



TITLE 24, PART 6

2028 CODE CYCLE



HVAC Fault Detection and Diagnostics



Codes and Standards Enhancement (CASE) Proposal
Nonresidential | HVAC Controls



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Measure Development Partner

This measure is being developed as a joint effort between the Statewide CASE Team and the California Energy Alliance (CEA)

- CEA supports a diverse group of California energy stakeholders through collaborative code proposal submissions.
- **CEA's Mission is to:** bring beneficial, equitable change to energy standards, policies, and programs by developing consensus among diverse and engaged stakeholders.



caenergyalliance.org

Code Change Description

- Code Change Proposal
- Benefits
- Background Information



Proposed Code Change

Mandatory requirement:

Add HVAC Fault Detection and Diagnostics (FDD) as a mandatory measure for new piece of HVAC equipment (and connected terminal units) with design heating or cooling capacity of 300,000 Btu/hr or larger, installed in new construction or alterations of buildings 100,000 square feet or larger; it is also required to have DDC.

- For example: if an AHU has a heating or cooling capacity over 300,000 Btu/hr the terminal units connected to the AHU would also need FDD.

Minimum fault requirements were identified as common faults through literature review and SME feedback.

- HVAC operating outside of scheduled hours or permitted user override
- Inoperable dampers and valves
- Zone temperature sensor failure/fault
- Building HVAC control fan motor command at 100% or placed in manual override

Proposed Code Change continued

Mandatory requirement (cont.):

Additional baseline functional requirements such as automatic detection and diagnosis of high-impact faults, minimum performance data trending and storage, and reporting.

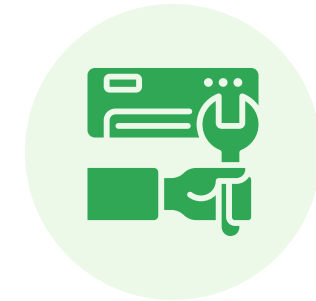
- Automatically diagnose faults to communicate findings with equipment/system identifiers and recommended corrective action
- Communicate faults to a regularly monitored system or application
- Trending of system performance

Adding to Definitions:

- Fault – a condition in a system or equipment that deviates from its intended operational state and results in measurable degradation of performance, efficiency, or control, such that corrective action is required to restore normal function.
- Fault Detection and Diagnostics – an automated process to identify faults in building systems using sensors and data analytics to monitor system performance, determine potential solutions, and communicate findings.

Benefits of the Proposed Change

- We recommend this change because it will save energy and simplify operations by enabling continuous monitoring of system operation and performance.
- FDD provides building operators with a proactive way to maintain and optimize their systems by collecting and reporting operational data that can provide actionable insights.
- FDD can also sustain other HVAC efficiency measures by monitoring their performance and identifying repairs.



Background Information

- 2013 Title 24 introduced a mandatory requirement to include economizer FDD for air-cooled DX systems with cooling capacity equal to or greater than 54,000 Btu/h.
- Manufacturers must certify the FDD systems to the Energy Commission.
- 2019 Title 24 expanded mandatory economizer FDD requirements to cover built-up systems.
- 2022 Title 24 lowered the trigger threshold for economizers and FDD to 33,000 Btu/hr (from 54,000 Btu/hr).
- 2025 Title 24 introduced requirements for HVAC systems that use DDC controllers to use controller logic originating from a programming library based on ASHRAE Guideline 36 sequences, which contains FDD algorithms.



Marked-up Code Language

See Title24stakeholders.com for marked-up code language

Title 24, Part 1

- No changes

Title 24, Part 6

- Definitions 100.1
- Section 120.2
- Section 120.5
- Section 141.0

Reference Appendices

- NA7.5

Poll

What is your role in the industry? Pick the option that best describes your role.

- a. Building owner
- b. Building operator
- c. HVAC designer
- d. HVAC contractor
- e. Controls contractor
- f. FDD provider
- g. Commissioning agent
- h. HVAC or controls manufacturer
- i. Building official (plan checker, inspector, etc.)
- j. Other (type in Q&A)



Market and Technical Considerations

- Current Conditions and Trends
- Potential Barriers and Solutions
- Technical feasibility

Current Market Conditions

Prevalence of HVAC faults in nonresidential buildings:

40% of air handling units and 30% of air terminal units reported faults daily in a study of over 60,000 pieces of HVAC equipment. Fault information was pulled from FDD providers as well as one large building portfolio (Crowe et al., 2023).

