

# Nonresidential HVAC Fault Detection and Diagnostics



Chris Battisti, Yuewei Li, Afshin Faramarzi, Rupam Singla, Michael Mutmansky, Mitch Greene, Tharanga Jayarathne TRC.

March 2026  
Draft CASE Report



The California Statewide Codes and Standards Enhancement (CASE) Program is funded in part by California utility customers under the auspices of the California Public Utilities Commission.

Copyright 2025 Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric Company, Los Angeles Department of Water and Power, and Sacramento Municipal Utility District. All rights reserved, except that this document may be used, copied, and distributed without modification.

Neither Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric Company, Los Angeles Department of Water and Power, Sacramento Municipal Utility District or any of its employees make any warranty, express or implied; or assume any legal liability or responsibility for the accuracy, completeness or usefulness of any data, information, method, product, policy or process disclosed in this document; or represent that its use will not infringe any privately-owned rights including, but not limited to, patents, trademarks or copyrights.



## Document Information

<b>Category:</b>	Codes and Standards
<b>Keywords:</b>	Statewide Codes and Standards Enhancement (CASE) Initiative; California Statewide Utility Codes and Standards Team; Codes and Standards Enhancements; 2028 California Energy Code; 2028 Title 24, Part 6; California Energy Commission; energy efficiency; fault detection and diagnostics, HVAC, operations and maintenance, data analytics, data visualization.
<b>Authors:</b>	Chris Battisti, Yuewei Li, Afshin Faramarzi, Rupam Singla, Michael Mutmansky, Mitch Greene, Tharanga Jayarathne (TRC)
<b>Project Support:</b>	Joe Singer and Ben Lalor (NORESO)
<b>Prime Contractor:</b>	TRC
<b>Project Management:</b>	California Statewide Utility Codes and Standards Team: Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric Company

# Table of Contents

- Acronyms** **vi**

---

- 1. Introduction** **1**
  - 1.1 Report Context.....1
  - 1.2 Proposal Sponsors .....2
  - 1.3 Stakeholder Engagement to Inform Proposal.....2
- 2. Measure Description** **3**
  - 2.1 Proposed Code Change .....3
  - 2.2 Benefits of Proposed Change .....4
  - 2.3 Background Information .....5
  - 2.4 Modifications to Energy Code Documents.....9
  - 2.5 Measure Context .....12
- 3. Compliance and Enforcement** **14**
  - 3.1 Compliance Considerations .....14
  - 3.2 Impact on Market Actors.....15
  - 3.3 Compliance Software Updates.....17
  - 3.4 Cost of Enforcement.....18
- 4. Market and Economic Analysis** **19**
  - 4.1 Market Structure and Availability.....19
  - 4.2 Design and Construction Practices .....26
  - 4.3 Energy Equity and Environmental Justice .....29
  - 4.4 Impacts on Jobs and Businesses.....29
  - 4.5 Economic and Fiscal Impacts.....29
- 5. Cost Effectiveness** **30**
  - 5.1 Cost Effectiveness Methodology.....30
  - 5.2 Energy and Energy Cost Savings Results.....30
  - 5.3 Incremental First Cost .....34
  - 5.4 Incremental Maintenance and Replacement Costs.....35
  - 5.5 Cost Effectiveness .....36
- 6. Statewide Impacts** **38**
  - 6.1 Statewide Energy and Energy Cost Savings.....38
  - 6.2 Statewide Greenhouse Gas Emissions Reductions.....42
  - 6.3 Statewide Water Use Impacts.....42
  - 6.4 Statewide Material Impacts .....42
  - 6.5 Environmental Impacts.....42
  - 6.6 Other Non-Energy Impacts.....42

<b>7. Proposed Language Code</b>	<b>43</b>
7.1 Guide to Markup Language	43
7.2 Administrative Code (Title 24, Part 1)	43
7.3 Energy Code (Title 24, Part 6)	43
7.4 Reference Appendices	45
7.5 Compliance Manuals	46
7.6 ACM Reference Manual	46
7.7 Compliance Forms	46
<b>8. Bibliography</b>	<b>47</b>
<b>Appendix A : Assumptions for Cost-Effectiveness Analysis</b>	<b>50</b>
<b>Appendix B : Purpose and Necessity of Proposed Code Changes</b>	<b>61</b>
<b>Appendix C : Assumptions for Statewide Savings Estimates</b>	<b>63</b>
<b>Appendix D : Environmental Analysis</b>	<b>68</b>
<b>Appendix E : Summary of Stakeholder Engagement</b>	<b>70</b>

## List of Tables

Table 1: List of Acronyms	vi
Table 2: Scope of Proposed Code Change	4
Table 3: Impacts on Market Actors and Suggested Training and Education Opportunities	16
Table 4: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code/Standard by Subsector in 2025 (Estimated)	17
Table 5. Energy and Energy Cost Savings – Per Square Foot– OfficeLarge Prototype	33
Table 6. 2029 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – OfficeLarge Prototype	34
Table 7. 30-Year Cost-Effectiveness Summary Per Square Foot – OfficeLarge	37
Table 8: Statewide Energy and LSC Impacts – New Construction and Additions	39
Table 9: Statewide Energy and LSC Impacts – Alterations	40
Table 10: Statewide Energy and LSC Impacts – New Construction, Additions, and Alterations	41
Table 11: First-Year Statewide GHG Emissions Impacts	42
Table 12: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis	52

Table 13: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change.....	56
Table 14: Fault Persistence and Recurrence Assumptions .....	57
Table 15: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2029, by Climate Zone and Building Type (Million Square Feet) .....	65
Table 16: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2026 (Alterations), by Climate Zone and Building Type (Million Square Feet).....	65
Table 17: Percentage of Nonresidential Floorspace Impacted by Proposed Code Change in 2029, by Building Type <sup>a</sup> .....	66
Table 18: Percentage of Nonresidential Floorspace Impacted by Proposed Measure, by Climate Zone <sup>a</sup> .....	67
Table 19: Utility-Sponsored Stakeholder Meetings .....	71
Table 20: Engaged Stakeholders.....	72

## List of Figures

Figure 1: Percent energy savings relative to the year before FDD installation by organizations participating in the Smart Energy Analytics Campaign (Kra20).....	7
Figure 2: Representative BAS with FDD Implementation Options .....	7
Figure 3: A Venn Diagram of the Differences Between HVAC controls and FDD Related Measures.....	9
Figure 4: Percentage Increase in Building Energy Use for Different Fault Models – OfficeLarge Prototype, All Climate Zones. ....	32
Figure 5: CZ 7 – Monthly Energy Use for Different Aggregated-Fault and Baseline Models – OfficeLarge Prototype .....	60
Figure 6: CZ 12 – Monthly Energy Use for Different Aggregated-Fault and Baseline Models – OfficeLarge Prototype. ....	60

# Acronyms

Table 1 presents a list of acronyms used in this report. Title24stakeholders.com also maintains a [glossary of terms](#)

Table 1: List of Acronyms

Acronym	Definition
<b>ACM</b>	Alternative Calculation Method
<b>ADA</b>	Americans with Disabilities Act
<b>ASHRAE</b>	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
<b>ATT</b>	Acceptance Test Technician
<b>BAS</b>	Building Automation System
<b>BCR</b>	Benefit-to-cost Ratio
<b>BEM</b>	Building Energy Modeling
<b>Btu</b>	British Thermal Units
<b>CALGreen</b>	California Green Building Standards Code
<b>Cal/OSHA</b>	California Division of Occupational Safety and Health
<b>CARB</b>	California Air Resources Board
<b>CASE</b>	Codes and Standards Enhancement
<b>CBSC</b>	California Building Standards Commission
<b>CBECC</b>	California Building Energy Code Compliance Software
<b>CBECC-Res</b>	California Building Energy Code Compliance for Residential Buildings Software
<b>CEC</b>	California Energy Commission
<b>CEQA</b>	California Environmental Quality Act
<b>CBO</b>	Community-Based Organization
<b>CPUC</b>	California Public Utilities Commission
<b>CSE</b>	California Simulation Engine
<b>CZ</b>	Climate Zone
<b>DAC</b>	Disadvantaged Community
<b>DDC</b>	Direct Digital Controls
<b>DOAS</b>	Dedicated Outdoor Air System
<b>DOSH</b>	Division of Occupational Safety and Health
<b>DX</b>	Direct Expansion
<b>ECC</b>	Energy Code Compliance
<b>EIR</b>	Environmental Impact Report
<b>EIS</b>	Energy Information Systems
<b>EPIC</b>	Electric Program Investment Charge

<b>ESJ</b>	Environmental and Social Justice
<b>FDD</b>	Fault Detection and Diagnostics
<b>FSOR</b>	Final Statement of Reasons
<b>GHG</b>	Greenhouse Gas
<b>GWh</b>	Gigawatt-Hour
<b>HVAC</b>	Heating, Ventilation, and Air Conditioning
<b>IDF</b>	Input Data File
<b>IECC</b>	International Energy Conservation Code
<b>IgCC</b>	International Green Construction Code
<b>IOU</b>	Investor-Owned Utility
<b>ISOR</b>	Initial Statement of Reasons
<b>IT</b>	Information Technology
<b>kWh</b>	Kilowatt-Hour
<b>kWh/year</b>	Kilowatt-Hour Per Year
<b>LSC</b>	Long-term System Cost
<b>MeasureSET</b>	CASE Measure Savings Estimation Template
<b>MG</b>	Million Gallons of Water
<b>NAICS</b>	North American Industry Classification System
<b>NPDI</b>	Net Private Domestic Investment
<b>PEP</b>	Public Engagement Plan
<b>PV</b>	Present Value
<b>ROI</b>	Return on Investment
<b>SaaS</b>	Software as a Service
<b>SDD</b>	Standards Data Dictionary
<b>SRIA</b>	Standardized Regulatory Impact Assessment
<b>UL</b>	Underwriters Laboratories
<b>W</b>	Watt

# 1. Introduction

---

*This is a draft report. The Statewide Codes and Standards Enhancement (CASE) Team encourages readers to provide comments on the proposed code changes and supporting analyses. The CEC will evaluate proposals that the Statewide CASE Team and other stakeholders submit and may revise or reject proposals. More information about the rulemaking schedule and how to participate in the process can be found on CEC's 2028 code cycle website. Suggested revisions will be considered when refining proposals and analyses. The final CASE Report will be submitted to the CEC later in 2026.*

*For this report, the Statewide CASE Team is requesting input on the following:*

- Market penetration of Fault Detection and Diagnostics (FDD) for large buildings (>100,000sf)*
- Building types that are implementing FDD*
- System types that should be implementing FDD*
- Range of HVAC energy savings that can be obtained from FDD*
- Reasons buildings may not see energy savings or sustained energy efficiency*
- Technical and market barriers to requiring FDD*
- First costs for FDD, and what building characteristics impact the costs*
- Ongoing costs for FDD*

*Email comments and suggestions to [info@title24stakeholders.com](mailto:info@title24stakeholders.com) and Chris Battisti ([cbattisti@trccompanies.com](mailto:cbattisti@trccompanies.com)). Comments will either not be released for public review or will be anonymized if shared.*

## 1.1 Report Context

This proposal describes specific energy efficiency code changes (referred to as “measures”) aimed at reducing wasteful, uneconomic, inefficient, or unnecessary consumption of energy in California. These measures are submitted to the California Energy Commission (CEC) for consideration and potential inclusion in California’s Energy Code (Title 24, Part 6), which sets statewide energy efficiency requirements for newly constructed buildings and for additions and alterations to existing buildings. Measures may also be considered for inclusion in CALGreen (Title 24, Part 11) as voluntary energy efficiency standards, which would take effect only if adopted by a local jurisdiction seeking to exceed the minimum requirements of the Energy Code. Measures submitted to the CEC will be reviewed, may be modified, and may be

incorporated into a broader regulatory package proposed and adopted by the CEC. To be included in the Energy Code, proposed measures must be both cost effective and technically feasible.

## **1.2 Proposal Sponsors**

Three California Investor-Owned Utilities (IOUs) — Pacific Gas & Electric Company, San Diego Gas & Electric, and Southern California Edison sponsored this effort as a group. Where the term, “Statewide CASE Team” is used in this report, it refers the authors of the CASE report and the Codes & Standards programs of the supporting California Investor-Owned Utilities. The California Energy Alliance (CEA) is a sponsor of this measure and contributed to this report.

## **1.3 Stakeholder Engagement to Inform Proposal**

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with many industry stakeholders, including building owners and facility teams, fault detection and diagnostics (FDD) providers, and heating, ventilation, and air conditioning (HVAC) designers, contractors, and controls manufacturers. The proposal incorporates feedback received during a public stakeholder workshop that the Statewide CASE Team held on October 23, 2025.

During the public stakeholder workshop, key takeaways included the difficulty of compliance verification for control systems, the use of energy management and control systems (ECMS) in conjunction with FDD, how this measure crosses over with American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Guideline 36 requirements, and whether third parties can implement the FDD, or whether it can operate in the native building automation system. Other comments included cybersecurity and data privacy concerns, and responding to faults.

The Statewide CASE Team reached out to several industry experts to use their insights in the measure. These meetings provided insight into the design and construction of FDD, and how it can impact the existing processes. There was also discussion on additional requirements to ease the use of FDD in design, construction, and operations of the FDD after construction is complete.

See Appendix E for details on the Statewide CASE Team’s stakeholder engagement.

## 2. Measure Description

---

### 2.1 Proposed Code Change

The proposed code change would require the use of a stand-alone or integrated fault detection and diagnostics (FDD) hardware and/or software for HVAC systems and equipment (e.g., air handling units (AHU), heat pumps, chillers, boilers) over the size of 300,000 British thermal units (Btu)/hr, supplying more than three zones, and serving the total conditioned space of 100,000 square feet or greater in nonresidential new construction, additions, or alterations. Specifically for existing buildings undergoing alterations, the proposed code change applies only to the newly installed equipment and its directly associated systems when replacing major HVAC equipment. Other than major alterations to existing HVAC systems, minor tenant improvements, such as adding VAV boxes, adjusting ductwork, or rebalancing existing systems without equipment replacement, would not trigger FDD requirements. The measure provides mandatory requirements for FDD, which includes baseline functionality performance specifications implemented by the design team to ensure project flexibility. The manufacturer and building automation system (BAS) installer implement the capabilities based on the design requirements. The proposed measure would add “Fault” and “Fault Detection and Diagnostics” definitions to the code definitions for clarity.

The proposed measure will require the FDD systems to detect and diagnose the following fault conditions:

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

Table 2 summarizes the scope of the proposed code change.

**Table 2: Scope of Proposed Code Change**

A  indicates the proposed code change is relevant.

Building Type(s)		Construction Type(s)		Type of Change	
<input type="checkbox"/> Single Family		<input checked="" type="checkbox"/> New Construction		<input checked="" type="checkbox"/> Mandatory	
<input type="checkbox"/> Multifamily		<input checked="" type="checkbox"/> Additions		<input type="checkbox"/> Prescriptive	
<input checked="" type="checkbox"/> Nonresidential (not Group R uses)		<input checked="" type="checkbox"/> Alterations		<input type="checkbox"/> Performance	
Application Climate Zones	Energy Code Sections	Compliance Forms	Sections of ACM Reference Manuals		
Climate Zones 1-16	<ul style="list-style-type: none"> <li>• Definitions</li> <li>• Part 6, Section 120.2(i)</li> <li>• Part 6, Section 120.5(a)</li> <li>• Part 6, Section 141.0(b)</li> </ul>	NRCA-MCH-12-A NRCA-MCH-13-A NRCC-MCH-E	5.7		
Third Party Verification			Updates to Compliance Software		
<input checked="" type="checkbox"/> No changes to third party verification			<input type="checkbox"/> No updates		
<input type="checkbox"/> Update existing verification requirements			<input checked="" type="checkbox"/> Update existing feature		
<input type="checkbox"/> Add new verification requirements			<input type="checkbox"/> Add new feature		

## 2.2 Benefits of Proposed Change

HVAC FDD systems provide building facility team with a proactive way to maintain and optimize their HVAC systems by bringing operational data together and providing actionable insights to address inefficient operation. FDD can sustain other HVAC efficiency measures by monitoring their performance and identifying need for repairs. FDD enables persistence of HVAC energy efficiency strategies.

HVAC systems are meant to be designed, built, and operated to meet conditioning and ventilation needs of the building occupants, ideally using as little energy as reasonably possible to accomplish the goals. Currently available HVAC direct digital control (DDC) systems have the capability to automatically control the HVAC system operation and provide the ability to monitor, trend, and analyze the system. As an additional long-term benefit, FDD can prevent the expected loss of HVAC system efficiency caused by wear-and-tear on system components, lack of maintenance, faulty or failed sensors, and changes in control strategies such as overrides and configurations.

Established processes such as start-up commissioning and existing building commissioning attempt to verify proper operation and/or optimize these systems, but building performance declines over time without continuous monitoring. FDD uses rule- or model-based approaches to continuously monitor HVAC systems by identifying faults

that increase energy consumption, limit the functionality of the system, and potentially lead to equipment and system failure. An FDD system can identify possible repairs to restore original system efficiency or optimization options to improve performance. FDD systems improve building energy performance by continuously monitoring HVAC operations and alerting facility team to faults and inefficiencies, enabling timely corrective action.

