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Codes and Standards Enhancement (CASE) Initiative

2028 California Energy Code

Nonresidential HVAC Fault Detection and Diagnostics

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

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Authors:	Chris Battisti, Yuewei Li, Afshin Faramarzi, Rupam Singla, Michael Mutmansky, Mitch Greene, Tharanga Jayarathne (TRC)
Project Support:	Joe Singer and Ben Lalor (NORESCO)
Prime Contractor:	TRC
Project Management:	California Statewide Utility Codes and Standards Team: Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric Company

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Executive Summary

This proposal presents updates to nonresidential heating, ventilation, and air-conditioning (HVAC) fault detection and diagnostics (FDD) requirements for consideration in the 2028 California Energy Code (Title 24, Part 6 or Energy Code). The proposal was developed by the Statewide Codes and Standards Enhancement (CASE) Team in partnership with the California Energy Alliance (CEA) to improve building performance through HVAC system data collection, data analytics, and ongoing monitoring. The proposal will result in significant energy savings in support of California's long-term energy efficiency and Greenhouse gas (GHG) goals. The Team developed will submit the proposal to the California Energy Commission (CEC) for potential inclusion in the 2028 update to Title 24, Part 6. To be adopted, the measure must be technically feasible and cost effective.

Stakeholder feedback informed the proposed code change, associated analyses and assumptions, and compliance and enforcement approach. The Statewide CASE Team engaged building owners and facility teams, FDD providers, HVAC designers, contractors, controls manufacturers, consultants, and engineers, including direct engagement with 14 stakeholders and interviews with seven stakeholders. Feedback was gathered through email, virtual meetings, and public stakeholder meetings on October 23, 2025 and April 21, 2026; key takeaways included market and cost information, adoption barriers, compliance and enforcement clarity, cybersecurity and data privacy considerations, and acceptance testing clarifications.

The Statewide CASE Team recognizes ongoing systemic inequities in environmental and social justice (ESJ) communities and evaluated potential unintended impacts. Based on a preliminary review, the Statewide CASE Team does not expect the proposed FDD measure to have significant impact on ESJ communities.

Proposed Code Change

The proposed code change would require a stand-alone software or building automation system (BAS)-integrated FDD system on each individual qualifying HVAC equipment item, such as air handling units or heat pumps, and associated distribution systems. The requirement would apply to equipment over 300,000 Btu/hour that supplies more than three zones and is part of an HVAC system serving total conditioned space of 100,000 square feet or greater in nonresidential new construction, additions, or alterations.

Distribution systems would include associated components necessary to evaluate operation, such as terminal unit boxes, heating and cooling valves, and related sensors.

Central chilled-water and hot-water generation and their distribution piping are excluded.

The measure would require FDD systems to detect and diagnose HVAC operation outside scheduled hours and permitted user override, leaking or inoperable cooling coil valves on air handling units, leaking or inoperable heating coil valves on air handling units, inoperable terminal unit dampers, zone temperature sensor failure or fault, and building HVAC control fan motor command at 100 percent or manual override. The proposal would also add definitions for “Fault” and “Fault Detection and Diagnostics” to the code.

For existing building alterations, the requirement would apply only to new or replacement HVAC equipment installed as part of the alteration and its distribution systems; minor tenant improvements such as adding VAV (variable air volume) boxes, replacing valves and dampers, adjusting ductwork, or rebalancing existing systems without equipment replacement would not trigger FDD requirements.

Benefits of Proposed Change

HVAC FDD systems provide building facility teams with a proactive way to maintain and optimize HVAC systems by using operational data to provide actionable insights. FDD can help sustain other HVAC efficiency measures by monitoring their performance and identifying when repairs are needed.

Unlike periodic existing building commissioning, FDD uses control-system data to provide continuous oversight, automatically detects faults, and identifies issues that might otherwise go unnoticed. When facility teams act on FDD information, the system can reduce fault duration, improve operations and maintenance effectiveness, and support cost-effective, resilient energy savings over the HVAC system lifecycle.

Compliance and Enforcement

The Statewide CASE Team proposes managing compliance through existing compliance and enforcement mechanisms while avoiding new compliance pathways or third-party verification requirements. Code officials would verify that the system meets minimum requirements for enforcement, without evaluating FDD quality or confirming corrective actions.

