information be related to the HERS rater? Will this be via CF2R? (p. 20)*
- *Does there need to be some type of restriction on this? [at least 2 CFAPs] It seems that this description allows a large range of values to be a CFAP. (p. 39)*
- *Does the HERS rater need to do anything regarding the test specifications? [new language for RA3.4.4.3 HERS verification requirements] (p. 41)*

It is expected that the HERS rater will simply look for evidence that an appropriate system is installed and verify up to five CFAPs. The manufacturer must provide instruction on how to verify the CFAPS. Note these CFAPs might be things like the zip code of the installation, the unit size, an email address for who to notify…

Response to specific comments:

- Thus, the verification will not be burdensome.
- It will not be possible to confirm that the system is detecting faults, but the manufacturer certification ensures that the system is *capable* of detecting the faults.
- Asking HERS Raters to verify that it is actually detecting faults is burdensome, particularly since different FDD systems provide alerts in different ways.
- One cannot know ahead of time what the critical parameters are for each FDD system…the manufacturer will have to determine that themselves and define it in their submission.
- The current proposal includes some specifications for things like how homeowner is alerted. That can be easily verified by the HERS rater. Configuring it to notify a

service contractor is more difficult and will vary by model.

8.	Provide some language to clarify that the CFAPs shall be “simple” to verify (note that this can’t be policed by the Energy Commission…perhaps the market will favor systems that are easy to verify).
9.	Add language saying that the manufacturer shall make information on how to verify the CFAPs readily available to installers and HERS raters (perhaps encouraging manufacturers to develop a report that is generated upon completion of installation that summarizes the values of the CFAPS, and HERS raters would only have to verify that it was shown to them)
10.	Provide better definition of what a CFAP is (it shall be a parameter that is critical to proper operation of the FDD system, and shall adequately demonstrate that the system was configured)
11.	Remove the language saying that the manufacturer will provide to the Energy Commission instructions on how to verify the CFAPs.
12.	Make sure wording is clear that there are up to five CFAPs.
13.	Remove wording suggesting that HERS Rater will verify that it’s installed correctly.
14.	Require that manufacturer shall provide some mechanism to verify that the display is connected, through a test mode or something similar.
15.	Require that at least one CFAP shall be related to ensuring that this communication is configured, when communication with service provider is used.
16.	Engage with HERS community to assess whether or not the verification requirements are appropriate.

Isn’t this Equivalent to Refrigerant Charge Verification or Fault Indicator Display Requirements?

- *How is equivalency determined for allowing FDD to be an option to RCV? (p. 6)*
- *Verification is provided 96% of its rated efficiency because in theory any issues with the refrigerant charge have been addressed. If FDD is installed it may identify an error but does not guarantee that this error was addressed before occupancy of the building. (p. 6)*
- *How was this determined? [100% if both Initial and ongoing verification] (p. 6)*
- *How will FDD credit work for packaged air conditioners if they’re aren’t penalized for not performing refrigerant charge verification? (p. 12)*
- *Do you know if the existing FDD systems can meet this? Just curious to know if there was any comparison of FDD abilities with FID requirements. (p. 13)*
- *In this case [Initial + Ongoing] if the FDD also meets the requirements of the FID does this mean that only the installer will verify the charge and that the HERS rater will verify the FID/FDD? (p. 16)*
- *I don’t see how this is equivalent to a refrigerant charge verification. Is there data to show some sort of comparison? % of RCV homes with refrigerant leak vs a system in this grey efficiency area? What are the chances of no degradation, but a system has improperly charged refrigerant, but won’t trigger the FDD? (p. 16)*
- *Is there any benefit to identifying FDD systems that would also meet the criteria of FID? (p. 19)*

The field study conducted for this effort (documented in Appendix G) found that homes experience about 3.6 percent performance degradation per year of system age. This translates to a baseline loss of performance averaging about 75 percent over 15 years—well below the baseline for this measure. (There was general agreement that 15 years was a reasonable estimate for the life expectancy of this measure). If the system is brought up to full efficiency every time the performance goes below 85 percent (with an FDD system resulting in a service call and remediation), the average loss of performance will only be 93 percent. The incremental improvement is about 18 percent. Assuming only 50 percent of this improvement is likely to occur (because the fault detection doesn't result in a service call and remediation in every case), it is an improvement of about 9 percent. This is well above the assumed performance improvement of 6 percent for Refrigerant Charge Verification, and the 4 percent assumed for adding FDD on top of RCV.