The energy savings achievable from using an FDD system are a result of two possible positive outcomes assuming the building facility team acts on the FDD fault report information appropriately. The facility team will maintain the building to a higher level of performance on average throughout the life of the HVAC systems because the FDD system will identify the faults quickly, and the facility team can take proper actions to correct the faults. This action results in a reduction in the meantime required to correct the faults, which leads to the building operating nearer to an ideal condition longer throughout the useful life. Second, the maintenance team can act on faults that may have never been detected without careful inspection of the system, making additional incremental gains to the ongoing efficiency of the HVAC system.

Note that an FDD system will not reduce the number of mechanical failures in the building without human action. It can provide the facility team with the information needed to rapidly correct faults, and in the case of maintenance items, can indirectly improve overall equipment life by reducing the failures and performance degradation associated with under-maintained hardware.

The Statewide CASE Team excluded several faults from this proposal and analysis, including outdoor air damper failures, outside air temperature (OAT) sensor faults, and economizer high-limit lockout setpoint errors, because existing economizer FDD requirements address these conditions. The Statewide CASE Team focused on HVAC system faults not covered by the current economizer FDD requirements.

The proposed code change would cost-effectively enable resilient energy savings throughout the lifecycle of the building. By identifying faults/failures and potential solutions in HVAC systems, operations and maintenance activities would be easier and more effective to keep the system operating properly and efficiently.

## **2.3 Background Information**

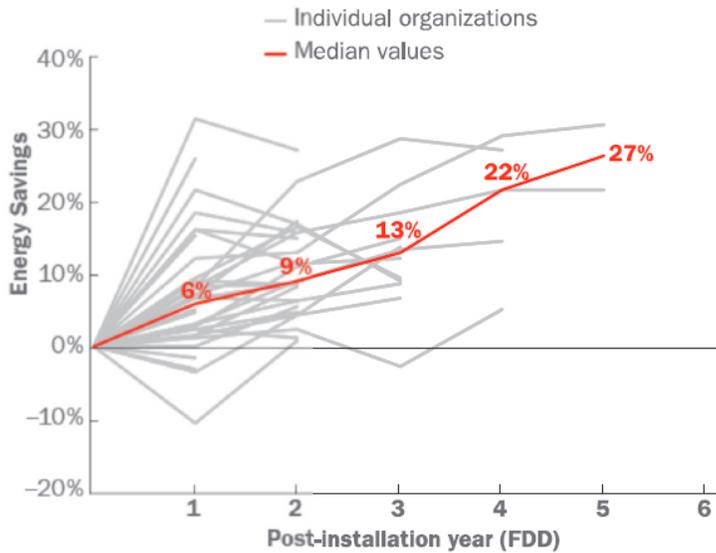
HVAC FDD uses advanced algorithms, sensor data, and control data to automatically identify performance and system issues (faults) while also providing potential solutions to repair the faults (diagnostics). By detecting the deficiencies automatically and immediately, repairs can quickly resolve the fault, improve system operation and maintenance costs while maintaining occupant comfort within intended design parameters. Unlike other historical control system measures, FDD does not control the

HVAC system but uses data from within the control system to detect the faults and provide a diagnosis. It is a monitoring tool that relies on action from the operations and maintenance (O&M) staff to remove the faults and bring the system back to energy-efficient operation. Additional benefits include keeping buildings at relatively low energy usage over time, which eases grid strain.

An FDD system saves energy when the facility team repairs identified equipment faults more quickly than if there was no FDD system in place. Historically, the building automation system (BAS) uses system data, such as sensors, to “alarm” the facility team of issues, but the information can be unhelpful because it does not provide more detailed information on the problem, the root cause, and the potential solutions. When investigating an alarm, system data is difficult to interpret to manually diagnose faults and identify corrective actions. The quantity of alarms can add up quickly, requiring an overwhelming number of items for the facility team to review, which leads to ignored alarms. Conflicting priorities such as comfort complaints or larger failures, can lead to problems going unaddressed. Even attentive and well-staffed facility programs that are proactive with maintenance would still miss small faults that potentially add up to increased energy consumption over time.

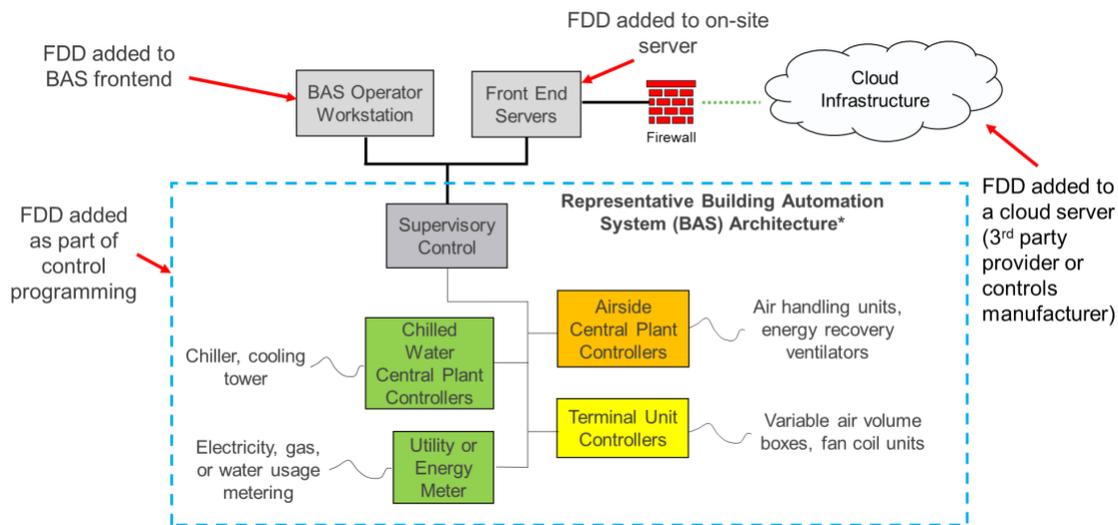
Studies have shown that FDD provides consistent energy savings (Kramer, et al. 2020) (Lin, Kramer and Granderson 2020) (Gorthala 2022) (Crowe, Chen and Granderson, et al. 2022) . In particular, a Lawrence Berkeley National Laboratory (LBNL) study working with the Smart Energy Analytics Campaign found a median energy savings of 9 percent (\$0.24/sq ft), with a range of 1 percent to 28 percent, and a simple payback of 2 years across multiple portfolios consisting of more than 6,500 buildings and 567 million square feet of gross area (Kramer, et al. 2020) (Lin, Kramer and Granderson 2020). The study also found that the longer the site used FDD, the savings would continue to increase. Figure 1 shows the cumulative savings of FDD.

(n = 28 in Year 1)



**Figure 1: Percent energy savings relative to the year before FDD installation by organizations participating in the Smart Energy Analytics Campaign (Kra20)**

FDD requires a DDC system or BAS to collect and analyze building and HVAC system data. The DDC or BAS platforms collect sensors and control data from the HVAC system to provide the monitoring capability necessary for FDD analysis. Figure 2 is a visual representation of how the BAS directly interacts with various options of FDD implementation. The control system architecture shows how sensors, controllers, actuators, and other system components are organized in a one-line diagram. It represents how the data is collected, and flows throughout the BAS.

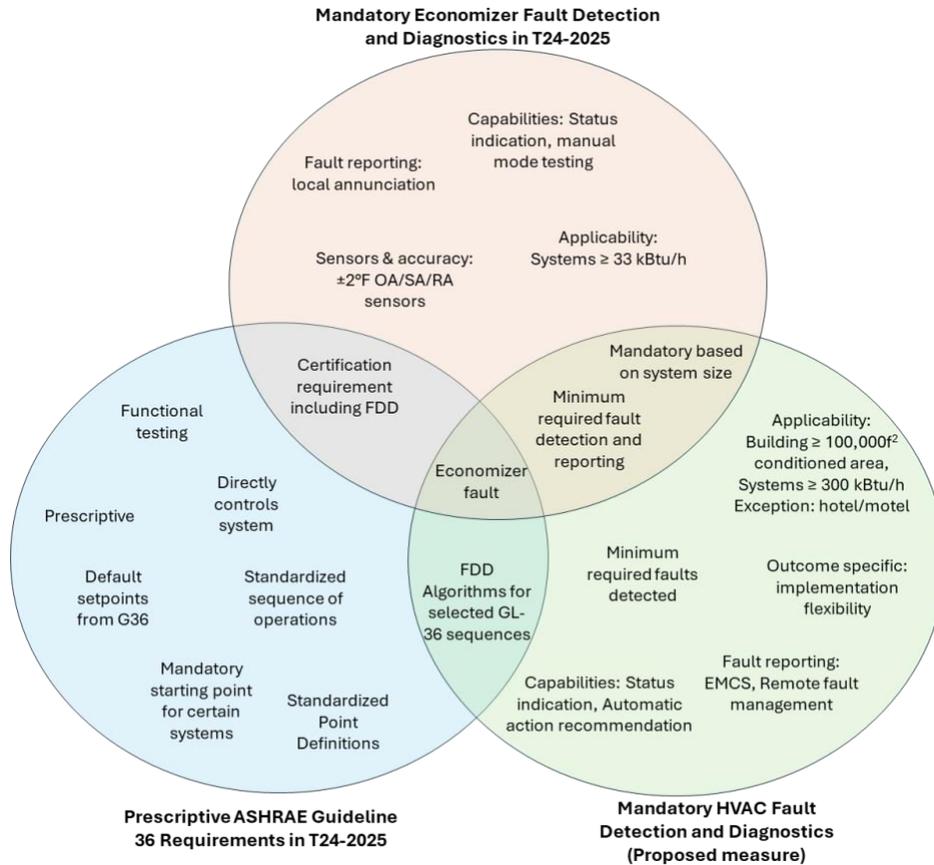


**Figure 2: Representative BAS with FDD Implementation Options**

Over the past 20 years, FDD capabilities have improved due to the design and adoption of communication protocol standards (e.g., BACnet), a better understanding of system performance through data analytics, and improvements in machine learning to analyze the data more effectively. There have been improvements in diagnosis techniques, reducing false positives, communication of information, and training staff to use FDD to its fullest capabilities.

Professional societies have developed standard ways to do FDD, such as in American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Guideline 36: High-Performance Sequences of Operation for HVAC Systems. Guideline 36 prescribes specific routines and requirements for FDD implementation (ASHRAE 2024). Controls contractors reference Guideline 36 when programming DDC controllers or BAS supervisory systems, using manufacturer-specific programming tools for each control platform. Many manufacturers also offer pre-programmed Guideline 36 control sequences in their programming libraries. The 2025 Title 24, Part 6 Section 140.4(r) requires HVAC systems with DDC to use controller logic from CEC-certified Guideline 36 programming libraries. Manufacturers must certify the programming of Guideline 36 with the Energy Commission, which includes FDD programming. The International Green Construction Code (IgCC) has a requirement for FDD usage, albeit in not as specific language as in Guideline 36.

There are similar requirements in Title 24, Part 6. The 2013 Standards adopted a mandatory requirement to include economizer FDD for air-cooled direct expansion (DX) systems with cooling equal or greater than 54,000 Btu/hr, with manufacturers certifying their FDD systems to the Energy Commission. The 2019 Title 24, Part 6 expanded the mandatory economizer FDD requirements to cover built-up systems and the 2022 Standards lowered the trigger threshold for economizer FDD to 33,000 Btu/hr. Figure 3 is a comparison between economizer FDD, ASHRAE Guideline 36, and the proposed FDD measure.



**Figure 3: A Venn Diagram of the Differences Between HVAC controls and FDD Related Measures**

FDD can provide other immediate performance benefits in a new construction project. FDD can aid the commissioning process, such as functional testing, as well as sustain energy savings over the building life. For implementation, FDD can be part of an onsite control system, or it can send data to a cloud server to enable remote system monitoring.

To calculate the performance benefit, the Statewide CASE Team modeled the prototype building with certain faults to determine their impact. The Statewide CASE Team focused on HVAC system faults not covered by the current economizer FDD mandate.

## 2.4 Modifications to Energy Code Documents

This section provides descriptions of how the proposed code change would affect each Energy Code document. See Section 7: Proposed Language Code of this report for detailed revisions to the code language.

## 2.4.1 Energy Code Change Summary

The following sections describe each proposed change to nonresidential language in Title 24, Part 6.

### SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

**Subsection 100.1(b):** Adding definitions of “Fault” and “Fault Detection and Diagnostics” to clarify these terms within the new language.

### SECTION 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

**Subsection 120.2(i): Fault Detection and Diagnostics (FDD)** The proposed measure would add the new requirements to the economizer FDD section, with the section name changed to accommodate additional requirements. The section includes baseline functional requirements for HVAC FDD in new construction and building alterations over a certain square footage (100,000 SF), and over the equipment heating and/or cooling capacity (300,000 Btu/h) threshold.

Baseline functional requirements are limited to focus on faults that are most prevalent and have the highest energy and maintenance impact based on field studies, research literature, and engineering judgement (Crowe, Chen and Granderson, et al. 2022 , Kim, et al. 2018, Zhong, Calautit and Wu 2022). The faults included in the measure are below, with explanations of their inclusion:

- HVAC operating outside of scheduled hours or permitted user override
  - Identified as one of the most common faults, high risk for energy waste, and common across building types
- Leaking or inoperable heating and cooling coil valves
  - Identified as one of the most common faults, often overlooked during routine system operation reviews, and common across building types
- Inoperable dampers
  - Similar to the valve fault, high risk for energy waste, and common across building types
- Temperature sensor failure/fault
  - Identified as one of the most common faults, often overlooked during routine system operation reviews, common across building types, and high sensor density increases the risk of missed faults
- Building HVAC control fan motor command at 100% or placed in manual override
  - Identified as one of the most common faults, and high risk for energy waste

The existing economizer FDD language would be in section 120.2(i).1, with all contents staying the same other than formatting for organization purposes. The new FDD language would be section 120.2(i).2.

## **SECTION 120.5 – REQUIRED NONRESIDENTIAL MECHANICAL SYSTEM ACCEPTANCE**

**Subsection 120.5(a)12:** The proposed changes may change the content of this subsection.

### **2.4.2 Reference Appendices Change Summary**

The Statewide CASE Team would modify NA7.5 – Mechanical Systems Acceptance Tests to specify proper testing requirements for FDD performance verification. Performance verification testing would include the following high-level steps, similar to testing for the current economizer FDD requirement:

1. Simulate the requirements to put the system in a fault condition
2. Verify the system detects the fault, diagnoses the fault, and communicates the fault per the measure
3. Return the system to normal operation
4. Verify system is functioning normally

### **2.4.3 Compliance Manuals Change Summary**

The proposed measure would add language in conjunction with the existing Economizer FDD mandatory section in Chapter 4 – Mechanical Systems, in the Nonresidential Compliance Manual. The language would describe the proposed language in Title 24, Part 6, and additional information on how stakeholders can meet the new mandatory requirement.

### **2.4.4 Alternative Calculation Method Reference Manual Change Summary**

The proposed measure would be a mandatory requirement. There are no changes needed to the Alternative Calculation Method Reference Manual.

### **2.4.5 Compliance Forms Change Summary**

**NRCA-MCH-12-A Fault Detection and Diagnostics (FDD) – Packaged Units (Certificate of Acceptance)** – The proposed measure would require updates to the form to include further FDD testing to include baseline functional requirements in the functional tests.

**NRCA-MCH-13-A Air Handling Unit (AHU) and Zone Terminal Fault Detection and Diagnostics (FDD) (Certificate of Acceptance)** – The proposed measure would

require updates to the form to include further FDD testing to include baseline functional requirements in the functional tests.

**New NRCA-MCH Certificate of Acceptance** – The goal is to include new FDD requirements in NRCA-MCH-13-A, but the proposed measure may require a new certificate of acceptance to fit the needs of the final code language.

**NRCI-MCH-E Mechanical Systems (Certificate of Installation)** – If the proposed measure requires a new Certificate of Acceptance, it would also require updates to the Mechanical Systems Certificate of Installation to include it.

**NRCC-MCH-E Mechanical Systems (Certificate of Compliance)** – If the proposed measure requires a new Certificate of Acceptance, it would also require updates to the Mechanical Systems Certificate of Compliance to include it.

**LMCC-MCH-E Mechanical Systems (Certificate of Compliance)** – If the proposed measure requires a new Certificate of Acceptance, it would also require updates to the Mechanical Systems Certificate of Compliance to include it.

**NRCC-PRF-E Non-Residential Energy Performance (Certificate of Compliance)** – If the proposed measure requires a new Certificate of Acceptance, the performance approach compliance software will require an update to include the new certificate in the auto-generated compliance form.

**LMCC-PRF-E Low-Rise Energy Performance (Certificate of Compliance)** – If the proposed measure requires a new Certificate of Acceptance, the performance approach compliance software will require an update to include the new certificate in the auto-generated compliance form.

## 2.5 Measure Context

### 2.5.1 Comparable Model Codes or Standards

The 2024 IgCC includes an FDD requirement. There are some differences between this proposed measure and the IgCC language:

- IgCC has a smaller building compliance threshold size (25,000 square feet) than the CASE proposed measure (100,000 square feet).
- The IgCC does not establish a minimum equipment cooling/heating threshold size, whereas the proposed measure language includes a minimum of 300,000 Btu/hr threshold to require FDD.
- The proposed CASE measure language includes specific faults the FDD must monitor for; the IgCC does not call out specific faults.

The Washington State Administrative Code has adopted the 2021 version of the International Energy Conservation Code (IECC) into its state building code and includes the same language as the 2024 IgCC FDD language in section WAC 51-11C-40323.