The measure would require field verification through acceptance testing by Acceptance Test Technicians (ATTs), similar to verification of existing economizer FDD requirements. The proposal would update NRCA-MCH-12-A (Nonresidential Certificate of Acceptance – Mechanical – Fault Detection and Diagnostics – Packaged Units) and NRCA-MCH-13-A (Nonresidential Certificate of Acceptance – Mechanical – Air Handling Unit and Zone Terminal Fault Detection and Diagnostics) to include additional FDD testing. ATTs would need additional training and the testing techniques would be an extension of existing economizer FDD testing.

Market Assessment

The market for FDD technology is technically mature and commercially available. The Statewide CASE Team identified more than 30 commercial FDD software tools currently available in the U.S. market, with capabilities ranging from basic FDD to advanced predictive maintenance. Implementation options include cloud-based platforms, on-site servers, BAS-integrated solutions, and embedded equipment-level FDD capabilities.

The proposed code change would not mandate a specific delivery model or business arrangement. Interviews with manufacturers and designers confirmed FDD was technically feasible and reflects current market practice. FDD adoption in large commercial buildings remains limited because of implementation and technical barriers, lack of standardization, high upfront integration complexity, ongoing maintenance costs, and insufficient awareness among facility teams about FDD capabilities and benefits. The proposed measure is expected to generate $1.19 million in total economic output and create job opportunities in building design, energy consulting, and building inspection sectors, without disrupting California's economy or eliminating existing jobs.

Cost Effectiveness

The proposed code change is cost effective across all applicable California climate zones. Benefit-to-cost ratios[1] range from 5.85 to 10.24 for new construction and additions and from 5.86 to 10.06 for alterations, depending on climate zone and prototypical building type. Measure costs include incremental first costs and ongoing maintenance costs for FDD, while benefits reflect long-term system cost savings from reduced fault persistence and improved HVAC system performance.

[1] The benefit-to-cost ratio (BCR) compares benefits or cost savings to costs over the 30-year period of analysis. Proposed code changes with a BCR of 1.0 or greater are cost effective.

First-Year Statewide Impacts

Table 1: Summary of Statewide Impacts

Metric	Total Statewide Impacts [a]
Annual Electricity Savings (GWh)	4.93
Peak Demand Reduction (MW)	2.48
Annual Natural Gas Savings (Million Therms)	0.14
Annual Source Energy Savings (Million kBtu)	1,236.75
30-Year Long-term System Cost Savings (Million 2029 PV$)	$854.25
Annual Avoided GHG (Metric Tons CO2e/yr)	1,920.31

a. Values represent impacts from buildings permitted during the first year the code is in effect. Positive values indicate savings or reductions.

Acronyms

Table 2 presents a list of acronyms used in this report. Title24stakeholders.com also maintains a glossary of terms.

Table 2: List of Acronyms

Acronym	Definition
ACM	Alternative Calculation Method
ADA	Americans with Disabilities Act
AHU	Air Handling Unit
AI	Artificial Intelligence
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ATT	Acceptance Test Technician
BAS	Building Automation System
BCR	Benefit-to-cost Ratio
Btu	British Thermal Units
CALGreen	California Green Building Standards Code
Cal/OSHA	California Division of Occupational Safety and Health
CARB	California Air Resources Board
CASE	Codes and Standards Enhancement
CBSC	California Building Standards Commission
CBECC	California Building Energy Code Compliance Software
CEA	California Energy Alliance
CEC	California Energy Commission
CBO	Community-Based Organization
CPUC	California Public Utilities Commission
CSE	California Simulation Engine
CZ	Climate Zone
DAC	Disadvantaged Community
DDC	Direct Digital Controls
DX	Direct Expansion
ECC	Energy Code Compliance
EIS	Energy Information Systems
EMCS	Energy Management Control System
EPIC	Electric Program Investment Charge
ESJ	Environmental and Social Justice
FDD	Fault Detection and Diagnostics

Acronym	Definition
GHG	Greenhouse Gas
GWh	Gigawatt-Hour
HVAC	Heating, Ventilation, and Air Conditioning
IECC	International Energy Conservation Code
IgCC	International Green Construction Code
IOU	Investor-Owned Utility
ISOR	Initial Statement of Reasons
IT	Information Technology
kWh	Kilowatt-Hour
kWh/year	Kilowatt-Hour Per Year
LBNL	Lawrence Berkeley National Laboratory
LSC	Long-term System Cost
MeasureSET	CASE Measure Savings Estimation Template
MG	Million Gallons of Water
NAICS	North American Industry Classification System
NISTIR	National Institute of Standards and Technology Interagency or Internal Report
NPDI	Net Private Domestic Investment
NRCA	Nonresidential Certificate of Acceptance
PV	Present Value
SaaS	Software as a Service
SRIA	Standardized Regulatory Impact Assessment
UL	Underwriters Laboratories
VAV	Variable Air Volume
W	Watt