This study and input from HVAC designers and building operators indicate a market need for FDD, which would evolve quickly with code adoption.



Crowe, E., Chen, Y., Reeve, H., Yuill, D., Ebrahimifakhar, A., Chen, Y., ... Granderson, J. (2023). Empirical analysis of the prevalence of HVAC faults in commercial buildings. *Science and Technology for the Built Environment*, 29(10), 1027–1038. <https://doi.org/10.1080/23744731.2023.2263324>

Current Market Penetration

The Statewide CASE Team has not found any studies on the prevalence of HVAC FDD specifically in California nonresidential buildings and will continue literature review for quantitative data.

A national study using the Smart Energy Analytics Campaign collected data from 104 commercial organizations with over 567 million square feet and more than 6,500 buildings.

63% of participants were using some form of FDD

(Kramer et al., 2020)

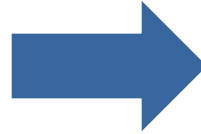
- The Statewide CASE Team does not believe 63% of organizations are using FDD. If an organization does not use energy analytics they would likely not participate in this survey.
- However, this shows there is a relatively high FDD market penetration in organizations with large building portfolios.



Market Barriers and Solutions

Market Barriers

1. Every building is unique, making FDD hard to consistently implement
2. FDD provider options vary in terms of implementation process and functionality
3. FDD approaches can have differences making it difficult for code officials to verify compliance
4. Proper training is lacking for measure stakeholders such as Acceptance Test Technicians (ATTs) and end users



Potential Solutions

1. Provide minimum baseline FDD functionality for easier adoption while still seeing savings
2. Make code language broad enough to allow flexibility in implementation
3. Clearly define requirements for easier compliance verification
4. Identify training barriers and solutions to communicate to stakeholders

Poll

What do you believe is the current market penetration in California of HVAC FDD for existing buildings over 100,000 square feet? In your experience, select a percentage of large buildings in California that currently have HVAC FDD.

- a. 0%
- b. Up to 10%
- c. 11% - 50%
- d. Over 50%
- e. I don't know

Poll

What do you believe is the current market penetration in California of HVAC FDD for new construction of buildings over 100,000 square feet? In your experience, select a percentage of new construction buildings in California that include HVAC FDD.

- a. 0%
- b. Up to 10%
- c. 11% - 50%
- d. Over 50%
- e. I don't know

Technical Considerations

Current Practice: Designers do not include FDD in most projects because building owners do not commonly require it for new construction or renovation projects. However, including building automation systems (BAS) in designs of buildings over 100,000 square feet is common practice and FDD relies on the BAS to gather data for analysis.