This proposal does not rely on an industry standard test procedure.

### **2.5.2 Interactions with Other Regulations**

The proposed language does not interact with federal laws and regulations, California Building Code, or any requirements local to California.

## 3. Compliance and Enforcement

---

### 3.1 Compliance Considerations

The validation process would include checking additional items for compliance and enforcement of this proposed measure. The process would mainly change by adding items to existing compliance forms and conducting similar checks that already exist for other requirements, such as economizer FDD.

The measure would require designers to include any additional requirements to enable the prescribed FDD functionality in HVAC system designs. The measure may require minor hardware control changes, but in most cases, compliance would only require updated software. To verify that the FDD requirements are met, the Plans Examiner would review the compliance forms, the controls drawings, and specifications at a high level to verify that the designer specified FDD in the design.

The measure would require field verification to ensure successful implementation, with additional acceptance testing being an ideal addition to ensure contractors are installing the functionality correctly. The acceptance test technician (ATT) would perform the required acceptance tests to verify the baseline functionality requirements in Title 24, Part 6. The code inspector would review those acceptance tests and compliance forms to verify that the FDD functionality meets minimum requirements.

The acceptance tests would be similar to acceptance tests in NRCA-MCH-13-A, which already has tests documented for economizer FDD compliance. The acceptance test technician (ATT) would need additional training to understand the FDD requirements. The new test procedures would be similar to existing economizer FDD training. The testing techniques should not be completely new to the ATT, but rather an extension of existing testing. Because there would be additional testing required, there would be an increased burden on the people responsible for verifying code compliance.

To mitigate some of the burden on code compliance verification, the proposed code change limits required FDD functionality to focus on faults that are most prevalent based on field studies, research literature (see Appendix A: Assumptions for Cost-Effectiveness Analysis for details), and engineering judgement to have the highest energy and maintenance impact in buildings.

Limiting the required faults will ease compliance verification with specific validations. Similar to existing economizer FDD faults and validation of other control system alarming, a clear description of the requirements will allow ATT and other code verification officials to more easily check for validation.

There could potentially be confusion around what triggers the requirements of this proposed code change in comparison to the new ASHRAE Guideline 36 measure and

the existing economizer FDD requirement. Compliance and enforcement officials need to understand which building types, building sizes, and HVAC system types trigger which requirements. The measure would require updates to compliance forms to include a reference table based on the mandatory criteria for each requirement. The measure would add two definitions to Title 24, Part 6, "Fault" and "Fault Detection and Diagnostics" for clear communication of what these terms mean.

## 3.2 Impact on Market Actors

The proposed code change will affect market actors during the entire lifecycle of the design and construction project. The key steps during the compliance process would impact the following market actors:

- **Design Phase:** The building owner would adjust their project requirements to adhere to the measure. Mechanical designers would need to review and ensure that their design standards include the necessary sensors for FDD functionality. They may also need to include more detail on points lists or notes on controls diagrams to show how to include FDD. Energy consultants would need to provide services documenting FDD compliance by the design teams.
- **Permit Application Phase:** The plans examiner would have to verify the NRCC-MCH-E for compliance. The proposed changes should not significantly alter the work of building officials.
- **Construction Phase:** Mechanical and controls contractors would implement the FDD functionality, either in the native BAS or enable connection to a cloud-based 3<sup>rd</sup> party FDD provider. The contractor would have to do pre-functional testing to verify the FDD is operating properly and install the additional sensors as needed.
- **Inspection Phase:** ATTs would need training to become familiar with the additional acceptance test procedures in the updated NRCA-MCH-13-A. Testing documentation would be more extensive as well. Expected additional testing would be 0.5 hours per additional fault. The builders and commissioning agents would need to include more time in the construction schedule and provide labor to support testing.

Table 3 summarizes impacts on market actors and suggests outreach and education that might be helpful to support market actors as they prepare for the effective date of the requirements.

**Table 3: Impacts on Market Actors and Suggested Training and Education Opportunities**

<b>Market Actor</b>	<b>Impact(s)</b>	<b>Suggested Outreach and Education</b>
<b>Builders <sup>a</sup></b>	Additional contracting cost and schedule for adding additional sensors and testing for FDD functionality.	Communication and training of cost estimating and scheduling impacts of FDD. Coordinating with ATT for additional compliance, schedule, and other needs.
<b>Design Professionals <sup>b</sup></b>	Understanding FDD functionality to properly specify sensors to make the FDD functionality work, and other features, such as data trending and storage.	Communication of sensor requirements, data trending, and data storage. Guideline 36 already includes sensor requirements, no additional education expected.
<b>Construction Team <sup>c</sup></b>	Installation of additional FDD functionality on the native BAS or assist in integration to a 3 <sup>rd</sup> party FDD provider.	Communication of new functional requirements, no expected additional education.
<b>Building Departments <sup>d</sup></b>	Additional compliance and enforcement reviews in permitting and inspection paperwork.	Training on what to look for during plan review and building inspections
<b>Verification Testers <sup>e</sup></b>	Learn additional skills and incorporate FDD verification testing requirements into workflow.	Additional training on new testing requirements, similar to already-required tests.
<b>Building Owners, Managers, and Occupants</b>	Reduced energy bills, better indoor air quality and comfort conditions, directed proactive O&M activities. Increased cost of installation and routine maintenance. Reduced major maintenance/replacement cost.	Communication of O&M requirements to realize energy savings, education for O&M and energy management staff on using FDD effectively.
<b>Manufacturers and Distributors</b>	Additional product demand requiring more service labor and product development.	Communication of new functional requirements.

a. Builders include builders and developers.

b. Design professionals include architects, interior designers, engineers (mechanical, electrical, plumbing, structural), specification writers, cost estimators, commissioning agents, lighting designers, and energy consultants.

c. Construction team includes general contractors, design-build contractors, installation sub-contractors (e.g., HVAC, plumbing, electrical, controls, and fire protection), commissioning agents, and tradespeople.

- d. Building departments include plans reviewers, building inspectors, specialty inspectors, permit counter technicians..
- e. Verification testers include commissioning agents, ECC Raters, and Acceptance Test Technicians.

The 2028 CASE Methodology Report presents a quantitative assessment of how changes to the California Building Code impact builders, building designers and energy consultants, and building owners and occupants. The analysis in the methodology report is not specific to the code change presented in this report. The following provides a qualitative description of how this specific code change affects various market actors and additional quantitative analyses of its potential impacts on building industry subsectors.

**Builders.** The proposed change would likely affect commercial builders; however, it would likely not impact firms focused on the construction or retrofitting of industrial buildings, utility systems, public infrastructure, or other heavy construction. The proposed change would not affect all firms and workers in the commercial building industries equally; instead, it would primarily affect specific subsectors within the industry. Table 4 shows the commercial building subsectors that the Statewide CASE Team expects to be impacted by the changes proposed in this report.

**Table 4: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code/Standard by Subsector in 2025 (Estimated)**

Construction Subsector	Establishments*	Employment	Annual Payroll (Billions \$)
<b>Nonresidential Plumbing &amp; HVAC Contractors</b>	2,270	55,182	\$5.8
<b>Other Nonresidential Equipment Contractors</b>	580	9,749	\$1.1

- a. Source: (State of California 2022)
- b. \*An establishment is single economic unit, typically at one physical location, that engages in one, or predominantly one, type of economic activity for which a single industrial classification may be applied. Many businesses are composed of multiple establishments. US Bureau of Labor Statistics, Handbook of Methods. <https://www.bls.gov/opub/hom/cew/concepts.htm>

### 3.3 Compliance Software Updates

Because the proposed code change is mandatory, the only update required to the compliance software would be incorporating any updates to compliance forms for verification as detailed in 2.4.5.

### 3.4 Cost of Enforcement

The Statewide CASE Team acknowledges that changes to the code will impact enforcement costs. This report is an evaluation of specific measures, and the collective impact of all proposed changes for the 2028 Title 24, Part 6 may represent an increase in training and/or workload for enforcement personnel.

There will be additional costs for more time to ensure compliance with the proposed code change, including training on the new measure and additional labor for enforcement and verification for all projects implementing the measure. The additional enforcement effort would be in addition to already existing compliance verification processes for HVAC equipment.

The Statewide CASE Team proposed to integrate the new training with existing training on economizer FDD. The Statewide CASE Team currently estimates additional training time to be one hour per person. For field inspection and testing, the estimated labor-hour addition for enforcement is as follows:

- **Central plant equipment (i.e., AHUs)** – An additional one and a half hours per unit for additional testing. For example, a 100,000 sq. ft. building, there are approximately 10 AHUs (one AHU per 10,000 sq. ft.), which would require an additional 15 hours of testing.
- **Terminal units (i.e., VAV boxes)** – An additional one and a half hours per tested unit for additional testing. NRCA-MCH-13-A requires testing of a minimum of 5 percent of terminal units. For example, a 100,000 sq. ft. building, there are approximately 50 terminal units (one terminal unit per 2,000 sq. ft.), which would require testing of three terminals, for an additional 4.5 hours of testing time.

*The Statewide CASE Team will be researching and documenting the projected impact on plan checkers and building inspectors, as well as additional administrative costs to manage and properly enforce the measure, including contacting AHJs and other stakeholders for estimates of additional staff time and training costs.*

## 4. Market and Economic Analysis

---

The Statewide CASE Team performed a market analysis to identify current technology availability, current market structure, and market trends. The Statewide CASE Team considered how the proposed code change may impact the market in general and individual market actors. The Statewide CASE Team gathered information through research and outreach with stakeholders, through participation in a utility-sponsored stakeholder meeting held on October 23, 2025. The Statewide CASE Team spoke with FDD providers, HVAC manufacturers, and consultants, for a total of five stakeholders interviewed.

### 4.1 Market Structure and Availability

#### 4.1.1 Current Market Structure and Availability

The market for FDD technology for HVAC systems has experienced substantial growth in recent years, driven by advances in cloud computing, product interfaces, data management capabilities, and the widespread availability of low-cost sensors. Advances in artificial intelligence (AI) technology have the potential to further enhance FDD capabilities in data tagging, pattern recognition, and automated diagnostics as the market continues to mature. Currently, more than 30 commercial FDD software tools are available in the United States (U.S.) market, offering a range of capabilities from basic fault detection to advanced predictive maintenance and automated diagnostics. These products have increasingly shifted toward software-as-a-service (SaaS) models, which align well with the continuous monitoring and real-time alert capabilities that this proposal requires. The SaaS delivery model enables building facility team to access FDD functionality without significant upfront capital investment in hardware or software infrastructure, lowering barriers to adoption.

The extent of additional sensor requirements depends on the existing BAS configuration, specific FDD capabilities desired, and existing code requirements. However, both new construction projects and existing buildings with BAS typically include comprehensive sensor arrays that support FDD functions that will meet the intent of the proposed code change without substantial additional hardware investment.

The proposed code change does not mandate any specific delivery model or business arrangement. Various approaches can achieve compliance, including SaaS platforms, on-premises software installations, BAS-integrated solutions, or embedded equipment-level FDD capabilities.

Modern FDD platforms can automatically monitor thousands of equipment faults simultaneously across multiple HVAC systems, providing real-time alerts and diagnostic

insights to the building facility team and maintenance personnel. This scalability makes FDD technology particularly well-suited for large commercial buildings, which typically operate multi-zone HVAC systems with complex operational requirements. Large facilities are well-positioned for FDD integration because they either have existing BAS or typically require new BAS installation. For existing buildings, the installed BAS provides immediate data connectivity for FDD tools. For new construction, building owners typically implement direct digital controls (DDC) through integrated BAS. In both cases, the BAS enables data exchange between building systems and FDD tools. The operational complexity inherent in large commercial buildings makes FDD implementation particularly valuable, as these facilities stand to realize significant energy savings and operational improvements through early fault detection and corrective action.

Figure 2, above in Section 2.3, illustrates various architectural approaches for implementing FDD, including cloud-based servers, on-site servers, BAS front-end integration, or embedded within control programming. These different implementation pathways involve distinct market actors within the FDD supply chain. The FDD supply chain for commercial HVAC systems encompasses three primary categories of market actors: software manufacturers and vendors, BAS and controls contractors, and commissioning service providers.

Dedicated FDD software vendors specialize in building analytics and diagnostics platforms, offering cloud-based solutions that integrate with multiple BAS platforms. Additionally, major BAS manufacturers integrate FDD capabilities within their platforms, providing unified control and diagnostics from a single vendor. Major HVAC equipment manufacturers also embed FDD features directly in their equipment controls, offering specific diagnostics at the equipment level. These vendors typically deliver their solutions through cloud-based platforms that integrate with existing BAS infrastructure.

Building automation and controls contractors serve as the primary installation and integration channel for FDD systems in commercial buildings. Controls contractors typically design FDD systems as part of the building's control package. Controls contractors install and configure both BAS and FDD software together for new construction projects, establishing integrated data connections and communication protocols. For existing buildings undergoing alterations, FDD requirements apply when major HVAC system upgrades occur. When alterations are substantial enough to trigger FDD requirements, they typically also trigger other control system upgrade requirements. Building owners would typically install or substantially upgrade their BAS infrastructure or DDC systems regardless of the FDD requirement. Controls contractors can integrate the FDD system with the existing compatible or upgraded BAS through direct protocol connections or gateway devices that translate between legacy

proprietary protocols and newer open standards, and configure data connections between existing equipment and the new FDD platform

The proposed code change does not mandate integration of FDD with an existing BAS. For both existing buildings and new construction, integrating the FDD system with the BAS is common because it is often the most cost-effective option. Alternatively, building owners may implement standalone FDD systems, as long as the systems can receive and analyze the HVAC operation data.

Commissioning providers represent a third category of market actor, often serving as the bridge between FDD technology and the building facility team. These third-party commissioning providers use FDD platforms as tools during initial commissioning for new construction, retro-commissioning for existing buildings, and ongoing commissioning activities to verify that HVAC systems continue to operate as designed over time.

Stakeholders indicated that despite increasing market share, the overall adoption of FDD in large commercial buildings remains limited. This limited adoption is due to implementation and technical barriers, including a lack of standardization, high upfront integration complexity, ongoing maintenance costs, and insufficient awareness among building facility teams about FDD capabilities and benefits.

Several emerging trends are shaping the FDD market in response to these challenges. First, the integration of AI and machine learning algorithms into FDD platforms is advancing rapidly, particularly for initial system configuration and data management, AI-assisted data tagging and cleaning are especially valuable where the quality of data labeling is often poor.

While rule-based FDD methods currently dominate the market, data-driven approaches using machine learning are gaining traction and promise to improve fault detection accuracy while reducing false alarms. The proposed code change, by mandating a system capable of providing continuous monitoring, would accelerate the accumulation of operational data necessary to train and refine these AI-based algorithms.

Second, edge computing deployment is emerging as a complement to cloud-based FDD platforms, enabling real-time processing of building data closer to the source and reducing latency in fault detection and response. This trend aligns well with the immediate notification requirements of the proposed code change.

Third, the market is experiencing increased integration between FDD platforms and other building analytics tools, including energy management systems, predictive maintenance platforms, and building performance benchmarking tools. The proposal would likely encourage further integration and interoperability among these systems, as the building facility team seeks to maximize the value of their FDD investments.

Title 24, Part 6 already has mandatory economizer FDD requirements specifically for equipment greater than 33,000 Btu/hr (2.75 tons) in size and equipped with an air-side economizer covering both packaged and built-up systems. The proposed code change would expand these requirements significantly, potentially accelerating market maturation.

Despite the technical maturity and availability of FDD solutions, current adoption rates in commercial buildings remain relatively modest. The Smart Energy Analytics Campaign targeted organizations that had already implemented or had committed to implementing FDD or energy information systems (EIS). This campaign specifically included early adopters and organizations rather than the broader commercial building market. The campaign researchers analyzed data from 104 participants representing over 567 million square feet and more than 6,500 buildings, finding that 63 percent of participants used FDD (Kramer, et al. 2020). This demonstrates that, even within this self-selected group of motivated organizations committed to energy management technology, FDD adoption was not universal. Actual market penetration across the general commercial building population is considerably lower.

The FDD market is in a relatively early stage of development, with adoption driven primarily by voluntary implementation in large commercial and institutional facilities such as universities, hospitals, corporate campuses, and portfolio owners with sustainability goals. Industry surveys indicate that approximately 38 percent of HVAC contractors report that fewer than 10 percent of their customers have inquired about FDD services, suggesting limited awareness among building owners and facility team (M. G. Albayati 2022). Through the stakeholder meeting with industry participants, over 37 percent of respondents believed there is only up to 25 percent market penetration of HVAC FDD in California for buildings over 100,000 square feet. Although the sample size is modest, this feedback provides helpful context for understanding current FDD adoption levels.

The target market for this proposal consists primarily of large commercial buildings. LBNL indicates that a substantial portfolio of large commercial buildings across the US represents a considerable opportunity for FDD deployment (Kramer, et al. 2020). These facilities typically have dedicated facility management staff capable of acting on faults diagnostics and sufficient energy consumption to justify investment in continuous monitoring systems. While this data is nationwide, it serves as the best available reference for characterizing the California market potential.

As building owners and facility teams become more familiar with the energy savings potential and operational benefits of FDD technology, the market is positioned for continued growth and maturation in the near future. The proposed code change could significantly accelerate this FDD adoption timeline and expand market penetration beyond the voluntary early adopter segment to encompass a broader cross-section of the commercial building stock.