1. Introduction

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 jointly sponsored this effort. Where the term “Statewide CASE Team” is used in this report, it refers to the authors and State Building Codes Advocacy activities supported through the Codes and Standards program.

The California Energy Alliance (CEA) is a sponsor and proposal originator 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 public stakeholder meetings held by the Statewide CASE Team on October 23, 2025 and April 21, 2026, as well as additional stakeholder engagement.

During the public stakeholder workshop, key takeaways included the difficulty of compliance verification for control systems, the use of energy management control systems (EMCS) in conjunction with FDD, how this measure aligns with American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Guideline 36-2024 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, clarifications on acceptance testing clarifications, and feedback on system usability feedback.

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. The Statewide CASE Team and industry experts discussed the validity of selected faults and additional requirements to ease the implementation of FDD in design and construction, which will improve operation of the FDD system after construction is complete.

In addition, CEA and its championing Member-Partners have been engaged in the development of this proposal, providing ongoing technical and collaborative support in the measure development. The Statewide CASE Team have integrated CEA's input into this report.

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

1.4 Addressing Energy Equity and Environmental Justice

The Statewide CASE Team recognizes, acknowledges, and accounts for a history of prejudice and inequality in environmental and social justice (ESJ) communities.[2] These issues persist today. To minimize the risk of perpetuating inequity, code change proposals were developed with intentional consideration of the unintended consequences on ESJ communities.

When analyzing impacts for nonresidential buildings, the Statewide CASE Team reviewed each nonresidential building type through the lens of the four criteria: cost, health, resiliency, and comfort. The Statewide CASE Team examined which building types are used by ESJ communities most frequently and evaluated the allocation of impacts related to the following areas among all populations. Some building types have

[2] The 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 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).

unique environmental justice concerns due to their common uses, location, or other factors.

The Statewide CASE Team will continue to build relationships with CBOs and other stakeholders to improve the identification of potential impacts for future code cycles and is open to additional resources that can contribute to this effort.

2. Measure Description

2.1 Proposed Code Change

The proposed code change would require the use of a stand-alone software or building automation system (BAS) integrated fault detection and diagnostics (FDD) on each individual HVAC equipment (e.g., air handling units (AHUs), heat pumps) and associated distribution systems that meet all of the following criteria in nonresidential new construction, additions, or alterations:

- Over the size of 300,000 British thermal Units (BTU)/hour
- Supplying more than three zones, and
- Is a part of a HVAC system which serves the total conditioned space of 100,000 square feet or greater

Distribution systems include the associated components necessary to evaluate operation, including terminal unit boxes, heating and cooling valves, and related sensors. Central chilled-water and hot-water generation, along with their distribution piping, are excluded.

For existing buildings undergoing alterations, the proposed code change applies only to new or replacement HVAC equipment (over 300,000 Btu/hour) installed as part of the alteration, and its distribution systems. Minor tenant improvements to systems that do not already have FDD, such as adding VAV (variable air volume) boxes, replacing valves and dampers, adjusting ductwork, or rebalancing existing systems without equipment replacement, do not trigger FDD requirements.

The measure establishes mandatory requirements for FDD, including baseline functional performance specifications implemented by the design team to allow for project flexibility. The proposed measure would also add definitions for “Fault” and “Fault Detection and Diagnostics” to the code for clarity.

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

- HVAC operating outside of scheduled hours and outside of permitted user override
- Leaking or inoperable cooling coil valves on Air Handling Units
- Leaking or inoperable heating coil valves on Air Handling Units
- Inoperable terminal unit dampers
- Zone temperature sensor failure/fault
- Building HVAC control fan motor command at 100% or placed in manual override

Table 3 summarizes the scope of the proposed code change.

Table 3: Scope of Proposed Code Change

A ☑ indicates the proposed code change is relevant.