Response to specific comments:

- Requiring manufacturers to do a study to verify that their system can detect faults with a 15 percent impact on efficiency or capacity will ensure that these savings are possible. No particular FDD tools were rigorously tested in this study to confirm this.
- No scenarios were tested of adding FDD on top of RCV. It is assumed that at least 4 percent improvement is possible, which is quite conservative given the field findings.
- No comparison was made of FDD abilities with FID requirements. Any FID tool would have to undergo the manufacturers study requirement to be granted FDD status, regardless of other requirements for FID.

Will This Identify Faults or Detect Performance Degradation?

- *Will the system display what individual fault is occurring, or will the service person need to identify the faults himself? (p. 6)*
- *This seems vague ["significant degree of performance degradation"]. How is the significance of each fault assigned? Could be open to ambiguity. Detail may be included in the body of the report later, but you may want to add more information here. (p. 6)*
- *Does this mean that the system does not identify specific faults? Would this make it more difficult for a service provider to figure out how to address the performance degradation? (p. 8)*
- *How will this be quantified with multiple causes of performance degradation? (p. 8)*
- *I'm a little confused whether these systems will identify individual faults or just notify when an overall performance degradation goal is reached? Could this be made clearer throughout the report? (p. 12)*
- *It should be made clear if the individual faults above result in a notification or if a notification only occurs if the degradation hits a certain point. (p. 14)*
- *Why not just have a defined list? ["there is not a defined list of faults that must be detected"]*

Wouldn't that make it clearer, especially for certification process? (p. 15)

- *This might need to be a little clearer that a combination of faults like those stated previously that cause a performance impact of 20% or greater will result in the notification. We don't want to confuse people that a single fault must have a 20% impact. (p. 15)*
- *This doesn't seem specific enough and ambiguous. How is the "significance" of each fault determined? Will these be defined/assigned by FDD manufacturer? Example. Low refrigerant charge = 8%, Evaporator airflow = 5%, noncondensables = 7%. Will it be something like this? This seems complex without being defined in this standard. Open to interpretation. (p. 15)*
- *If this is based on a cumulation of faults does each contributing fault need to be identified? (p. 16)*
- *How is this percentage threshold determined? (p. 16)*
- *Why not report a warning here…yellow light? (red light >20%) (p. 16)*
- *Would these types of faults [without impact on efficiency or capacity] be identified so that a verifier has this information when they go out to test? (p. 16)*
- *This [statement that severity is not the metric] adds another level to the complexity I describe above. (p. 16)*
- *As mentioned before, this should be more clearly defined. [proposed language JA6.4.1 system is capable of "detecting that either the rated efficiency or the capacity of the HVAC system is reduced by more than 20%"] (p. 39)*
- *It should be clear what is displayed as a fault. Is there a notification that the system is running at less than 20% efficiency/capacity, or when the system hits 20% reduction will a list of all faults (i.e. low refrigerant charge) be provided in some type of notification? (p. 39)*

The requirements as written do not require that the FDD system is able to diagnose what led to the efficiency or capacity degradation. It was felt that the primary benefit is alerting someone to the fact that there is a problem and leaving it to qualified technicians to use well established existing methods to determine what the underlying problem is and fix it.

Response to specific comments:

- The proposal does not include a defined list, because the focus is not on diagnosing specific faults, but on detecting performance degradation.
- The intent is to identify when any combination of faults that are occurring results in a significant performance degradation.
- After discussion, it was generally agreed that fault detection—as opposed to diagnosis—is appropriate.
- The 20 percent threshold was selected because it is a level that is unambiguously a problem. Anything lower could be open to interpretation. It was since decided to lower that to 15 percent: still pretty clearly a problem but increasing the overall savings estimates. There was general agreement that 15 percent is a reasonable limit.
- Warning lights would certainly be a good thing, but they are not required. They also raise a concern about "nuisance alarms" that result in non-fruitful truck rolls, and the lack of faith this would cause.
- Detection of faults that do not have an energy or capacity impacts would also

certainly be a good thing, but it is not required for Title 24, Part 6.
- Diagnosing the fault that is causing the performance degradation would also certainly be a good thing, but it is not required (it would add a lot of complexity to the code and be much harder to accomplish).