## 4.1.2 Market Challenges and Solutions

Through literature review and interviews with different stakeholders, the Statewide CASE Team identified several categories of challenges that currently limit broader FDD deployment. The identified barriers are:

1. **Technical barriers:** Stakeholders consistently identified the complexity of integrating FDD software with BAS as a significant implementation barrier. Both new construction and existing buildings face integration challenges. In new construction, integration challenges arise from ensuring compatibility between newly installed BAS and FDD systems during the specification and commissioning phases. While in existing buildings, this barrier becomes more challenging as legacy BAS platforms with varying communication protocols present additional integration concerns. Many commercial buildings operate old BAS platforms with varying communication protocols, making seamless data exchange more challenging and costly. Additionally, when a building portfolio owner implements multiple different FDD tools across different building systems, integrating data from these different sources into a unified monitoring platform presents technical difficulties.

The second technical barrier is regarding the data quality issues, including incomplete data, low data interpretability, lack of interoperability between systems, and inconsistent control setup intervals. Poor data quality undermines FDD and may lead to false positives, missed fault detection, and reduced confidence in the FDD system.

Third, a lack of standardization across different FDD platforms creates barriers, including difficulty comparing FDD system performance across vendors, challenges in benchmarking faults across buildings for portfolio owners, and complications in developing industry-wide best practices for fault classification and response protocols. Stakeholder interviews also identified the lack of standardized point naming conventions and semantic data models as a critical technical barrier. FDD vendors reported that this absence of standardization creates major onboarding challenges, significantly increasing implementation time and costs.

Lastly, stakeholders reported challenges regarding communication and data management issues, including data overload from FDD systems generating excessive faults, a lack of labeled training datasets for FDD development, and concerns about secure two-way communications between FDD tools and building control systems. These issues can overwhelm facility staff and undermine the practical value of FDD implementation.

- 2. Economic barriers:** High upfront costs and unclear return-on-investment (ROI) are the two most referenced economic barriers for FDD adoption (Albayati, De Oliveira, et al. 2022). The upfront costs include FDD system procurement, installation, and commissioning. There are very few comprehensive studies specifically on the full range of benefits, including energy savings, maintenance cost reductions, and equipment life extension.

Stakeholders also brought up similar issues that it is difficult to demonstrate the cost-effectiveness of FDD due to challenges in isolating direct energy savings. Stakeholders reported that subscription-based pricing models face resistance, and use remains low even after installation, with vendors noting that only a small number of customers actively engage with FDD services.

- 3. Operational barriers:** The largest concern regarding the operation of FDD is the limited resources of trained staff (Pritoni, et al. 2022); (Albayati, De Oliveira, et al. 2022); (Crowe, Chen and Granderson, et al. 2022 ). Through the stakeholder meeting, 43 percent of the respondents also identified the lack of trained staff as one major barrier that prevents buildings from seeing energy efficiency benefits from FDD. Even when FDD systems successfully detect faults, limited staff resources, insufficient technical knowledge, and a lack of clear protocols for responding to identified faults can prevent timely corrective action (Chen, et al. 2022). Additionally, many FDD systems lack sophisticated functions for ranking fault severity based on energy impact or urgency levels. Without effective prioritization, the building facility team struggles to determine which faults warrant immediate attention versus routine maintenance scheduling.

Operational barriers identified through stakeholder interviews include the perception of FDD as an additional burden on the building facility team rather than a helpful tool. Vendors reported that FDD systems require six to twelve months before the facility team develops trust in the technology. The false positives and unclear response guidance would undermine system credibility as well. Inadequate operator training on system use and fault response further limits effective implementation.

Stakeholder interviews revealed several market-driven solutions emerging to address technical barriers. FDD vendors reported that advances in machine learning and artificial intelligence are reducing the manual effort required for system onboarding and metadata mapping. Currently available FDD platforms increasingly support multiple communication standards (BACnet, Modbus, etc.), reducing integration barriers. This multi-protocol support benefits both new construction and existing buildings. In new construction projects, designers may select BAS and FDD vendors independently, while in existing buildings, FDD must integrate with previously installed BAS platforms. The shift toward SaaS delivery models reduces upfront capital requirements, as building

facility teams can access FDD functionality through subscription-based pricing rather than large initial software purchases. Stakeholders reported that portfolio-based pricing structures are emerging as an alternative to per-point pricing, which improves cost predictability for building owners and encourages deployment across entire building portfolios rather than limiting coverage to reduce per-point charges.

To address other technical barriers, specifically for data quality concerns, the proposed code change establishes recommended minimum data quality metrics, including requirements for long-term continuous monitoring and specified data logging intervals. This standardized requirement would facilitate better comparability of FDD performance across different installations and vendors.

As for economic barriers, the proposed code change applies to large commercial buildings, where the cost-recovery potential is the greatest. Cost-effectiveness analysis provided in Section 5 quantifies the substantial energy savings achievable through FDD implementation in large commercial buildings, demonstrating favorable payback. Stakeholders identified that some major HVAC manufacturers, including Trane, Honeywell, and Johnson Controls, have already integrated FDD capabilities into their control platforms. Buildings with compatible BAS infrastructure from these manufacturers can access FDD functionality directly as part of the control system without requiring separate third-party subscriptions. Additionally, third-party FDD providers can still serve as a solution to buildings with diverse equipment or older systems.

To address the operational barriers, the proposed code change requires FDD systems to automatically notify the building facility team when faults occur and provide diagnostic information, including fault type and affected equipment. Automatic notification is the minimum code requirement and does not mandate specific software features or diagnostic methodologies. Additionally, the proposed code change would drive demand for training and technical support services. Beyond the minimum FDD capabilities, some FDD products available in the market include additional capabilities beyond these basic requirements. Based on stakeholder outreach, some FDD products offer fault prioritization features that rank issues by severity, energy impact, or user-defined criteria, enabling facility staff to focus limited resources on the most critical issues. The proposed code language does not require these value-added features. The specific diagnostic capabilities and prioritization methods vary by product and remain at the discretion of individual vendors. Stakeholders noted that the industry is moving toward more sophisticated fault management and AI-assisted fault diagnosis to reduce false positives and provide clearer guidance on appropriate responses. Furthermore, manufacturers are developing integrated solutions that combine control sequences with embedded FDD functionality, creating a more seamless operator experience rather than treating FDD as a separate add-on system.

## 4.2 Design and Construction Practices

### 4.2.1 Current Design and Construction Practices

In today's market, system designers do not include FDD in most projects because building owners do not commonly require it during construction or renovation projects. Many design and construction firms don't have experience with the technology and would have to adjust their processes to include FDD requirements.

#### 4.2.1.1 Design Practices

Proper HVAC system design should account for both the BAS and the FDD, and the integration between the two. The BAS is how the FDD system collects the data for analysis and would need to include FDD functionality, such as proper sensor placement for algorithms to have adequate data and data collection requirements. The current practice of designing BAS to include FDD is:

1. Developing controls drawings (i.e., schematics) and include sensors that would enable FDD functionality per the Energy Code.
2. Writing sequences of operation.
3. Writing specifications to meet the needs of the system, including specifying required system functionality such as sequences of operation and graphical user interface. Designers can specify FDD as a monitoring system to ensure the system runs as intended and efficiently.

Per individual stakeholder engagement with design and commissioning engineers, current design practices typically include performance-based requirements, specifying sequences and controls along with performance criteria for FDD implementation. There is not a deep expertise in controls for designers, but baseline design requirements need to ensure the inclusion of proper sensors to meet the performance criteria or allow the controls installer flexibility to add sensors if needed. Some sensors are harder to implement during construction after the design is complete. For example, flow sensors require a certain amount of straight duct or piping for accurate readings, designing around those sensors is more prudent.

For other design requirements like communication protocols and sequences of operations, industry standardization for controls has occurred. The industry has standardized on BACnet data protocols to allow system interoperability. Guideline 36 has standardized controls drawings and sequences, along with FDD algorithms for those sequences that are more specific requirements rather than performance based, which also standardizes FDD implementation in projects.

### 4.2.1.2 Construction Practices

During construction, controls installers have the flexibility to design the system to meet the design requirements. The implementation typically meets the design requirements for sequences of operation or point requirements, but is often manufacturer specific. For example, controls manufacturers design system architecture and controller requirements during construction to meet manufacturer-specific requirements. This impacts data collection and flow, which could impact FDD performance. Where the FDD occurs impacts how controls installers and integrators do their design.

Hosting FDD natively in the BAS or hosted remotely in the cloud has different infrastructure requirements.

- If hosted natively in the BAS:
  - The design is limited to specifying specific FDD functional requirements.
  - Construction would include the control system installer to include the FDD as part of their BAS installation. Testing would include verifying FDD functionality per the design and could happen during pre-functional testing, depending on the construction schedule.
- If hosted remotely in the cloud:
  - Many DDC systems already include cloud connectivity for remote access and monitoring, which reduces the infrastructure requirements for adding cloud-based FDD.
  - The design may require additional specifying language to include the building owner's information technology (IT) cybersecurity requirements, along with other requirements that vary by the building owner. Designers may consider specifying open communication protocols (i.e., BACnet) to provide flexibility for future system modifications or vendor changes to minimize the risk of stranded assets. Additionally, since most FDD vendors already offer BACnet connectivity, this specification maintains broad vendor choice while ensuring system interoperability.
  - Construction would impact the FDD provider, system integrator, and control system installer to ensure they properly connect the FDD. The FDD implementation could be one of the last tasks completed on the HVAC project after testing and commissioning by the HVAC contractor and commissioning agent.

The 2022 Nonresidential and Multifamily Compliance Manual has language included for economizer fault detection and diagnostics. The manual specifically calls out what requirements the system needs to meet to comply with the energy code, including required design parameters. This proposed code change would be similar to the current NR and MF economizer FDD compliance manual language, where the design would

need to call out specific ways to comply with the code requirements (California Energy Commission 2023). The 2022 CEC certificate of compliance includes a checkbox on whether the design includes current FDD measures, relying on permitting officials to verify the design.

For construction, BAS installation typically includes start-up, pre-functional testing, and functional testing of the specified control systems. The CEC certificate of acceptance for economizer FDD requires a construction inspection on whether the specified sensors are installed to their accuracy, and includes functional testing simulates the conditions of a fault so that the system (as fully under normal operation as possible) would detect the abnormal condition and verify the faults as well as the accompanying diagnostics and recommended correction are communicated properly to the BAS workstation.

#### **4.2.2 Health and Safety Considerations**

FDD will lead to a more properly performing HVAC system throughout the system's lifecycle, which will improve indoor air quality for occupants. Issues such as low airflow, stuck damper actuators, and uncalibrated sensors can lead to improper levels of ventilation, and FDD can automatically identify these faults and recommend corrective actions.

#### **4.2.3 Design and Construction Challenges and Solutions**

Because FDD is generally not a building owner requirement and included in designs, one of the biggest challenges is to ensure that design teams provide design packages that enable the FDD system. Per stakeholder interviews, control point naming conventions ease the implementation of FDD functionality because the FDD providers can easily map points to the proper algorithms.

For large buildings with thousands of control points, standardized data structures ease controls integration to BAS, and to FDD platforms. Without a naming convention or a metadata schema, mapping the control points to the proper algorithms is difficult to automate and can become a tedious and time-intensive task. A solution suggested by a stakeholder is to require a standard metadata schema as part of design and construction. There are several standard metadata schemas, such as Project Haystack, Brick Schema, and ASHRAE 223P, but they are still new to the industry. While this is a potential solution to easily implement FDD, this could be a future code change proposal to include point naming or metadata standards.

Another challenge is there would potentially be additional time during construction for the additional installation and testing required. Third-party providers can implement FDD near the end of the controls installation, or before acceptance testing begins. Since commissioning activities start during pre-design and continue throughout construction, and given the FDD installation typically occurs during the later construction phase, it

allows the commissioning agent to verify FDD functionality during performance testing. Per stakeholder meetings with third-party FDD providers, there can be minimal communication between the third-party FDD provider and the contractor, which can lead to schedule delay.

See Table 3 in Section 3.2 for a description of workforce trainings that could support effective design, installation, and commissioning.

### **4.3 Energy Equity and Environmental Justice**

The Statewide CASE Team evaluated the potential impact on environmental and social justice (ESJ) communities,<sup>1</sup> including impacts related to race, class, and gender.

The Statewide CASE Team identified potential impacts of the proposed code change via research and stakeholder input. While the listed potential impacts should be comprehensive, they may not yet be exhaustive. Recognizing the importance of engaging ESJ communities and gathering their input to inform the code change process and proposed measures, the Statewide CASE Team is working to build relationships with community-based organizations (CBOs) to facilitate meaningful engagement. Please reach out to Chris Battisti (cbattisti@trccompanies.com) if you have input on how this proposal may impact ESJ communities or if you would like to offer your perspective.

### **4.4 Impacts on Jobs and Businesses**

*The Statewide CASE Team will complete this section for the Final CASE Report.*

### **4.5 Economic and Fiscal Impacts**

*The Statewide CASE Team will complete this section for the Final CASE Report.*

---

<sup>1</sup> The California Public Utilities Commission (CPUC) refers to ESJ communities as “low-income or communities of color that have been underrepresented in the policy setting or decision-making process, are subject to a disproportionate impact from one or more environmental hazards, and likely to experience disparate implementation of environmental regulations and socio-economic investments in their communities” (CPUC 2022). ESJ communities also include the CPUC definition for Disadvantaged Communities, which comprises “(1) Census tracts receiving the highest 25 percent of overall scores in CalEnviroScreen 4.0 (1,984 tracts); (2) Census tracts lacking overall scores in CalEnviroScreen 4.0 due to data gaps, but receiving the highest 5 percent of CalEnviroScreen 4.0 cumulative pollution burden scores (19 tracts); (3) Census tracts identified in the 2017 disadvantaged community (DAC) designation as disadvantaged, regardless of their scores in CalEnviroScreen 4.0 (307 tracts); and (4) Lands under the control of federally recognized Tribes (OEHHA 2022).

## 5. Cost Effectiveness

---

### 5.1 Cost Effectiveness Methodology

The Statewide CASE Team collaborated with CEC staff to confirm that the cost-effectiveness methodology aligns with CEC guidelines, including cost inclusion parameters. The 2028 CASE Methodology Report and Appendix A provide reproducibility details.

Per California Law (Public Resources Code 25000), a measure is considered cost effective if its Benefit-Cost Ratio (BCR) is 1.0 or greater, amortized over the economic life of the structure. The Statewide CASE Team calculates BCR by dividing total dollar benefits by total dollar costs over a 30-year analysis period.

Benefits are based on Long-term System Cost (LSC), which assigns an hourly dollar value to energy use. LSC hourly factors weigh the long-term value of each hour differently, where times of peak demand are valued more than off-peak hours. These factors are not utility rates, forecasts, or bill estimates. The CEC develops and publishes LSC hourly conversion factors for each code cycle.

Costs include first costs and ongoing maintenance costs assessed over the 30-year period. Benefits and costs are evaluated incrementally, relative to the most recently adopted Energy Code. The analysis excludes design costs and incremental code compliance verification costs.

### 5.2 Energy and Energy Cost Savings Results

The Statewide CASE Team modeled each fault individually to isolate its energy impact and modeled all-faults-combined to capture interactive effects between co-occurring faults. The Statewide CASE Team then applied temporal parameters to account for realistic fault persistence durations with and without FDD. With this understanding, the savings calculation methodology provides an estimation of fault prevalence rates, persistence times, and the extent to which the FDD system reduces the time for facility team to detect and correct faults.

The Statewide CASE Team selected the large office prototype as the reference case. This building type represents a significant portion of the large commercial building stock subject to the proposed code change. The Statewide CASE Team ran simulations for all sixteen California climate zones.

*Note: The draft report presents energy savings analysis for the large office prototype only. For the final report, the Statewide CASE Team will expand the analysis to include*

*additional California Building Energy Code Compliance Software (CBECC) building prototypes representative of the commercial building stock affected by this proposal.*

The Standard Design assumes properly functioning economizer controls, reflecting the presumed effectiveness of existing economizer FDD requirements, but includes prevalent faults in other HVAC systems that are beyond the scope of current code requirements. The Proposed Design represents a building that uses the proposed HVAC FDD system to detect and correct faults in other HVAC systems more rapidly, reducing their duration and energy impact. The simulations included multiple fault conditions which are common, based on literature review (Crowe, Chen and Granderson, et al. 2022 , Kim, et al. 2018, Zhong, Calautit and Wu 2022):

- **Temperature sensor faults:** Temperature sensor faults occur when sensors drift from calibration or provide inaccurate readings, causing the control system to make decisions based on incorrect temperature data. These faults can result in multiple operational problems. For example, when zone thermostats read incorrectly, the system may provide excessive heating or cooling to maintain the incorrect setpoint, which wastes energy. Temperature sensor errors can also cause the system to run longer or at higher speeds than necessary.
- **Valve leakage:** Valve leakage occurs when heating or cooling coil valves fail to close completely, allowing continuous flow of hot or cold water through the coil even when the system calls for no heating or cooling, which increases heating and cooling energy use.
- **HVAC scheduling:** This fault represents HVAC systems maintaining occupied setpoints throughout unoccupied periods, without implementing thermostat setback. While not a mechanical failure, this operational fault wastes significant energy by conditioning spaces when unnecessary.
- **Fan failure:** Fan failure in this context refers to the fan motor manually overridden to a fixed speed, typically at maximum speed, rather than modulating based on system demand.