Building Type(s)	Construction Type(s)	Type of Change
☐ Single Family	☑ New Construction	☑ Mandatory
☐ Multifamily	☑ Additions	☐ Prescriptive
☑ Nonresidential (not Group R uses)	☑ Alterations	☐ Performance

Application Climate Zones	Energy Code Sections	Compliance Forms	Sections of ACM Reference Manuals
Climate Zones 1-16	• Definitions • Part 6, Section 401.2.2.10 *[New Section]* • Part 6, Section 501.5.2 *[Section 141.0(b)]*	NRCA-MCH-12-A NRCA-MCH-13-A	5.7

Third Party Verification	Updates to Compliance Software
☐ No changes to third party verification	☐ No updates
☑ Update existing verification requirements	☑ Update existing feature
☐ Add new verification requirements	☐ Add new feature

2.2 Benefits of Proposed Change

HVAC FDD systems provide building facility teams 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 when repairs are needed. FDD enables persistence of HVAC energy-efficiency strategies.

HVAC systems are meant to be designed, built, and operated to meet the 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 can automatically control HVAC operation and monitor, trend, and analyze the system. As an additional long-term benefit, FDD can help 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 system functionality, 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 the facility team to faults and inefficiencies, enabling timely corrective action.

The energy savings achievable with an FDD system result from two possible positive outcomes, assuming the building facility team acts on the FDD fault report information appropriately. The facility team will maintain the building at a higher level of performance on average throughout the life of the HVAC systems because the FDD system will quickly identify faults, allowing the facility team to take proper actions to correct them. This action reduces the time required to correct faults, leading the building to operate closer to an ideal condition for a longer period throughout its useful life.

Second, the maintenance team can address faults that may never have been detected without careful inspection of the system, thereby improving the ongoing efficiency of the HVAC system.

Note that an FDD system will not reduce 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) and provide potential solutions to repair them (diagnostics). By automatically detecting deficiencies and immediately repairing them, faults can be quickly resolved, improving system operation and reducing maintenance costs while maintaining occupancy comfort within intended design parameters. Unlike other historical control system measures, FDD does not control the HVAC system; instead, it uses data from within the control system to detect faults and provide a diagnosis. It is a monitoring tool that relies on action by operations and maintenance (O&M) staff to remove faults and restore the system 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 because the facility team repairs identified equipment faults more quickly than without one. Historically, the building automation system (BAS) uses system data, such as sensor readings, to “alarm” the facility team about issues, but this information can be unhelpful because it does not provide more detailed information on the problem, its root cause, or potential solutions. When investigating an alarm, system data is difficult to interpret for manual fault diagnosis and identifying corrective action. The number of alarms can add up quickly, requiring the facility team to review an overwhelming number of items, leading to ignored alarms. Conflicting priorities, such as comfort complaints or larger failures, can lead to problems going unaddressed. Even in attentive, well-staffed facility programs that are proactive about maintenance, small faults can potentially add up to increased energy consumption over time.

Studies have shown that FDD provides consistent energy savings (Kramer, Lin, Curtin, Crowe, & Granderson, 2020) (Lin, Kramer, & Granderson, 2020) (Gorthala, 2022) (Crowe, 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, Lin, Curtin, Crowe, & Granderson, 2020) (Lin, Kramer, & 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.

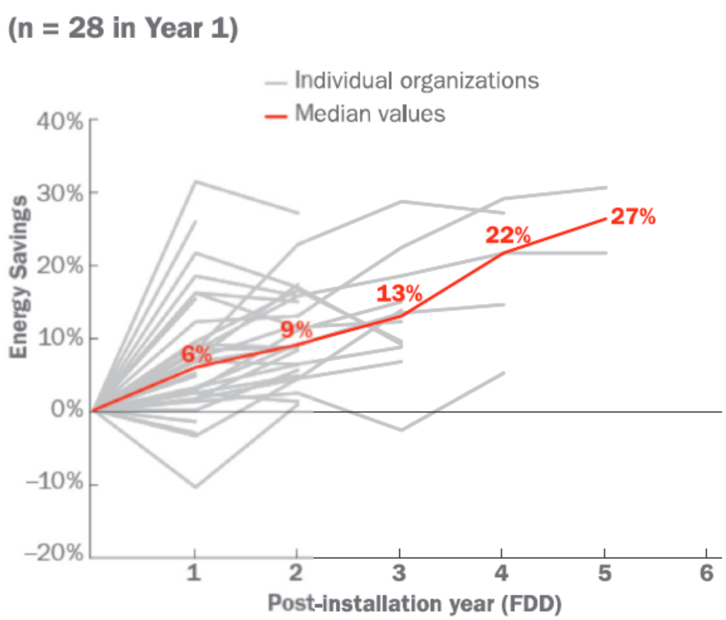

Figure 1: Percent energy savings relative to the year before FDD installation by organizations participating in the Smart Energy Analytics Campaign (Kra20)