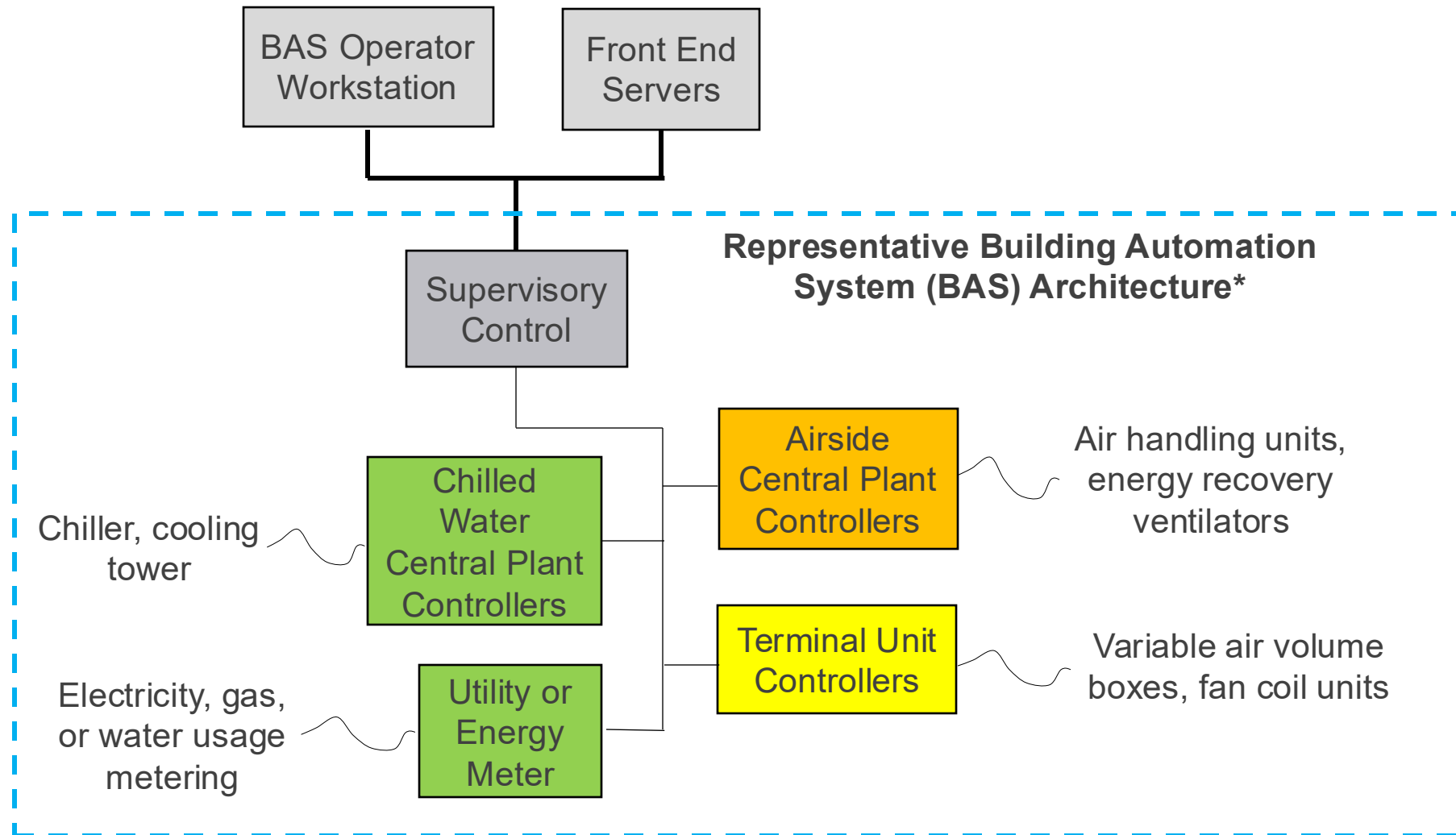


Proposed code change:

- Designers specify and design the BAS for HVAC FDD functionality.
- Controls contractors install the BAS as designed with HVAC FDD as a requirement.
- Long-term system performance will improve through building life cycle through FDD information and facility manager actions.