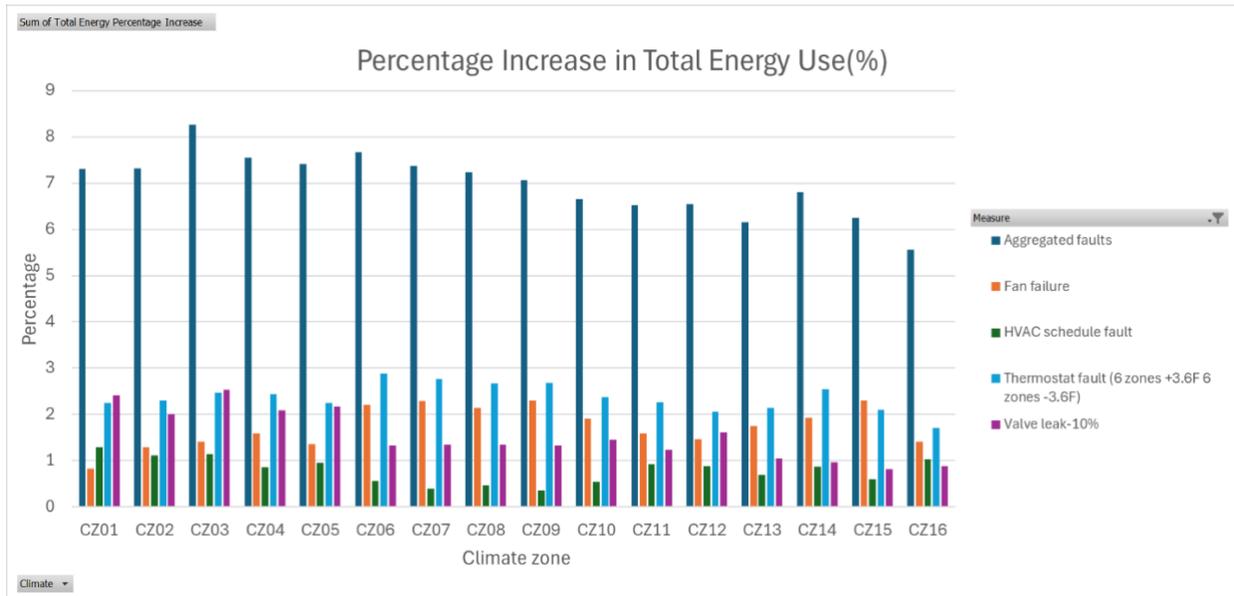
Assumptions for Cost-Effectiveness Analysis details the assumptions used for energy and energy cost savings analysis, the modeling setups, and how the modeling setups incorporate fault prevalences, temporal factors, and other modeling details.

Below, Figure 4 shows the percentage increase in whole building energy use for each individual and aggregated faults modeled in all climate zones. Each bar represents a different fault model. The x-axis shows the climate zones, and the y-axis shows the percentage increase in total building energy use.

The aggregated faults model, representing the combination of all faults, has the greatest impact, ranging from 5.5 percent to 8.2 percent increase in total building energy use.

The aggregated fault condition is not additive in a simple way with the individual faults,

and it compounds significantly due to the interactive effects that each individual fault has on the HVAC system and the other faults. Appendix A provides monthly energy use breakdowns for two representative climate zones, illustrating how faults impact electricity and natural gas usage throughout the year.



**Figure 4: Percentage Increase in Building Energy Use for Different Fault Models – OfficeLarge Prototype, All Climate Zones.**

The Statewide CASE Team applied the fault-specific savings from EnergyPlus modeling and proposed post-processing results (see Appendix A: Assumptions for Cost-Effectiveness Analysis) to CASE Measure Savings Estimation Template (MeasureSET) to generate energy and energy cost savings. Table 5 presents energy savings, peak demand reductions, natural gas savings, and source energy savings. First-year per-unit electricity savings range from 0.04 to 0.05 kilowatt-hour (kWh). Per-unit peak demand reductions range from 0.02 to 0.03 W. Total per-unit natural gas savings range from 0.08 to 0.16 kBtu. Per-unit site source energy savings range from 7.07 to 15.03 kBtu.

The total per-unit energy cost savings in terms of LSC savings realized over a 30-year period in 2029 present value dollars (2029 PV\$) ranged from \$5.51 to \$9.75 per square foot. The LSC methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 6 presents a breakdown of total LSC savings from electricity and natural gas cost savings for the large office prototype building.

**Table 5. Energy and Energy Cost Savings – Per Square Foot– OfficeLarge Prototype**

<b>Climate Zone</b>	<b>First Year Electricity Savings (kWh)</b>	<b>First Year Peak Demand Reduction (W)</b>	<b>First Year Natural Gas Savings (kBtu)</b>	<b>First Year Source Energy Savings (kBtu)</b>	<b>Total 30-Year LSC Savings (2029 PV\$)</b>
<b>1</b>	0.04	0.02	0.16	15.02	9.62
<b>2</b>	0.04	0.02	0.15	13.99	9.06
<b>3</b>	0.04	0.02	0.16	15.03	9.75
<b>4</b>	0.04	0.02	0.14	12.41	8.30
<b>5</b>	0.04	0.02	0.14	12.96	8.46
<b>6</b>	0.05	0.02	0.10	9.36	6.67
<b>7</b>	0.05	0.02	0.09	8.53	6.25
<b>8</b>	0.05	0.02	0.10	8.93	6.42
<b>9</b>	0.05	0.02	0.09	8.15	6.02
<b>10</b>	0.04	0.03	0.10	9.58	6.75
<b>11</b>	0.05	0.03	0.11	10.33	7.28
<b>12</b>	0.04	0.02	0.13	11.77	7.97
<b>13</b>	0.05	0.03	0.09	8.16	5.91
<b>14</b>	0.05	0.03	0.10	9.38	6.86
<b>15</b>	0.05	0.03	0.08	7.07	5.51
<b>16</b>	0.04	0.03	0.11	10.06	6.90

**Table 6. 2029 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – OfficeLarge Prototype**

Climate Zone	30-Year LSC Electricity Savings (2029 PV\$)	30-Year LSC Natural Gas Savings (2029 PV\$)	Total 30-Year LSC Savings (2029 PV\$)
1	0.71	8.90	9.62
2	0.76	8.30	9.06
3	0.78	8.98	9.75
4	0.78	7.52	8.30
5	0.76	7.70	8.46
6	0.83	5.83	6.67
7	0.82	5.40	6.23
8	0.82	5.60	6.42
9	0.84	5.18	6.02
10	0.81	5.94	6.75
11	0.84	6.44	7.28
12	0.76	7.20	7.97
13	0.83	5.07	5.91
14	0.93	5.93	6.86
15	1.01	4.50	5.51
16	0.80	6.10	6.90

### 5.3 Incremental First Cost

Based on the most comprehensive study to date on FDD implementation costs, the median incremental first cost for FDD is \$0.06 per square foot for commercial buildings (Kramer, et al. 2020). This cost reflects a median of \$9 per data point or a median of \$13,000 per building. The Smart Energy Analytics Campaign, which included over 6,500 buildings and 567 million square feet of total floor area nationwide, collected the cost data. The campaign collected data spanning 2016–2020, meaning the costs reflect 2020 and earlier pricing and market conditions. The Campaign collected the costs through organization reports, online surveys, and ongoing interviews. The incremental first cost includes FDD software licensing and labor fees for software installation and configuration, integration with existing BAS, and initial setup of fault prioritizations.

The study's assumption of existing 'building-level meters' meant that FDD would connect to existing data streams. So, the reported costs did not include new sensor/meter installation and initial commissioning costs beyond FDD setup. The \$0.06/sq ft cost was based on existing building implementations that added FDD to already-operational HVAC systems. The study did not include new construction

projects. For new construction applications, the Statewide CASE Team expected implementation costs to be lower due to integrated system design during initial construction, clean data from newly commissioned BAS systems, and minimal requirements for additional sensors or meters. However, the Statewide CASE Team used this conservative cost estimate in the cost-effectiveness analysis to avoid overstating economic benefits. Based on interviews with FDD industry stakeholders, FDD vendors typically price the FDD system based on building size or number of points, rather than project type. The Statewide CASE Team assumed the incremental first costs are consistent across both new construction projects and existing building alterations. After adjusting for inflation, the Statewide CASE Team estimated a \$0.09 per square foot incremental first cost for the cost-effectiveness analysis in the draft report<sup>2</sup>

## 5.4 Incremental Maintenance and Replacement Costs

Based on the Smart Energy Analytics Campaign data, the median annual recurring cost for FDD is \$0.02 per square foot (Kramer, et al. 2020). This cost reflects a median of \$4 per data point per year, and a median of \$3,500 per building per year. Additionally, organizations reported spending approximately eight hours per building per month on in-house labor for ongoing FDD use, management, and follow-up on identified issues. The annual recurring cost of \$0.02 per square foot includes annual software licensing or subscription fees and technical support from FDD vendors. According to the U.S. Bureau of Labor Statistics Occupational Employment and Wage Statistics for HVAC technicians in California, the Statewide CASE Team assumed the labor rate of \$50/hour, representing experienced technician compensation at the 90th percentile (U.S. Bureau of Labor Statistics 2023). The total annual maintenance cost is \$0.03 per square foot for the CBEECC large office prototype building. Using the same inflation rate, the Statewide CASE Team estimated that the annual maintenance cost would reach \$0.04 per square foot by the time the proposed code change takes effect<sup>2</sup>. The annual recurring costs should be similar for new construction and alterations. For the draft report, the Statewide CASE Team assumed \$0.04 per square foot per year of incremental maintenance cost for cost-effectiveness analysis.

The Statewide CASE Team assumed that mechanical systems or the BAS would require replacement at year 15 of the 30-year analysis period, which would then necessitate FDD system replacement or reconfiguration. For this analysis, the

---

<sup>2</sup> According to the U.S. Bureau of Labor Statistics Inflation Calculator, the cumulative inflation rate from year 2020 to 2026 is 25.7 percent (U.S. Bureau of Labor Statistics 2026). The Statewide CASE Team estimated the cost by the time the proposed code change takes effect assuming the same inflation rate continues.

Statewide CASE Team assumed an additional \$0.09 per square foot incremental first cost to account for FDD system replacement/upgrade.

## 5.5 Cost Effectiveness

The measure proposes a mandatory HVAC requirement. As such, this analysis demonstrates the measure's cost effectiveness over the 30-year period through lifecycle cost analysis. The Energy Commission establishes the procedures for calculating lifecycle cost-effectiveness. In the tables below, all values are presented in 2029 present value dollars (2029 PV\$). Benefits represent 30-year LSC savings and other savings, including incremental first-cost savings if the proposed first cost is less than the current first cost, incremental maintenance cost savings if the proposed maintenance costs are less than the current maintenance costs, and incremental residual value if proposed residual value is greater than current residual value at the end of the 30-year period of analysis. Costs represent the total incremental PV cost, including incremental equipment, replacement, and maintenance costs over the period of analysis. The analysis treats a negative incremental maintenance cost as a positive benefit. If total incremental costs are zero, the benefit-cost ratio (BCR) is considered infinite. Costs and other savings are discounted at a real (inflation-adjusted) three percent rate. If there are no total incremental PV costs, the BCR is infinite.

Results of the per-unit cost-effectiveness analyses are presented in Table 7 for both new construction/additions and alterations.

**Table 7. 30-Year Cost-Effectiveness Summary Per Square Foot – OfficeLarge**

<b>Climate Zone</b>	<b>Benefits LSC Savings + Other PV Savings (2029 PV\$)</b>	<b>Costs Total Incremental PV Costs (2029 PV\$)</b>	<b>Benefit-to-Cost Ratio</b>
<b>1</b>	9.62	1.38	6.97
<b>2</b>	9.06	1.38	6.56
<b>3</b>	9.75	1.38	7.07
<b>4</b>	8.30	1.38	6.01
<b>5</b>	8.46	1.38	6.13
<b>6</b>	6.67	1.38	4.83
<b>7</b>	6.23	1.38	4.51
<b>8</b>	6.42	1.38	4.65
<b>9</b>	6.02	1.38	4.36
<b>10</b>	6.75	1.38	4.89
<b>11</b>	7.28	1.38	5.27
<b>12</b>	7.97	1.38	5.77
<b>13</b>	5.91	1.38	4.28
<b>14</b>	6.86	1.38	4.97
<b>15</b>	5.51	1.38	3.99
<b>16</b>	6.90	1.38	5.00
<b>Total</b>	7.05	1.38	5.11

## 6. Statewide Impacts

---

### 6.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the statewide savings for new construction and alterations by multiplying the per square foot savings, by the statewide new construction and alterations forecast for 2029 for large office buildings, respectively (presented in Section 5.2). Appendix C presents the assumptions on the percentage of the total construction forecast that the proposed measure would impact.

For more details on the methodology and context about estimating the current market share rate, as well as statewide energy and energy cost savings, see the 2028 CASE Methodology Report.

The tables below present the first-year statewide energy and LSC savings from newly constructed buildings and additions (Table 8) and alterations (Table 9) by climate zone. Table 10 presents first-year statewide savings from new construction, additions, and alterations.

Given the data regarding the forecasts for 2029, the Statewide CASE Team estimates that the proposed code change, over the 30-year period of analysis, will reduce:

- For new constructions and additions:
  - Annual statewide electricity use by 0.60 gigawatt-hour (GWh) with an associated demand reduction of 0.32 MW.
  - Annual statewide natural gas and source energy use by 0.02 million therms and 140.63 million kBtu, respectively.
  - LSC savings by \$97.45 million in present value.
- For alterations:
  - Annual statewide electricity use by 3.13 GWh with an associated demand reduction of 1.64 MW.
  - Annual statewide natural gas and source energy use by 0.08 million therms and 689.84 million kBtu, respectively.
  - LSC savings by \$483.20 million in present value.

**Table 8: Statewide Energy and LSC Impacts – New Construction and Additions**

Climate Zone	Statewide New Construction & Additions Impacted by Proposed Change in 2029 (Million Square Feet)	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2029 PV\$)
1	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
3	2.90	0.13	0.07	0.005	43.56	28.26
4	1.41	0.16	0.03	0.002	17.55	11.74
5	N/A	N/A	N/A	N/A	N/A	N/A
6	1.27	0.06	0.03	0.001	11.93	8.50
7	0.74	0.03	0.02	0.001	6.31	4.60
8	2.05	0.09	0.05	0.002	18.31	13.16
9	3.72	0.18	0.09	0.003	30.34	22.40
10	0.35	0.02	0.01	0	3.36	2.37
11	0.10	0.00	0.00	0	1.01	0.71
12	0.51	0.02	0.01	0.001	6.06	4.10
13	N/A	N/A	N/A	N/A	N/A	N/A
14	0.18	0.01	0.01	0	1.68	1.23
15	0.01	0.001	0.0040	0	0.08	0.06
16	0.04	0.002	0.001	0	0.45	0.31
<b>Total</b>	<b>12.30</b>	<b>0.60</b>	<b>0.32</b>	<b>0.02</b>	<b>140.63</b>	<b>97.45</b>

“N/A” refers to the fact that CEC forecasts zero square feet of construction activity in this climate zone for this building type

**Table 9: Statewide Energy and LSC Impacts – Alterations**

Climate Zone	Statewide Alterations Impacted by Proposed Change in 2029 (Million Square Feet)	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2029 PV\$)
1	0.01	0	0	0	0.13	0.08
2	0.21	0.01	0.005	0	2.88	1.86
3	9.27	0.40	0.22	0.015	139.38	90.44
4	4.80	0.21	0.11	0.007	59.55	39.83
5	0.12	0.01	0.003	0	1.58	1.03
6	6.60	0.31	0.16	0.007	61.79	44.02
7	4.82	0.22	0.11	0.004	41.16	30.02
8	10.79	0.50	0.25	0.010	96.31	69.25
9	20.10	0.95	0.47	0.018	163.94	121.04
10	3.88	0.17	0.10	0.004	37.17	26.20
11	0.17	0.01	0.01	0	1.79	1.26
12	5.21	0.22	0.12	0.007	61.35	41.55
13	0.61	0.03	0.02	0.001	5.01	3.63
14	1.34	0.07	0.04	0.001	12.61	9.23
15	0.29	0.02	0.01	0	2.08	1.62
16	0.31	0.01	0.01	0	3.11	2.13
<b>Total</b>	<b>68.55</b>	<b>3.13</b>	<b>1.64</b>	<b>0.08</b>	<b>689.84</b>	<b>483.20</b>

**Table 10: Statewide Energy and LSC Impacts – New Construction, Additions, and Alterations**

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2029 PV\$)
<b>New Construction &amp; Additions</b>	0.60	0.32	0.02	140.63	97.45
<b>Alterations</b>	3.13	1.64	0.08	689.84	483.20
<b>Total</b>	<b>3.73</b>	<b>1.96</b>	<b>0.10</b>	<b>830.47</b>	<b>580.65</b>

## 6.2 Statewide Greenhouse Gas Emissions Reductions

Table 11 presents the estimated first-year reduction in greenhouse gas (GHG) emissions resulting from the proposed code change. In this initial year, the Statewide CASE Team expects to avoid 1,390 metric tons of carbon dioxide equivalent (CO<sub>2</sub>e) emissions. These reductions, along with their associated monetary value, were calculated using hourly GHG emissions factors published alongside the LSC hourly factors and source energy hourly factors in the research versions of CBECC, as well as data from the CEC’s 2028 Metrics Report. See the 2028 CASE Methodology Report for additional information.