FDD requires a DDC system or BAS to collect and analyze building and HVAC system data. These platforms collect sensors and control data from the HVAC system to provide the monitoring capability necessary for FDD analysis. Figure 2 illustrates how the BAS interfaces with various FDD implementation options. The control system architecture organizes sensors, controllers, actuators, and other system components in a one-line diagram, illustrating how data is collected and flows throughout the BAS.

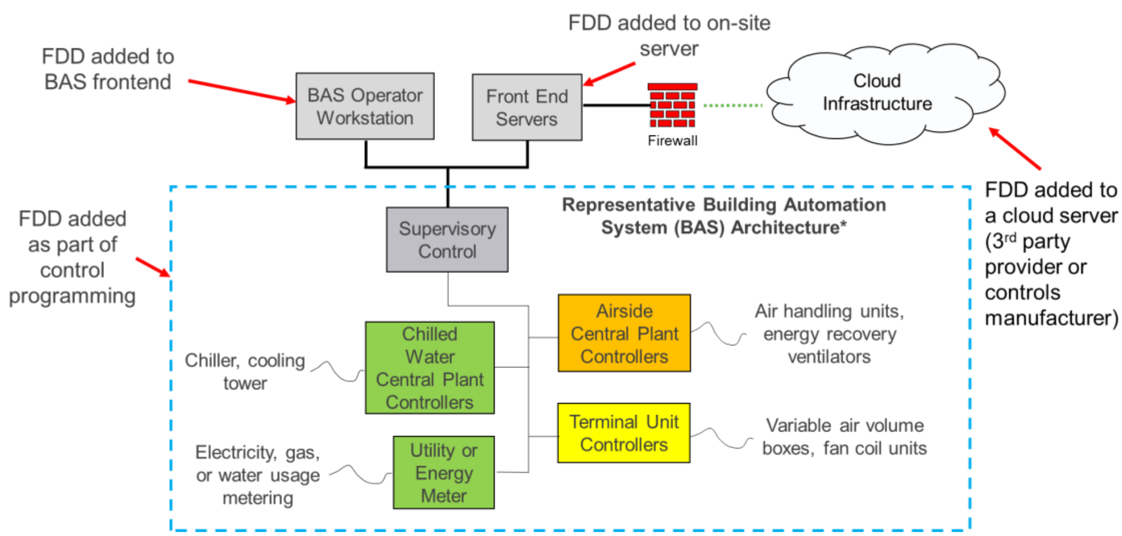

Figure 2: Representative BAS with FDD Implementation Options

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 approaches to implementing FDD, such as in the 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, with standard and accessible FDD algorithms, descriptions, and possible diagnoses for the AHU-level mechanical failure faults as included in the proposed code language. Faults include sensor errors, static pressure, and failures of the cooling and heating coil valve (ASHRAE, 2024). The FDD in Guideline 36 is based on NISTIR 7365. In addition to covering AHU FDD, NISTIR 7365 also covers terminal units and includes FDD algorithms, descriptions, and diagnoses for the terminal-unit faults in the proposed language.

The 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 compliance with Guideline 36 with the Energy Commission, including FDD programming. The International Green Construction Code (IgCC) requires FDD use, albeit in less specific language than 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.