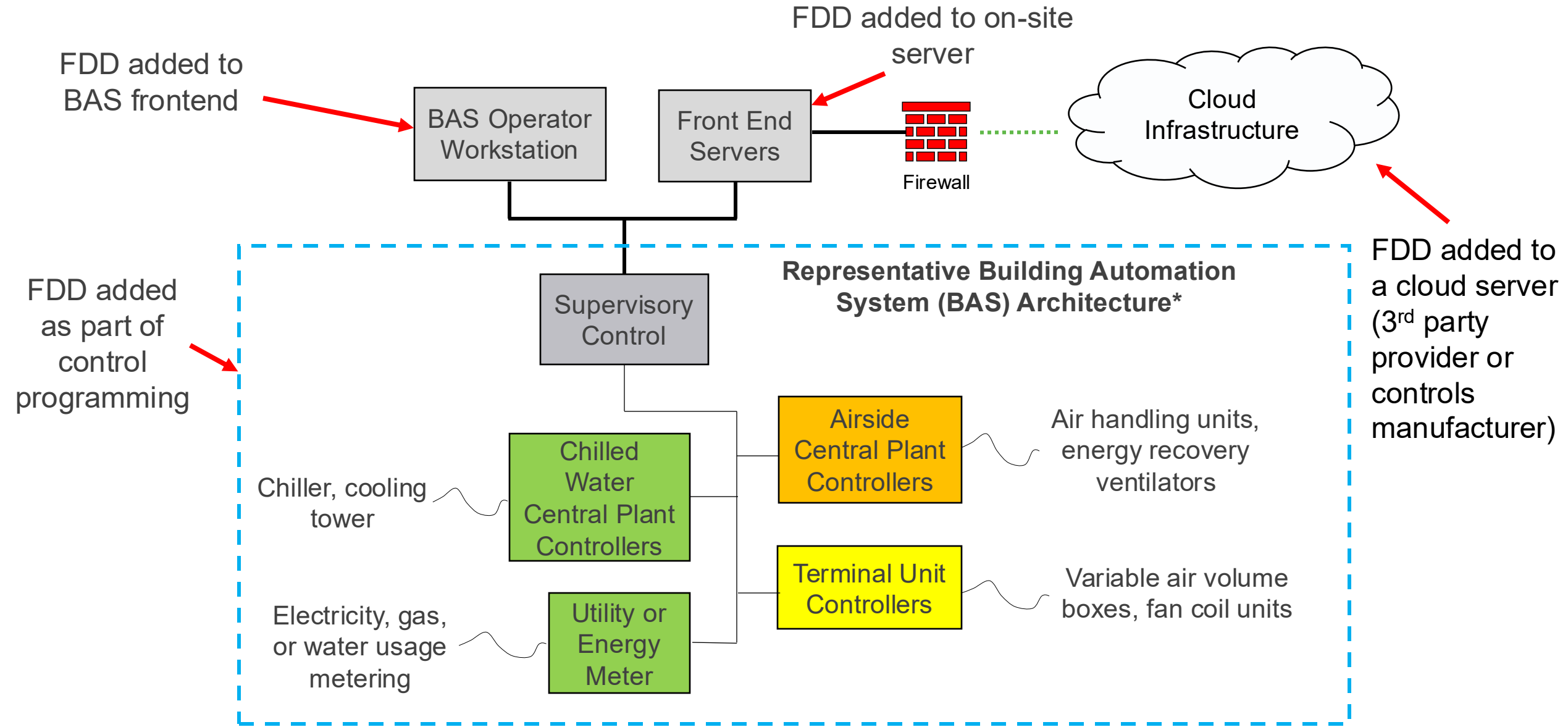


Technical Considerations – Current Standard



*Example of BAS architecture, every building will be different

Technical Considerations – Potential Options



*Example of BAS architecture, every building will be different

Technical Barrers and Solutions

Technical Barrers

1. Lack of standardization of HVAC FDD functionality
2. Complexity of integrating FDD with BAS
3. If cloud based, building owner cybersecurity approval may be needed



Potential Solutions

1. Defining HVAC FDD
2. Defining baseline functional requirements of an HVAC FDD system.
3. Integrating FDD and BAS is easier in new buildings because it can be included as part of the installed system
4. Allowing onsite and cloud options to meet requirement provides flexibility for different levels of cybersecurity requirement

Poll

If buildings are not seeing energy savings or sustained energy efficiency from FDD, why? Select all that apply from the list below on the most common reasons buildings would not see energy efficiency benefits from FDD.

- a. Inaccessibility to fault information
- b. Lack of staffing
- c. Lack of staff training
- d. Lack of resources
- e. Improper implementation
- f. Other (Add to Q&A)
- g. I don't know

Poll

What are the largest technical and market barriers? Select all that apply from the list below on identified barriers to the measure.

- a. FDD standardization
- b. Integration complexity with BAS
- c. IT/cybersecurity
- d. High upfront cost
- e. Unclear return-on-investment
- f. Lack of designer market knowledge of FDD benefits
- g. Lack of contractor market knowledge of FDD benefits
- h. Lack of operator market knowledge of FDD benefits
- i. Other (Add to Q&A)
- j. I don't know

Poll

What else should we know?

Are there market or technical barriers or solutions we should consider?