**Table 11: First-Year Statewide GHG Emissions Impacts**

Measure	Reduced GHG Emissions from Electricity Savings (Metric Tons CO <sub>2</sub> e)	Reduced GHG Emissions from Natural Gas Savings (Metric Tons CO <sub>2</sub> e)	Total Reduced GHG Emissions (Metric Ton CO <sub>2</sub> e)	Total Monetary Value of Reduced GHG Emissions (\$)
<b>HVAC FDD</b>	897	493	1,390	171,178
<b>Total</b>	<b>897</b>	<b>493</b>	<b>1,390</b>	<b>171,178</b>

## 6.3 Statewide Water Use Impacts

The proposed code change will not result in water use impacts.

## 6.4 Statewide Material Impacts

The proposed code change will not result in any material impacts.

## 6.5 Environmental Impacts

The proposed code change will not result in any additional environmental impact besides GHG emissions.

## 6.6 Other Non-Energy Impacts

The proposed code change would lead to HVAC systems operating as intended more reliably, resulting in more consistent occupant thermal comfort and more consistently maintaining acceptable indoor air quality.

# 7. Proposed Language Code

---

## 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 2025 documents should be marked with dark blue underlining (new language) and ~~strikethroughs~~ (deletions).

## 7.2 Administrative Code (Title 24, Part 1)

There are no proposed changes to Title 24, Part 1.

## 7.3 Energy Code (Title 24, Part 6)

### Section 100.1:

Fault – a condition or a status in a system, equipment, or component 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.

---

### Section 120.2(i).1:

#### Economizer Fault Detection and Diagnostics (FDD).

---

### Section 120.2(i).2:

#### HVAC Fault Detection and Diagnostics (FDD).

A stand-alone or integrated FDD system shall be provided as specified by Table 120.2(i)2-A. The provided FDD system shall:

- A. Monitor HVAC equipment and system, and
- B. Have the capability of displaying the value of each sensor being monitored in an energy management control system or a fault management application;  
and
- C. Automatically detect the following faults:
  - i. HVAC operating outside of scheduled hours or permitted user override
  - ii. Leaking or inoperable cooling coil valves
  - iii. Leaking or inoperable heating coil valves
  - iv. Inoperable dampers

- v. Temperature sensor failure/fault
- vi. Building HVAC control fan motor command at 100% or placed in manual override
- D. Automatically diagnose faults and recommend actions to resolve the fault and return the system to original or improved operations, and
- E. Trend system performance data at least once every 15 minutes or as event-based and store data for a minimum of six months, and
- F. Communicate faults and recommended actions in one of the following ways:
  - i. Report to an energy management control system regularly monitored by facility personnel.
  - ii. Report to a fault management application, which automatically provides notification of the fault to a remote HVAC service provider.

Exception to 120.2(i)2: Systems serving hotel/motel buildings.

**Table 120.2(i)2-A HVAC FDD Applications and Qualifications**

<b>Building Status</b>	<b>Applications</b>	<b>Qualifications</b>
<b><u>Newly constructed buildings with 100,000 square feet of conditioned floor area or larger.</u></b>	<u>Air-handling system and all zones served by the system.</u>	<u>Individual systems supplying more than three zones and with design heating or cooling capacity of 300 kBtu/h and larger.</u>
<b><u>Newly constructed buildings with 100,000 square feet of conditioned floor area or larger.</u></b>	<u>Chilled water plant and all coils and terminal units served by the system.</u>	<u>Individual plants supplying more than three zones and with design cooling capacity of 300 kBtu/h and larger.</u>
<b><u>Newly constructed buildings with 100,000 square feet of conditioned floor area or larger.</u></b>	<u>Hot water plant and all coils and terminal units served by the system.</u>	<u>Individual plants supplying more than three zones and with design heating capacity of 300 kBtu/h and larger.</u>
<b><u>Additions or alterations in buildings with 100,000 square feet of conditioned floor area or larger.</u></b>	<u>Zone terminal unit such as a VAV box.</u>	<u>Where existing zones served by the same air-handling, chilled water, or hot water systems have FDD.</u>
<b><u>Additions or alterations in buildings with 100,000</u></b>	<u>Air-handling system or fan</u>	<u>Where existing air-handling system(s) and fan coil(s)</u>

Building Status	Applications	Qualifications
<u>square feet of conditioned floor area or larger.</u>	<u>coil.</u>	<u>served by the same chilled or hot water plant have FDD.</u>
<u>Additions or alterations where additions, alterations, and replacements of space conditioning systems serve a total combined floor area of 100,000 square feet or larger.</u>	<u>New air-handling system and new zones served by the system.</u>	<u>Individual systems with design heating or cooling capacity of 300 kBtu/h and larger, and supply more than three zones, and more than 75% of zones are new.</u>
<u>Additions or alterations.</u>	<u>New or upgraded chilled water plant.</u>	<u>Where all chillers are new and plant design cooling capacity is 300 kBtu/h and larger.</u>
<u>Additions or alterations.</u>	<u>New or upgraded hot water plant.</u>	<u>Where all boilers are new and plant design heating capacity is 300 kBtu/h and larger.</u>

### **Section 120.5(a)12**

Automatic FDD for chilled water plants, hot water plants, air handling units, fan coils, and zone terminal units shall be tested in accordance with NA7.5.12.

### **Section 141.0(b)2**

Exception to Section 141.0(b)2: The requirements of Section 120.2(i)1 shall not apply to alterations of space-conditioning systems or components.

## **7.4 Reference Appendices**

The Statewide CASE Team would modify NA7.5 – Mechanical Systems Acceptance Tests to specify proper testing requirements for FDD performance verification. Performance verification testing would include the following high-level steps, similar to testing for the current economizer FDD requirement:

1. Simulate the requirements to put the system in a fault condition
2. Verify the system detects the fault, diagnoses the fault, and communicates the fault per the measure

3. Return the system to normal operation
4. Verify system is functioning normally

## **7.5 Compliance Manuals**

The Statewide CASE Team will provide CEC with recommended revisions to compliance manuals after the 45-Day Language is published.

## **7.6 ACM Reference Manual**

Update section 5.7 to include FDD requirements in compliance software.

## **7.7 Compliance Forms**

As discussed in Section 2.4.5, the proposed measure will update the following compliance forms to reflect the change. The Statewide CASE Team can support the CEC in implementing these updates if the proposed change is adopted.

- NRCA-MCH-12-A Fault Detection and Diagnostics (FDD) – Packaged Units (Certificate of Acceptance)
- NRCA-MCH-13-A Air Handling Unit (AHU) and Zone Terminal Fault Detection and Diagnostics (FDD) (Certificate of Acceptance)
- New NRCA-MCH Certificate of Acceptance - if needed
- NRCC-MCH-E Mechanical Systems (Certificate of Compliance)
- LMCC-MCH-E Mechanical Systems (Certificate of Compliance)
- NRCI-MCH-E Mechanical Systems (Certificate of Installation)
- NRCC-PRF-E Non-Residential Energy Performance (Certificate of Compliance)
- LMCC-PRF-E Low-Rise Energy Performance (Certificate of Compliance)

## 8. Bibliography

---

n.d.

Albayati, M. G., De Oliveira, J., Patil, P., Gorthala, R., & Thompson, A. E. 2022. "A market study of early adopters of fault detection and diagnosis tools for rooftop HVAC systems." *Energy Reports* 14915-14933.

Albayati, Mohammed, Julia De Oliveira, Prathamesh Patil, Ravi Gorthala, and Amy E. Thompson. 2022. "A Market Study of Early Adopters of Fault Detection and Diagnosis Tools for Rooftop HVAC Systems." *Science Direct*. November. <https://www.sciencedirect.com/science/article/pii/S2352484722024039>.

Albayati, Mohammed, Ravi Gorthala, Amy Thompson, Patil Prathamesh, and Annika Hacker. 2020. "Bringing Automated Fault Detection and Diagnostics Tools for HVAC&R Into the Mainstream." *The American Society of Mechanical Engineers Digital Collection*. August. <https://asmedigitalcollection.asme.org/sustainablebuildings/article/1/3/030902/1085925/Bringing-Automated-Fault-Detection-and-Diagnostics>.

ASHRAE. 2024. "High-Performance Sequences of Operation for HVAC Systems."

California Energy Commission. 2023. "2022 Nonresidential and Multifamily Compliance Manual: for the 2022 Building Energy Efficiency Standards." <https://www.energy.ca.gov/publications/2022/2022-nonresidential-and-multifamily-compliance-manual-2022-building-energy>.

—. 2022. "Final Staff Workshop on Energy Accounting for the 2025 Building Energy Efficiency Standards." *California Energy Commission*. Prepared for the California Energy Commission. November 10. <https://www.energy.ca.gov/event/workshop/2022-11/final-staff-workshop-energy-accounting-2025-building-energy-efficiency>.

California Statewide Utility Codes and Standards. 2025. *HVAC Fault Detection and Diagnostics*. November. <https://title24stakeholders.com/measures/2028-cycle/hvac-fault-detection-and-diagnostics/>.

CBECS, Commercial Buildings Energy Consumption Survey. 2018. *2018 CBECS Survey Data*. <https://www.eia.gov/consumption/commercial/data/2018/#b1-b2>.

Chen, Yimin, Eliot Crowe, Guanjing Lin, and Jessica Granderson. 2022. "Integration of FDD Data to Aid HVAC System Maintenance ." *Proceedings of the 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*. New York: Association for Computing Machinery . 492-495.

- Crowe, Eliot, Yimin Chen, Hayden Reeve, David Yuill, Amir Ebrahimifakhar, Yuxuan Chen, Lucas Troup, Amanda Smith, and Jessica Granderson. 2023. "Empirical Analysis of the Prevalence of HVAC Faults in Commercial Buildings." *Science and Technology for the Built Environment* 1027-1038. doi:10.1080/23744731.2023.2263324.
- Crowe, Eliot, Yimin Chen, Jessica Granderson, Hayden Reeve, Lucas Troup, David Yuill, and Yuxuan Chen. 2022 . "What We Learned From Analyzing 18 Million Rows of Commercial Buildings' HVAC Fault Data." *Energy Technologies Area Publications Berkeley Lab*. August. [https://eta-publications.lbl.gov/sites/default/files/what\\_we\\_learned\\_from\\_analyzing\\_18\\_0.pdf](https://eta-publications.lbl.gov/sites/default/files/what_we_learned_from_analyzing_18_0.pdf).
- Farahmand, Farhad, Catherine Chappell, and Hillary Weitze. 2017. *Economizer Fault Detection and Diagnostics (FDD) for Built-Up Air Handlers - Final Report*. California Energy Codes and Standards Enhancement (CASE) Initiative.
- Federal Reserve Economic Data (FRED). n.d. *Data series relied on: Net Domestic Private Investment, Corporate Profits After Taxes*. Accessed September 18, 2022. <https://fred.stlouisfed.org> .
- Goel, Supriya, Rosenberg Michael, and Eley Charles. 2017. *ANSI/ASHRAE/IES standard 90.1-2016 performance rating method reference manual*. PNNL.
- Goetzler, W., R. Zogg, J. Burgos, H. Hiraiwa, and J. Young. 2011. *Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems*. US DOE.
- Gorthala, Ravi. 2022. *Bringing Fault Detection and Diagnostics (FDD) Tools into the Mainstream: Retro Commissioning and Continuous Commissioning of HVAC and Refrigeration Systems*. US DOE. <https://www.osti.gov/biblio/1889818>.
- Kim, Janghyun, Jie Cai, James E. Braun, and Stephen M. Frank. 2018. *Common faults and their prioritization in small commercial buildings*. NREL.
- Kramer, H., G. Lin, C. Curtin, E. Crowe, and J. Granderson. 2020. *Proving the Business Case for Building Analytics*. Lawrence Berkeley National Laboratory.
- Lin, Guanqing, H. Kramer, and J. Granderson. 2020. "Building fault detection and diagnostics: Achieved savings, and methods to evaluate algorithm performance." *Building and Environment* 168. doi:10.1016/j.buildenv.2019.106505.
- OEHHA. 2022. *SB 535 Disadvantaged Communities*. Accessed 2025. <https://oehha.ca.gov/calenviroscreen/sb535>.
- Pritoni, Marco, Guanqing Lin, Yimin Chen, John House, Eliot Crowe, and Jessica Granderson. 2022. "Market barriers and drivers for the next generation Fault

- Detection and Diagnostic Tools." *Energy Technologies Area Publications Berkeley Lab*. August. [https://eta-publications.lbl.gov/sites/default/files/market\\_barriers\\_and\\_drivers.pritoni.pdf](https://eta-publications.lbl.gov/sites/default/files/market_barriers_and_drivers.pritoni.pdf).
- SBW Consulting, Inc. 2022. *Water-Energy Calculator 2.0 Project Report*. Project Report, San Francisco: California Public Utility Commission.
- State of California. 2022. *Employment Development Department, Quarterly Census of Employment and Wages (data search tool)*. <https://www.labormarketinfo.edd.ca.gov/cgi/dataanalysis/areaselection.asp?tablename=industry>.
- U.S. Bureau of Labor Statistics. 2023. *California - Occupational Employment and Wage Statistics*. [https://www.bls.gov/oes/2023/may/oes\\_ca.htm](https://www.bls.gov/oes/2023/may/oes_ca.htm).
- . 2026. *CPI Inflation Calculator*. [https://www.bls.gov/data/inflation\\_calculator.htm](https://www.bls.gov/data/inflation_calculator.htm).
- Zhong, Fangliang, John Kaiser Calautit, and Yupeng Wu. 2022. "Assessment of HVAC system operational fault impacts and multiple faults interactions under climate change." *Energy*.

# Appendix A: Assumptions for Cost-Effectiveness Analysis

---

## Key Assumptions for Energy Savings Analysis

This measure proposes that new construction and building additions/alterations over 100,000 square feet of conditioned space, and with heating and/or cooling equipment capacity over 300,000 Btu/h shall include baseline functional requirements for HVAC FDD. Because the 2025 Standard has economizer FDD requirements in Section 120.2(i), the faults selected for this simulation exclude those economizer-side faults. Through the literature review, this simulation included four common fault conditions (Crowe, Chen and Granderson, et al. 2022 , Kim, et al. 2018, Zhong, Calautit and Wu 2022):

- Temperature sensor faults
- Valve leakages
- Fan failure
- HVAC scheduling

The analysis used the following simplifying assumptions regarding fault occurrence and persistence for each of the simulation cases.

- **For Standard Design:** The Statewide CASE Team assumed faults occur and persist until detected through traditional building operations. The Statewide CASE Team assumed that scheduling faults, fan stuck-at-maximum faults, and valve leakage faults each persist for three months before the building facility team detects and corrects them without FDD. For thermostat temperature sensor faults, the Statewide CASE Team assumed a two-month duration, as occupants are more likely to notice and report discomfort since this fault directly affects thermal comfort. Additionally, in buildings that allow occupants to adjust setpoints themselves, occupants may change the thermostat settings, which would essentially address the energy impact of the fault. These durations represented typical processes for how the facility team traditionally detects faults, which include addressing occupant comfort complaints, trend data analysis, and analyzing utility bills. These fault persistence assumptions represented a baseline scenario for buildings without HVAC FDD systems. The equipment would operate fault-free once corrected until the next fault occurrence for the Standard Design.
- **For Proposed Design:** The Statewide CASE Team assumed faults occur at the same rates as in the Standard Design, but the fault detection and repair are faster with FDD in place. The Statewide CASE Team assumed a one-month

duration for all faults with FDD. The equipment would operate fault-free in the Proposed Design once corrected until the next fault occurrence. For the combined-fault scenario, the Statewide CASE Team assumed the FDD can detect all co-occurring faults simultaneously if the faults are on the same piece of equipment.

The Statewide CASE Team applied the climate-zone-specific LSC hourly factors when calculating energy and energy cost impacts.

To calculate the FDD performance benefit, the Statewide CASE Team modeled the baseline prototype building with the common fault conditions found in the literature review. The Statewide CASE Team modeled each fault individually to isolate its energy impact and modeled all-faults-combined to capture interactive effects between co-occurring faults. The Statewide CASE Team then applied temporal parameters to account for realistic fault persistence durations with and without FDD. With this understanding, the savings calculation methodology provides an estimation of fault prevalence rates, persistence times, and the extent to which the FDD system reduces the time for the facility team to detect and correct faults. The Statewide CASE Team calculated the whole-building savings using a multi-step process:

- **Step 1: Determine individual and combined fault energy impacts.** The Statewide CASE Team simulated each fault type separately to determine its individual energy impact compared to fault-free operation. The Statewide CASE Team then simulated the scenario where all four faults occur simultaneously to capture realistic interactive effects when multiple faults co-occur.
- **Step 2: Decompose combined fault results and apply temporal scaling.** The Statewide CASE Team assumed the relative energy impact of each fault for each hour of the year is proportional to the annual average impact of the fault. Under this assumption, the Statewide CASE Team decomposed the total energy penalty from the combined fault scenario into individual fault components based on the proportional contribution of each fault from single-fault simulations. This decomposition enabled the application of fault-specific temporal parameters. The Statewide CASE Team then scaled the annual energy penalties from full-year simulations by realistic fault persistence durations for individual faults. This temporal scaling approach calculated the energy savings attributable to FDD by quantifying the avoided energy penalty from earlier fault correction.
- **Step 3: Calculate aggregate whole-building savings.** The Statewide CASE Team presented the whole-building level annual energy savings by combining the decomposed savings after applying temporal parameters.