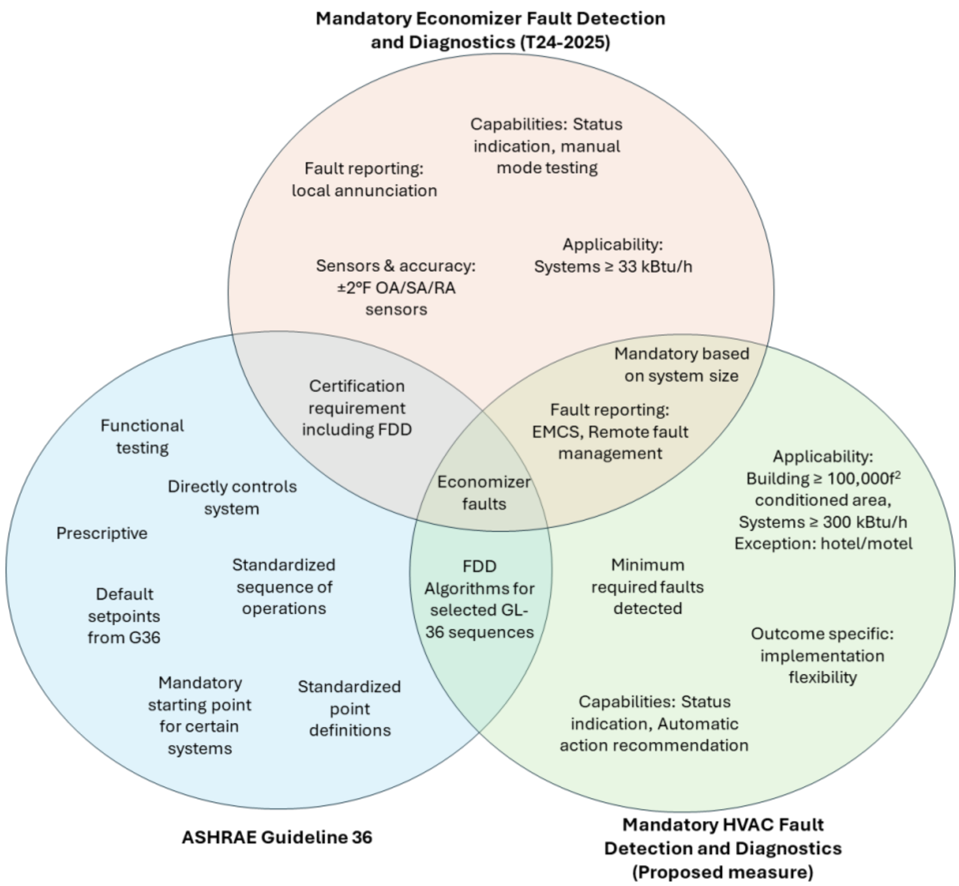

Figure 3: A Venn Diagram of the Differences Between HVAC controls and FDD Related Measures

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.

CHAPTER 2 – DEFINITIONS

Section 201 *[Subsection 100.1(b)]:* Adding definitions of “Fault” and “Fault Detection and Diagnostics” to clarify these terms within the new language.

SECTION 401.2.2 *[SECTION 120.2]* –CONTROLS FOR SPACE-CONDITIONING EQUIPMENT

Section 401.2.2.10 *[new section]:* Fault Detection and Diagnostics (FDD) The proposed measure would add the new requirements following the economizer FDD section. 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, et al., 2022 ; Kim, Cai, Braun, & Frank, 2018; Zhong, Calautit, & 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 remain in section 401.2.2.9 *[120.2(i)]*, with all contents staying the same.

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 (Nonresidential 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) (Nonresidential 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.

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, 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 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 have 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 be confusion around what triggers the requirements of this proposed code change compared to the new ASHRAE Guideline 36 measure and the existing economizer FDD requirement. Compliance and enforcement officials need to understand which building types, sizes, and HVAC systems 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" to clarify 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 point lists or notes on control 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 must verify compliance with the NRCC-MCH-E and NRCC-PRF-E. 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 by enabling connection to a cloud-based third-party FDD provider. The contractor would need to perform 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 certificate of acceptance. 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 4 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 4: Impacts on Market Actors and Suggested Training and Education Opportunities

Market Actor	Impact(s)	Suggested Outreach and Education
Owner/Developer [a]	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.
Design Professional [b]	Understanding FDD functionality to properly specify sensors to make 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.
Construction Team [c]	Installation of additional FDD functionality on the native BAS or assist in integration to a 3rd party FDD provider.	Communication of new functional requirements, no expected additional education.
Building Department [d]	Additional compliance and enforcement reviews in permitting and inspection paperwork.	Training on what to look for during plan review and building inspections
Verification Tester [e]	Learn additional skills and incorporate FDD verification testing requirements into workflow.	Additional training on new testing requirements, similar to already-required tests.
Manufacturers and Distributors	Additional product demand requires more service labor and product development.	Communication of new functional requirements.