Are there other faults and FDD requirements for large buildings that we should know about?

Open ended response

Per Unit Energy and Cost Impacts

Methodology and Assumptions

- Energy and Energy Cost Savings
- Incremental Costs



Energy and Energy Cost Savings Methodology

Per-sq ft energy and demand impacts:

- **Base case:** represents the non-FDD system:
 - reasonable system ongoing operation,
 - faults are being resolved/repaired slower than it would be with FDD.
- **Proposed case:** represents the system with FDD:
 - faults are being resolved/repaired faster than a non-FDD system.
- Difference of one to two months of resolution time between the base case and proposed case.
- **2025 prototypes:** Large Office and School
- **Climate zones modeled:** All climate zones



Energy Modeling Assumptions

- Simulating using the following prototypical buildings and climate zones

Prototype Buildings

- Office Large
- School Large

Climate Zones

- Simulating in 1 – 16

Poll

What is the range of HVAC energy savings that can be expected? Based on HVAC FDD usage, select the range of total HVAC energy savings that can be expected.

- a. < 5%
- b. 6% – 20%
- c. > 20%
- d. I don't know

Poll

Would you agree with the assumption that systems *with* FDD resolve faults on average 1 to 2 months sooner than systems *without* FDD? The assumption was made to provide a conservative estimate on savings potential.

- a. Yes
- b. No*

*If no, please comment what assumption you would make or email cbattisti@trccompanies.com.

Assumptions for Standard and Proposed Designs



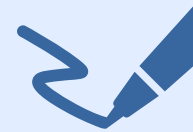
Baseline Case

System with common faults* across the measure life. Time to repair faults is 2-3 months, depending on the fault.

Faults include:

- HVAC operating outside of scheduled hours or permitted user override
- Leaking or inoperable heating and cooling coil valves
- Inoperable dampers
- Temperature sensor failure/fault
- Fan motor command at 100% or placed in manual override

*Literature review identified the most common and impactful faults



Proposed Design

Same faults as in the Baseline Case. Time to repair faults 1-2 months, depending on the fault.

Incremental Cost Framework



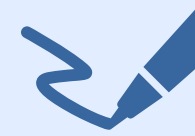
Baseline

First Cost

- System with no FDD

30-Year Maintenance Costs

- Regular maintenance and/or service agreements for system without FDD



Proposed

First Cost

- Additional design and construction requirements
- Fault detection and diagnostics software and integration to BAS
- Compliance verification

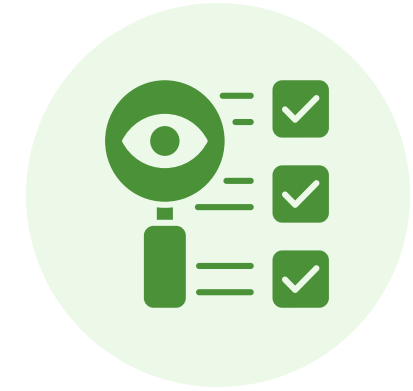
30-Year Maintenance Costs

- Labor for addressing faults
- Regular FDD software update and/or service agreements

Approach for Gathering Costs

Literature review of cost of implementation

- The Smart Energy Analytics Campaign have costs associated with FDD incremental first cost and maintenance cost (Kramer et al., 2020)
 - Median incremental first cost of \$0.06 per sq ft, reflecting \$9 per data point
 - Includes FDD software licensing, labor, and integration.
 - Median incremental maintenance costs of \$0.02 per sq ft, reflecting a \$4 per data point per year
 - Includes software support and updates
 - Additional eight hours per building per month of in-house labor
- Costs are escalated to 2029 dollars assuming constant inflation.