The Statewide CASE Team applied the resulting annual energy savings to calculate first-year savings and projected them over the 30-year analysis period to determine total lifetime savings.

## Energy Savings Methodology per Prototypical Building

The 2028 CASE Methodology Report provides details on estimating energy savings per prototypical building and unit. The CEC directed the Statewide CASE Team to model energy impacts using specific prototypical building models that represent typical building geometries for different building types. To quantify the energy and energy cost savings potential of the proposed code change, the Statewide CASE Team conducted fault simulations using EnergyPlus. This approach was necessary because EnergyPlus includes an operational fault class that enables modeling of HVAC faults, while CBECC does not currently support fault modeling. The Statewide CASE Team exported the input data file (IDF) from a CBECC standard prototype model for use in EnergyPlus fault simulations. This section details the energy modeling results and energy savings analysis. Table 12 presents the prototype building used in the analysis. The Statewide CASE Team only modeled the large office prototype building.

**Table 12: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis**

Prototype Name	Number of Stories	Floor Area (Square Feet)	Description
<b>CBECC Large Office</b>	13	498,589	12-story + 1 basement office building with 5 zones and a ceiling plenum on each floor.

The CBECC Large Office prototype represents a 13-story office building. However, CBECC models only five representative floors to improve computational efficiency while maintaining accuracy. The prototype uses multipliers to represent multiple identical floors with a single modeled floor:

- Basement: multiplier of 1, represents 1 floor
- Ground Floor: multiplier of 1, represents 1 floor
- Mid Floor: multiplier of 5, represents 5 identical mid-level floors
- High Floor: multiplier of 5, represents 5 identical upper-level floors
- Top Floor: multiplier of 1, represents 1 floor

The Mid and High floors each have 5 thermal zones in the model. With their respective multipliers of 5, each represents 25 actual zones, though CBECC prototype handles this internally in load calculations. In total, the CBECC Large Office prototype represents 13

AHUs (containing one supply fan and one cooling coil for each AHU) and 61 thermal zones, each served by one air terminal unit (ATU). Each AHU serves five ATUs, except for the basement AHU, which serves only one ATU.

The HVAC system in the CBECC Large Office prototype is a VAV system, which includes:

- AHU:
  - The following design supply airflow rates:
    - Basement: 24,706 cfm (one unit)
    - Ground Floor: 27,512 cfm (one unit)
    - Mid Floor: 150,465 cfm (total cfm from five identical units)
    - High Floor: 150,164 cfm (total cfm from five identical units)
    - Top Floor: 28,922 cfm (one unit)
  - Each AHU contains:
    - One main heating coil and one cooling coil<sup>3</sup>
    - One supply fan
    - A set of economizer dampers
    - Temperature sensors for outdoor air, return air, mixed air, and supply air
  - Each AHU serves five ATUs, except for the Basement AHU, which serves only one ATU.
- Three return fans
- Central plant systems:
  - Central hot water heating system, which includes two boilers and two hot water pumps
  - Central water-cooled chilled water system, which includes two chillers, two cooling towers, two chilled water pumps, and two condenser water pumps
- Zonal equipment:
  - Twenty-one ATUs with hot water reheat coils, representing 61 ATUs
  - Twenty-one zone thermostats for temperature control, representing 61 thermostats

This system configuration is representative of typical large office buildings in California and contains the components most susceptible to the operational faults modeled in this analysis, including valve leakage, temperature sensor errors, HVAC scheduling, and fan

---

<sup>3</sup> CBECC Standard Design includes heating coils as part of the VAV system

malfunctions. The Statewide CASE Team simulated each fault individually using the following approaches for the Standard Design:

- Temperature sensor faults: Temperature sensor faults occur when thermostats provide inaccurate readings, causing the HVAC system to believe the zone temperature differs from actual conditions. The Statewide CASE Team modeled this fault by applying offsets of  $\pm 3.6^{\circ}\text{F}$  ( $\pm 2^{\circ}\text{C}$ ) to the affected thermostats, meaning that the system believed that the zone temperature was  $3.6^{\circ}\text{F}$  higher or lower than it actually was. The Statewide CASE Team assumed a 20 percent failure rate for thermostats (Crowe, Chen and Granderson, et al. 2022 ). The Statewide CASE Team assumed that half of the zones failed with a positive temperature offset, and the other half failed with a negative offset. Each group of thermostat failures included one core zone and five perimeter zones, resulting in a total of twelve zones with thermostat issues out of 61 total zones.
- Valve leakage: Valve leakage occurs when cooling coil valves fail to close completely, allowing chilled water to flow through the coil even when the system commands the valve to close. The Statewide CASE Team assumed a cooling coil leakage rate of 10 percent, meaning that the chilled water flow through the coil is at least 10 percent of the coil design flow rate at all times. The Statewide CASE Team assumed 40 percent of the cooling coil valves had leakages (Crowe, Chen and Granderson, et al. 2022 ). Applying this prevalence rate to the prototype model with 13 AHUs, the Statewide CASE Team modeled five AHUs with cooling coil valve leakage.
- HVAC scheduling: HVAC scheduling faults occur when systems fail to implement setback controls during unoccupied periods. In the prototype model and in the Proposed Design, the HVAC system maintained occupied thermostat setpoints ( $70\text{-}75^{\circ}\text{F}$ ) from 5 a.m. to 12 a.m. Monday through Friday. From 12 a.m. to 5 a.m. Monday through Friday and all day Saturday and Sunday (12 a.m. to 12 a.m.), the HVAC system set back and maintained unoccupied thermostat setpoints ( $60\text{-}85^{\circ}\text{F}$ ). In the Standard Design, for systems with the HVAC scheduling fault, the Statewide CASE Team assumed no HVAC set back controls for weekdays, with the system maintaining occupied thermostat setpoints all day Monday through Friday (12 a.m. to 12 a.m.), while weekend and holiday operations still had set back controls. Based on a report on common faults prevalence from NREL, the Statewide CASE Team assumes a 23 percent prevalence rate as the percentage of equipment have the scheduling faults (Kim, et al. 2018). Applying this prevalence rate to the prototype model with 13 AHUs, the Statewide CASE Team modeled three AHUs with HVAC scheduling faults.
- Fan failure: Fan failure occurs when supply fans become stuck at a fixed speed instead of modulating based on system demand. The Statewide CASE Team

modeled this scenario using a constant-speed fan curve adapted from the PNNL Performance Rating Method Reference Manual (Goel, Michael and Charles 2017), representing a fan operating at a fixed speed. For the baseline case, the team used a fan curve with static pressure reset from the same reference. The Statewide CASE Team assumed 20 percent of supply fans experience failure. Applying this prevalence rate to the prototype model with 13 AHUs, the Statewide CASE Team modeled three of them with fan failure.

To select the faulty equipment, the Statewide Case Team summed all corresponding equipment's rated capacities/design flow rates, multiplied the total by the respective prevalence percentage, and then selected one or multiple pieces of the equipment whose total capacities/flow rates were closest to that value.

The energy modeling assumptions described above represent fault conditions for estimating energy savings. The modeling assumptions are not the same as the code requirements. The Statewide CASE team uses the best information available and engineering judgment to estimate reasonable achievable savings for the cost-effectiveness analysis. FDD designers and manufacturers will determine their own actual FDD implementation details, including specific detection thresholds, time delays, fault-clearing logic, and diagnostic message formats.

An existing Title 24, Part 6 requirement covers the economizer FDD, but does not mandate FDD for other HVAC systems or components, hence the Standard Design does not detect the above HVAC systems' faults. The Proposed Design was identical to the Standard Design in all ways except for the modifications that represent the proposed code change on FDD requirements. The Standard Design represents a building minimally complying with 2025 Title 24, Part 6, simulated with the fault conditions described above to reflect typical real-world performance. The Proposed Design represents the same building with FDD enabled, allowing detection and correction of a higher percentage of faults. Table 13 presents the modified parameters and the values used in the Standard Design and Proposed Design. Specifically, the proposed conditions assume normal operations for the modeled faults.

**Table 13: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change**

Prototype ID	Climate Zone	Measure name	Equipment/Zone Modified	Objects Modified	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
CBECC Large Office	All	Temperature sensor fault (+ offset)	Core Zone: 1 in Basement Perimeter Zones: 5 on Mid-floor	Added FaultModel	ThermostatOffset	+3.6°F (+2 °C)	0 (No offset)
CBECC Large Office	All	Temperature sensor fault (- offset)	Core Zone: 1 on Top-floor Perimeter Zones: 3 on Ground-floor, 2 on Top-floor	Added FaultModel	ThermostatOffset	-3.6°F (-2 °C)	0 (No offset)
CBECC Large Office	All	Fan failure	Basement AHU, Ground-floor AHU, Top-floor AHU	Fan Performance curve	Fan Power Coefficients	A = 0.1224 B = 0.612 c = 0.5983 d = -0.3334	A = 0.04076 B = 0.0881 c = -0.0729 d = 0.9437
CBECC Large Office	All	HVAC scheduling	Basement AHU, Ground-floor AHU, Top-floor AHU	Set back HVAC Schedule	Heating and cooling thermostat setpoints	Setback thermostat setpoint to: 60°F for heating and 85°F for cooling 12 a.m.-5 a.m. M-F	Thermostat setpoint maintained at: 70°F for heating and 75°F for cooling 24 hours/day M-F
CBECC Large Office	All	Valve leakage	High-floor AHUs (multiplier of 5)	Water coil controller	Minimum Actuated flow	10% leakage (10% of design flow rate)	0 (No leakage)

At any given time in a building, there may be faults occurring, and some may have been occurring for a while. While the facility team may notice some significant faults fairly quickly, a large building over 100,000 square feet typically has unknown faults, known faults, and known faults that the facility team is actively resolving. Since each of these faults is likely to cause some energy efficiency loss, the overall performance of the building will be at a state of efficiency decline that can be represented through the likelihood of the faults occurring due to the life expectancy of the mechanical items involved (thermostats that drift over time, valves that begin to allow leak-by, and other similar items). In addition, accidental or intentional HVAC controls systems overrides can occur that cause the system, while mechanically sound, to operate in a poor efficiency manner considering the environmental conditions or other factors.

The Statewide CASE Team developed an integrated model that had all faults in a single model, as well as individual models for each fault. The Statewide CASE Team also developed temporal parameters to derive the FDD benefit by considering the incremental fault duration decrease that the proposed HVAC FDD system provides. All individual-fault and combined-faults energy models incorporated fault prevalence rates by applying the fault to only a fraction of the applicable equipment, devices, and zones. Table 14 details the temporal parameters.

The Statewide CASE Team made assumptions regarding fault duration time with and without FDD based on the expected impact on occupant comfort. Faults that significantly affect zone temperatures and thermal comfort have a higher likelihood of occupant reports to the building facility team, leading to faster detection and repair even without FDD. In contrast, faults with minimal comfort impact typically persist undetected for longer periods without FDD systems. Repair complexity also influences fault duration time. More complex faults require additional diagnostic time to identify root causes and may need specialized expertise or replacement parts, extending the time between initial detection and full resolution. The Statewide CASE Team also considered routine trend data reviews and energy bill inspections, as these analyses can reveal faults with high energy impacts. The Statewide CASE Team took the repair complexity into consideration when developing the duration time assumptions. The Statewide CASE Team assumed each fault happened once per year.

**Table 14. Fault Persistence and Recurrence Assumptions**

<b>Fault Type</b>	<b>Duration – No FDD</b>	<b>Duration – FDD</b>	<b>Fault recurrence frequency</b>
<b>Temperature sensor fault</b>	2 months	1 month	Once per year
<b>HVAC scheduling</b>	3 months	1 month	Once per year
<b>Fan failure</b>	3 months	1 month	Once per year
<b>Valve leakage</b>	3 months	1 month	Once per year

To account for the different fault durations and recurrence frequencies, the Statewide CASE Team developed a methodology that estimates the relative energy impact of each fault in the combined fault model and adjusted the energy savings based on fault-specific persistence times. The methodology decomposed the total energy penalty from combined fault simulations into individual fault components based on the interaction factors derived from individual-fault and combined-faults simulations. The Statewide CASE Team then scaled each component by its specific persistence duration with and without FDD to calculate the expected energy impact and FDD-attributable savings. This approach captured both the interaction effects between co-occurring faults and the realistic temporal dynamics of fault detection, diagnostics, and repair.

For the fault decomposition methodology, the Statewide CASE Team first calculated the annual energy penalty for each individual fault scenario  $i$  and the combined fault simulation:

$$\Delta E_{individual,i} = E_i - E_{baseline}$$

$$\Delta E_{combined} = E_{combined} - E_{baseline}$$

Then, the Statewide CASE Team calculated the interaction factor  $IF$ , which quantified how faults interacted when co-occurring:

$$IF = \frac{\Delta E_{combined}}{\sum \Delta E_i}$$

If the calculated interaction factor is greater than one, it indicates that the faults amplify each other during co-occurrence. If the interaction factor is below one, it indicates that the faults partially offset each other. If the interaction factor is equal to one, it means the faults are perfectly additive.

After calculating the interaction factor  $IF$ , the Statewide CASE Team allocated the combined energy penalty to individual fault components based on their proportional contributions:

$$\Delta E_{component,i} = IF \times \Delta E_{individual,i}$$

From there, the Statewide CASE Team applied the duration time to the decomposed energy penalty to calculate the whole building-level energy penalty with and without FDD:

- Without FDD:

$$\Delta E_{NoFDD,i} = \Delta E_{component,i} \times (t_{NoFDD,i}/1 \text{ year})$$

$$\Delta E_{NoFDD} = \sum \Delta E_{NoFDD,i}$$

- With FDD:

$$\Delta E_{FDD,i} = \Delta E_{component,i} \times (t_{FDD,i}/1 \text{ year})$$

$$\Delta E_{FDD} = \sum \Delta E_{FDD,i}$$

The final FDD savings were the difference between the energy penalties with and without FDD. The Statewide CASE Team also applied the fault recurrence rate to calculate the final savings. In this analysis, the Statewide CASE Team assumed all faults happened only once per year, so the fault recurrence rate is one:

$$\Delta E_{final} = (\Delta E_{NoFDD} - \Delta E_{FDD}) \times \rho_{rec}$$

The Statewide CASE Team applied the calculated FDD energy savings after post-processing to the MeasureSET file to calculate LSC impacts for cost-effectiveness analysis.

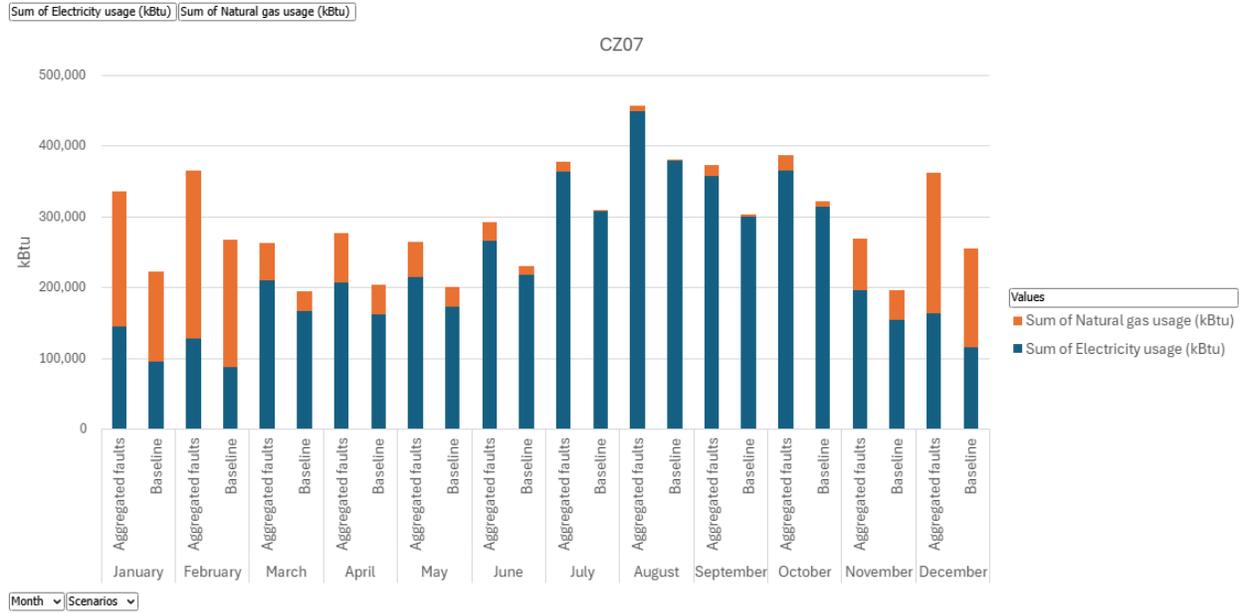
The energy impacts of the proposed code change vary by climate zone. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the CZ-specific LSC hourly factors when calculating energy and LSC impacts.