17.	Make it clearer earlier in the report that it is focused on DETECTING performance degradation and not DIAGNOSING specific faults.

Can This Measure Be Included if Few Products Are Available?

- *Is this going to be an issue since only one company has the available technology? (p. 7)*
- *Is there an estimated date for these systems? [other systems on the market and coming soon] (p. 7)*
- *Will this cause an issue if only a single manufacture is able to meet the requirement? (p. 15)*
- *Is there an estimate for when these products will be available and the length of time it will take to certify? It would be better to have multiple manufacturers available at the time the code language goes into effect. (p. 15)*
- *This would require some kind of subscription. [Emerson "data are stored in the cloud"] (p. 22)*
- *Maybe I missed it... Do these units in general have hardware display (fault indicator display) inside the house to notify homeowner, or are they all based on software for notification? (p. 22)*
- *Area of concern regarding future software support and compatibility. How do these software components and information get passed on to the next homeowner? [re Truveon smartphone app] (p. 23)*

It is expected that there are at least two tools, and more emerging all the time. This option in Title 24, Part 6—and a requirement to submit tests of performance of FDD systems—will encourage development of more tools and encourage additional rigor in claims of savings.

Miscellaneous Comments

- *Less than a year data to determine an annual degradation? [Field test] Where these newly installed systems? (p. 7)*
  - The field test reported on degradation in EER, which only requires a short period of steady state cooling operation. The impact that is modeled in CBECC-RES is a change to the EER.
- *Will testing of one FDD tool be adequate to develop a methodology for full range of FDD tools? (p. 7)*
  - The intent was not to develop a methodology but to provide lessons learned that will help in development of a methodology. The primary lesson learned in the lab testing was how difficult and expensive it is to do this testing, and how well specified the test must be. This result—along with prior experience in attempting to develop standardized methods of

test for FDD—led to the proposal to ask manufacturers to specify their test methods subject to Energy Commission approval. Lessons learned from the lab testing are documented in Appendix H.

- *How reliable are FDD systems? Is there any research or expectation on the failure of the FDD system itself? (p. 12)*
  - There is very little data on this.
- *Sensors and electronics may go bad over time, software may get outdated, etc. I can see the HVAC system outliving the FDD system. (p. 12)*
  - There is very little data on this.
- *Can FDD be removed or shut-off without any impact on the HVAC system? (p. 12)*
  - FDD is typically a monitoring-type system. Removing it or shutting it off should not impact the HVAC system. It will depend on the system.
- *Do HVAC manufacturers accept/agree that after-market add-ons will work on their systems and do not negatively impact the performance in any way? (p. 13)*
  - FDD is typically a monitoring-type system. Removing it or shutting it off should not impact the HVAC system. It will depend on the system.
- *Is there a CA study? Is there any reason to believe degradation in FL would be similar to CA? Would the different environments change degradation? Longer use in FL with longer cooling season? Etc? (p. 14)*
  - A study was conducted in California in the course of this development, included as Appendix G. Florida results have to be applied to California buildings with care.
- *Were these restricted to CZ 2 & 8-15, or in all CZs? [Field study] (p. 14)*
  - No, the field study wasn't climate-specific. The climate-specific impacts will be captured in the CBECC-RES modeling of the impact of changing the EER.
- *I think it will be helpful to provide more technical information here on how these systems work. Example pictures, graphics, diagrams, sensor locations on the HVAC system, etc. (p. 15)*
  - This is difficult since FDD systems vary quite a bit in what sensors they use etc.
- *Add another MF prototype for midrise (p. 31)*
  - When this was drafted, only the low rise MF prototype was available. A midrise prototype subsequently became available, but there in the interest of wrapping up this Research report and posting it for public review, that prototype was not added to analysis.
- *In these categories [bullets on categories of costs] what were the specifics for the two existing FDD systems that met the requirements? (p. 35)*
  - That information was not available.
- *Did any of the FDD providers have information regarding preventative maintenance cost vs reactive maintenance costs? (p. 35)*
  - This was not asked.