Kramer, H., Lin, G., Curtin, C., Crowe, E., and Granderson, J. *Proving the Business Case for Building Analytics*. Lawrence Berkeley National Laboratory, October 2020. <https://doi.org/10.20357/B7G022>

Cost-Effectiveness Results (New Constructions & Additions)

Climate Zone	Electricity LSC Savings (2029 PV\$/sq ft)	Gas LSC Savings (2029 PV\$/sq ft)	Total Costs (2029 PV\$/sq ft)	Benefit-to-Cost Ratio
1	0.59	12.96	1.36	9.99
2	0.66	13.22	1.36	10.24
3	0.76	9.08	1.00	9.89
4	0.75	7.98	1.05	8.34
5	0.62	9.29	1.36	7.31
6	0.80	6.00	1.04	6.55
7	0.81	5.48	1.00	6.28
8	0.78	5.90	1.06	6.30
9	0.81	5.36	1.02	6.04
10	0.78	6.50	1.05	6.96
11	0.73	11.21	1.36	8.81
12	0.76	7.67	0.99	8.49
13	0.73	9.92	1.36	7.86
14	0.90	7.24	1.07	7.62
15	0.98	5.00	1.02	5.84
16	0.79	8.22	1.07	8.38
Total	0.78	6.79	1.03	7.32

Large gas savings for heating-dominated zones

Large electricity savings for cooling-dominated zones

Cost-Effectiveness Results (Alterations)

Climate Zone	Electricity LSC Savings (2029 PV\$/sq ft)	Gas LSC Savings (2029 PV\$/sq ft)	Total Costs (2029 PV\$/sq ft)	Benefit-to-Cost Ratio
1	0.59	12.78	1.34	9.99
2	0.69	11.51	1.22	10.03
3	0.75	9.19	1.04	9.57
4	0.76	7.78	1.01	8.48
5	0.66	8.82	1.24	7.66
6	0.80	6.01	1.04	6.54
7	0.80	5.51	1.02	6.21
8	0.80	5.74	1.01	6.51
9	0.81	5.34	1.01	6.07
10	0.78	6.45	1.04	6.97
11	0.77	9.76	1.23	8.53
12	0.74	8.57	1.06	8.75
13	0.79	7.29	1.14	7.09
14	0.92	6.43	1.00	7.36
15	0.98	5.01	1.03	5.84
16	0.79	7.63	1.04	8.08
Total	0.79	6.63	1.03	7.20

Large gas savings for heating-dominated zones

Large electricity savings for cooling-dominated zones



Compliance Verification

- Key Aspects of Compliance Verification
- Barriers and Solutions
- Revisions to Compliance Software

Key Aspects of Compliance Verification



- **Design**

- Designers specify FDD functionality in specifications and include additional sensors as needed.
- Compliance forms will include checkboxes for designers to indicate whether FDD requirement is applicable and if the requirement is satisfied.



- **Permit application**

- Plans examiner would verify using an updated NRCC-MCH-E – Mechanical Systems Certificate of Compliance.

- **Construction**

- Contractor installs FDD to meet requirements

- **Inspection**

- Acceptance test technician (ATT) performs required acceptance tests using updated acceptance forms such as NRCA-MCH-13-A – AHU & Zone Terminal FDD
- Inspector reviews acceptance tests and compliance forms to verify FDD system meets minimum requirements.



Key Aspects of Compliance Verification



High-Level performance verification testing procedures:

1. Simulate the requirements to **put the system in a fault condition**.
 - a. This can be done either with physically changing the system to detect a fault, or overriding the control system to simulate the fault.
2. Verify the system **detects** the fault, **diagnoses** the fault, and **communicates** the fault per the measure and design.
 - a. Communicating the fault type, affected equipment or system, and recommended corrective actions.
3. Return the system to normal operation.
4. Verify system is functioning normally.
5. Pass/fail based on the detection, diagnosis, and communication of the faults.



Compliance Barriers and Solutions

Compliance Verification Barriers

1. Verification of control system capabilities is difficult and can be complex
2. Defining a compliant FDD system (“What right looks like”)
3. Additional validation requires more time from code officials
4. New acceptance tests for FDD system verification



Potential Solutions

1. Research verification strategies from FDD providers
2. Clearly define minimum control capabilities code requirements
3. Develop clear instructions in NA7.5.
4. Provide training to ATTs based on instruction and compliance documents

Compliance Software Updates

The only update required to the compliance software would be incorporating any updates to compliance forms for verification.

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More information on

[CEC's 2028 proceeding website.](#)

**We want to
hear from you!**