## Monthly Energy Use Patterns by Climate Zone

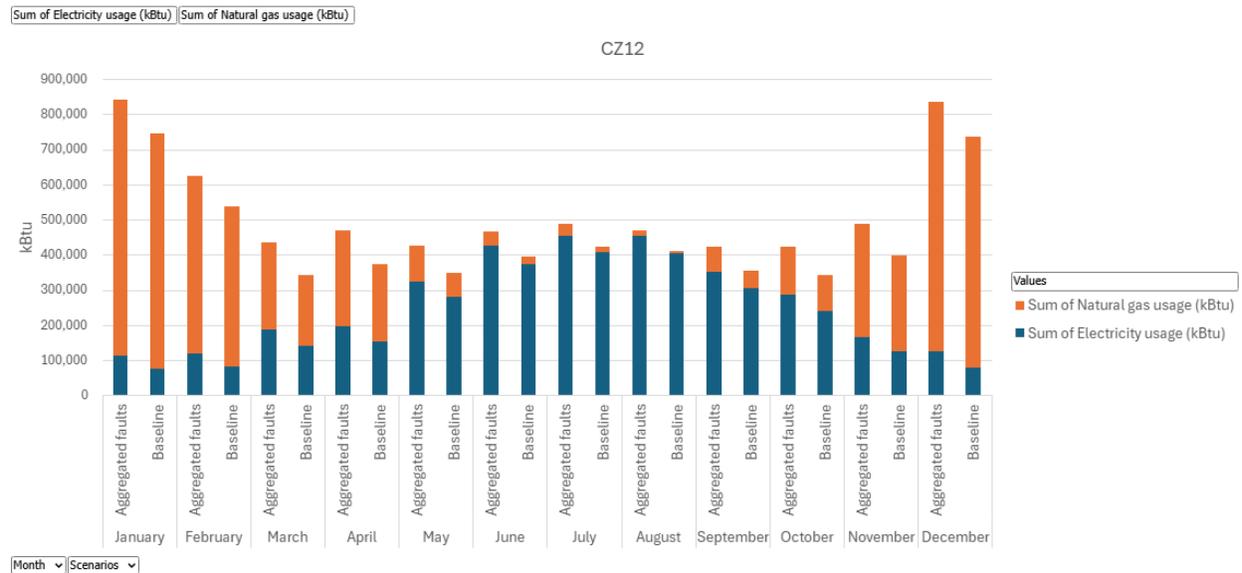
Figure 5 and Figure 6 show monthly electricity and natural gas usage for the baseline and aggregated-faults scenarios in climate zone (CZ) 7 and CZ 12, representing California's most moderate climate and a climate with significant heating and cooling loads, respectively.

In CZ 7, total energy use remained relatively consistent throughout the year with modest seasonal variations. Natural gas usage stayed stable due to minimal heating demand, while electricity consumption increased slightly during the summer months. In CZ 12, monthly energy usage varied dramatically throughout the year. Winter months showed peak natural gas consumption for heating, while summer months had elevated electricity use for cooling.

The composition of energy savings varied by climate zone and season. In CZ 7, electricity savings dominated, ranging from 40,000 to 70,000 kBtu per month with greatest savings during summer months. Natural gas savings ranged from 7,000 to 64,000 kBtu per month, changing significantly with different seasonal conditions. In CZ 12, electricity savings were consistent throughout the year, ranging from 37,000 to 52,000 kBtu per month, while natural gas savings also showed dramatical variations throughout the year, ranging from 10,000 to 58,000 kBtu per month. The monthly breakdowns demonstrate that HVAC faults increase building energy consumption year-round, with impacts varying by climate zone and seasonal variations. In both climate zones, natural gas savings are greatest during winter months while electricity savings peak during summer months, corresponding to periods when heating or cooling systems dominate energy usage.



**Figure 5: CZ 7 – Monthly Energy Use for Different Aggregated-Fault and Baseline Models – OfficeLarge Prototype**



**Figure 6: CZ 12 – Monthly Energy Use for Different Aggregated-Fault and Baseline Models – OfficeLarge Prototype.**

# Appendix B: Purpose and Necessity of Proposed Code Changes

---

## Introduction

The sections below provide the purpose and necessity of proposed changes to Title 24, Part 1; Title 24, Part 6; and the reference appendices. This section intends to provide the CEC with the information needed for the Initial Statement of Reasons.

See Section 7 of this report for marked-up code language.

## Purpose and Necessity of Changes to Title 24, Part 1

There are no proposed changes to Title 24, Part 1

## Purpose and Necessity of Changes to Title 24, Part 6

**Section:** Subsection 100.1(b)

**Purpose:** Adding definitions of “Fault” and “Fault Detection and Diagnostics”.

**Necessity:** To clarify the terms and ensure clear communication of the update.

---

**Section:** Subsection 120.2(i)

**Purpose:** The change would include baseline functional requirements for HVAC FDD in new construction and building alterations over a certain square footage (100,000 SF), and over a certain equipment heating and/or cooling capacity (300,000 Btu/h).

**Necessity:** The necessity for this change is to provide the requirements for FDD in the mandatory section of the energy code.

---

**Section:** Subsection 120.5(a)12

**Purpose:** If the proposed measure requires an additional Certificate of Acceptances, changes in this section would describe the acceptance requirements.

**Necessity:** The necessity for this change is to include the required acceptance requirements for mechanical systems when they need to include FDD.

## Purpose and Necessity of Changes to the Reference Appendices

**Section:** JA6 – HVAC Fault Detection and Diagnostic Technology

**Purpose:** The purpose of this change is to include description of the proposed FDD requirements along with the economizer FDD language, including any declaration requirements.

**Necessity:** The necessity for this change is to include updated FDD language for system manufacturers, controls suppliers, or FDD suppliers provide a declaration the requirement is met.

---

**Section:** NRCA-MCH-13-A Air Handling Unit (AHU) and Zone Terminal Fault Detection and Diagnostics (FDD) (Certificate of Acceptance)

**Purpose:** The purpose of this change is to include further testing of baseline functional requirements of FDD in systems other than AHUs and zone terminal units.

**Necessity:** This change adds new mandatory FDD requirements to the relevant Certificate of Acceptance.

---

**Section:** New Hydronic System Fault Detection and Diagnostics (FDD) (Certificate of Acceptance)

**Purpose:** The purpose of this change is to include another process to accept FDD in hydronic systems.

**Necessity:** This change adds new mandatory FDD requirements to a new Certificate of Acceptance.

---

**Section:** NRCC-MCH-E Mechanical Systems (Certificate of Compliance)

**Purpose:** The purpose of this change is to include design verification that the functional requirements of FDD were included.

**Necessity:** This change adds the new mandatory FDD requirements to the relevant Certificate of Compliance.

---

## Appendix C: Assumptions for Statewide Savings Estimates

---

The Statewide CASE Team is anticipating updated construction forecasts to be released by the California Energy Commission in February 2026. This will impact statewide energy savings but not the cost effectiveness of the proposal. The final CASE Report will present the updated savings based on the new forecasts.

The Statewide CASE Team estimated statewide impacts for the first year by multiplying per-unit savings estimates by statewide construction forecasts provided by the CEC. The 2028 CASE Methodology Report includes additional information about the methodology and assumptions used to calculate statewide energy impacts.

The statewide savings and cost estimates take the current market share rate into account. The Statewide CASE Team estimated the current market share rate based on interviews with well-informed FDD manufacturers. To estimate the percentage of floorspace affected by the proposed code change, the Statewide CASE Team combined the stakeholder input from an FDD manufacturer and LBNL Smart Energy Analytics Campaign analysis. One major FDD vendor reported approximately 450 million square feet of active projects across a 40 billion square feet of addressable U.S. market, with around 90 percent existing buildings and 10 percent new construction. On that basis, the implied market penetrations by floorspace within the vendor-defined market are around 1 percent for existing buildings and around 0.1 percent for new construction. The Statewide CASE Team treats these values as point estimates for current penetration within the vendor's market scope. For the existing buildings, LBNL's Smart Energy Analytics Campaign confirms at least 63 percent of 567 million square feet have some form of FDD (Kramer, et al. 2020). Relative to the 96 billion square feet of U.S. commercial floorspace (CBECS 2018), the Statewide CASE Team assumed 0.4 percent of existing commercial buildings were using FDD as an establishment of a verified minimum. For statewide scaling, the Statewide CASE Team assumed California's large commercial stock is similar in technology mix to the vendor's national portfolio. To assess the impacted percentage of existing buildings, the Statewide CASE Team assumed HVAC system replacement triggers the measure. With a typical HVAC system life of 15 years, the measure would impact approximately 1/15 (~6.7 percent) of building alterations annually.

Table 15 presents the projected nonresidential new construction that the proposed code change will impact in 2026. Table 16 shows the projected nonresidential existing statewide building stock that the proposed code change would affect through alterations in 2026. The Statewide CASE Team developed these estimates using the methods described in this section.

The Statewide Case Team estimated the percentage of newly constructed floorspace that the proposed code change would impact. Table 17 shows the assumed percentage of affected floorspace by building type. If a proposed code change does not apply to a specific building type, the Statewide CASE Team assumes no impact on floorspace. If the assumed percentage is non-zero, but less than 100 percent, the proposal is expected to affect some—but not all—buildings. Table 18 represents the assumed percentage of affected floorspace by climate zone.

**Table 15: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2029, by Climate Zone and Building Type (Million Square Feet)**

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	All
Large Office	0.00	0.00	2.90	1.41	0.00	1.27	0.74	2.05	3.72	0.35	0.10	0.51	0.00	0.18	0.01	0.04	13.30

**Table 16: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2026 (Alterations), by Climate Zone and Building Type (Million Square Feet)**

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	All
Large Office	0.01	0.21	9.27	4.80	0.12	6.60	4.82	10.79	20.10	3.88	0.17	5.21	0.61	1.34	0.29	0.31	68.55

**Table 17: Percentage of Nonresidential Floorspace Impacted by Proposed Code Change in 2029, by Building Type<sup>a</sup>**

<b>Building Type</b>	<b>New Construction Impacted (Percent Square Footage)</b>	<b>Existing Building Stock (Alterations) Impacted (Percent Square Footage)</b>
Large Office	100%	6.7%
Medium Office	0%	0%
Small Office	0%	0%
Large Retail	TBD	TBD
Medium Retail	0%	0%
Strip Mall	0%	0%
Mixed-Use Retail	0%	0%
Large School	TBD	TBD
Small School	0%	0%
Non-refrigerated Warehouse	0%	0%
Hotel	N/A	N/A
Assembly	TBD	TBD
Hospital	N/A	N/A
Laboratory	0%	0%
Restaurant	0%	0%
Enclosed Parking Garage	0%	0%
Open Parking Garage	0%	0%
Grocery	0%	0%
Refrigerated Warehouse	0%	0%
Controlled-Environment Horticulture	0%	0%
Vehicle Service	0%	0%
Manufacturing	0%	0%
Unassigned	0%	0%

a. Note: For Draft report, the Statewide CASE Team only applied to Large Offices. The Statewide CASE Team will expand the analysis to other building types labeled as “TBD” in the table.

**Table 18: Percentage of Nonresidential Floorspace Impacted by Proposed Measure, by Climate Zone<sup>a</sup>**

<b>Climate Zone</b>	<b>New Construction Impacted (Percent Square Footage)</b>	<b>Existing Building Stock (Alterations) Impacted (Percent Square Footage)</b>
<b>1</b>	0%	0%
<b>2</b>	0%	0%
<b>3</b>	14%	1%
<b>4</b>	12%	1%
<b>5</b>	0%	0%
<b>6</b>	8%	1%
<b>7</b>	8%	1%
<b>8</b>	10%	1%
<b>9</b>	14%	1%
<b>10</b>	3%	0%
<b>11</b>	3%	0%
<b>12</b>	3%	1%
<b>13</b>	0%	0%
<b>14</b>	6%	1%
<b>15</b>	1%	0%
<b>16</b>	4%	0%

- a. Note: For the draft report, the Statewide CASE Team assumed the percentages based on Large Office only. The Statewide CASE Team will update this table for the final report when considering other applicable large commercial building types.

## Appendix D: Environmental Analysis

---

### Potential Significant Environmental Effect of Proposal

The Statewide CASE Team has considered the environmental benefits and adverse impacts of its proposal, including—but not limited to—an evaluation of factors contained in the California Code of Regulations, Title 14, section 15064, and has determined that the proposal will not result in a significant effect on the environment.

### Direct Environmental Impacts

#### Direct Environmental Benefits

The proposed measure would result in sustained energy savings due to improved HVAC system repair and optimization, improving HVAC efficiency, and lowering GHG emissions due to increased efficiency.

#### Direct Adverse Environmental Impacts

This measure does not have any expected direct adverse environmental impacts.

### Indirect Environmental Impacts

#### Indirect Environmental Benefits

The proposed measure would lead to energy savings and would have lowered GHG emissions due to increased efficiency.

#### Indirect Adverse Environmental Impacts

This measure does not have any expected indirect adverse environmental impacts.

### Mitigation Measures

The Statewide CASE Team has considered opportunities to minimize the environmental impact of the proposal, including an evaluation of “specific economic, environmental, legal, social, and technological factors” (Cal. Code Regs., tit. 14, § 15021). The Statewide CASE Team did not determine that this measure would result in significant direct or indirect adverse environmental impacts and therefore, did not develop any mitigation measures.

## **Reasonable Alternatives to the Proposal**

The Statewide CASE Team has considered alternatives to the proposal and determined that no alternative would achieve its purpose with less environmental effect.

## **Water Use and Water Quality Impacts Methodology**

There are no impacts to water quality or water use.

# Appendix E: Summary of Stakeholder Engagement

---

## Introduction to Stakeholder Engagement

Collaborating with stakeholders who may be affected by proposed code changes is a core component of the Statewide CASE Team's process. The Statewide CASE Team engages interested parties to identify and address issues related to the proposals, with the goal of submitting recommendations to the CEC in this Draft CASE Report that reflect broad support. Public stakeholders provide valuable feedback on draft analyses and help identify and address adoption challenges, including cost effectiveness, market and technical barriers, compliance and enforcement, and 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 conducted by the Statewide CASE Team during the development and refinement of the report's recommendations.

## 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 2025 code cycle. The goal of these 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 promote transparency in the development of code change proposals, the Statewide CASE Team uses stakeholder meetings to solicit feedback on:

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

The Statewide CASE Team hosted one stakeholder meeting for NR HVAC Fault Detection and Diagnostics via webinar, as described in Table 19. Please see below for dates and links to event pages on [Title24Stakeholders.com](https://www.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.

**Table 19: Utility-Sponsored Stakeholder Meetings**

Meeting Name and Link to Materials	Meeting Date	Summary of Items Discussed
<b>First Round of Nonresidential Water Heating, HVAC, Utility-Sponsored Stakeholder Meeting</b>	Thursday, October 23, 2025	Expected baseline requirements, current market penetration, most impactful FDD algorithms, code barriers, and compliance requirements.
<b>Second Round of Nonresidential Water Heating, HVAC, Utility-Sponsored Stakeholder Meeting</b>	March, 2026	N/A

The first round of utility-sponsored stakeholder meetings began in October 2025 and served as an early forum to promote transparency and gather stakeholder feedback on measures under consideration by the Statewide CASE Team.

The objectives of the first round of stakeholder meetings were to solicit input on the scope of the 2025 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for the energy impacts and cost-effectiveness analyses; and understand potential technical and market barriers. The Statewide CASE Team also presented the initial draft code language for stakeholders to review.

The second round of utility-sponsored stakeholder meetings occurred from January to March 2026 and provided updated details on proposed code changes. These meetings introduced early results of energy, cost effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

Utility-sponsored stakeholder meetings were open to the public. For each stakeholder meeting, two promotional emails were distributed from [info@title24stakeholders.com](mailto:info@title24stakeholders.com). One email was sent to the full Title 24 Stakeholders listserv, which includes over 3,000 individuals. A second email targeted specific recipients based on their subscription preferences.

The Title 24 Stakeholders listserv is an opt-in service comprising participants from diverse industries and trades, such as manufacturers, advocacy groups, local government, and building and energy professionals. Each meeting was announced on the Title 24 Stakeholders LinkedIn page and cross-promoted on the CEC LinkedIn page approximately two weeks in advance to engage individuals, organizations, and broader channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted in to the listserv. Exported webinar meeting data, captured attendance numbers,

individual comments, and results from live attendee polls to help evaluate stakeholder participation and support.

## Statewide CASE Team Communications

The Statewide CASE Team held personal communications over email and phone with stakeholders when developing this report, listed in Table 20.

**Table 20: Engaged Stakeholders**

Organization/Individual Name	Market Role	Mentioned in CASE Report Sections
<b>Hwakong Cheng and Steve Taylor (Taylor Engineers)</b>	Design Engineering	1.3, 2.1, 4.1.2, 4.2.1, 4.2.3
<b>Paul Ehrlich (Building Intelligence Group)</b>	Smart Building Consulting	1.3, 4.1.2, 4.2.1, 4.2.3
<b>Nicholas Gayeski (Clockworks Analytics)</b>	FDD Provider	1.3, 2.1, 4.1.2, 4.2.3, 5.3
<b>James Lee (Cimetrics)</b>	FDD Provider	1.3, 4.1.2, 4.2.3, 5.3
<b>Colin Hensel, Jonathan Carosh, Wayne Stoppelmoor (Schneider Electric)</b>	Controls Manufacturer	1.3, 2.1, 4.1.2, 4.2.1, 4.2.3
<b>Eliot Crowe, John House (LBNL)</b>	Research Laboratory	2.3, 4.1.1, Appendix C