a. Owner/Developer is funding the project and is the primary decision maker.
b. Design professionals include architects, 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 contractors (e.g., HVAC, plumbing, electrical), commissioning agents, and tradespeople.
d. Building departments include plans reviewers, building inspectors, specialty inspectors, permit counter technicians and third-party plan review and inspection.
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. While the analysis in the methodology report is not specific to the code change(s) presented in this report, this measure focuses on facility managers and property owners, since these market actors are expected to experience the most direct impacts from the requirement of FDD on certain-sized HVAC equipment in nonresidential facilities with conditioned space larger than 100,000 square feet. 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 5 lists the commercial building subsectors the Statewide CASE Team expects will be impacted by the changes proposed in this report.

Building occupants (owners and tenants). The proposed code change would have incremental costs and would reduce building owners' utility bills throughout the measure's lifetime. See the [2028 CASE Methodology Report] for a description of how LSC savings relate to occupant utility bill savings.

Table 5: 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 $)
Nonresidential Plumbing & HVAC Contractors	2,270	55,182	$5.8
Other Nonresidential Equipment Contractors	580	9,749	$1.1

Source: (State of California, 2022)

*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 to incorporate 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 the time required to ensure compliance with the proposed code change, including training on the new measure and additional labor across enforcement and verification for all projects implementing the measure. The additional enforcement effort would be in addition to the 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 that additional training time will take 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) –** Each AHU would require testing on three faults at 0.5 hours per fault, leading to an additional one and a half hours per unit for additional testing, For example, in 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, in 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 plan review function would consist of reviewing NRCC-MCH-E, LMCC-MCH-E, NRCC-PRF-E, or LMCC-PRF-E and ensuring that it meets the new code requirements and is consistent with the drawings and specifications.

Inspection review would consist of reviewing NRCI-MCH-E and ensuring the information on the forms is consistent with the approved NRCA-MCH-12-A and NRCA-MCH-13-A forms.

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 utility-sponsored stakeholder meetings held on October 23, 2025, and April 21, 2026. The Statewide CASE Team spoke with FDD providers, HVAC manufacturers, and consultants, for a total of seven 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 alerting capabilities required by this proposal. The SaaS delivery model enables building facility teams 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 of large commercial buildings makes FDD implementation particularly valuable, as these facilities can 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.

The 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 channel for installing and integrating FDD systems in commercial buildings. The controls contractors typically design FDD systems as part of the building's control package. The 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 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.

Where 2025 Title 24, Part 6 requires the use of an ASHRAE Guideline 36 certified programming library, controls contractors may use the FDD algorithms in the library to meet the intent of this measure within the BAS. For zone-level faults not covered in the programming library, contractors may reference NISTIR 7365. Aside from implementing the FDD algorithms, contractors would also need to program and configure the other features required by the proposed code language, including displaying values of monitored sensors, communicating faults and diagnoses, and trending system performance. All of these are typical features and uses of a BAS.

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 operational 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 increased market share, 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 because data-labeling quality 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 significantly expand these requirements, 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 were 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 used FDD (Kramer, Lin, Curtin, Crowe, & Granderson, 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 at 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 teams (Albayati M. G., 2022). During a stakeholder meeting with industry participants, over 37 percent of respondents believed that HVAC FDD market penetration in California for buildings over 100,000 square feet is only up to 25 percent. 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, Lin, Curtin, Crowe, & Granderson, 2020). These facilities typically have dedicated facility management staff capable of acting on fault 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. In existing buildings, this barrier becomes more challenging, as legacy BAS platforms with varying communication protocols create 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 FDD tools across different building systems, integrating data from these 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 communication 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 are the two most referenced economic barriers for FDD adoption (Albayati, De Oliveira, Patil, Gorthala, & Thompson, 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 noted 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, Patil, Gorthala, & Thompson, 2022); (Crowe, 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, Crowe, Lin, & Granderson, 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 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, improving cost predictability for building owners and encouraging deployment across entire building portfolios rather than limiting coverage to reduce per-point charges.

To address other technical barriers, specifically regarding 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. The cost-effectiveness analysis in Section 5 quantifies the substantial energy savings achievable through FDD implementation in Large Commercial buildings, demonstrating favorable payback. Stakeholders identified that major HVAC manufacturers 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 be 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 rarely require it during construction or renovation. Many design and construction firms lack experience with the technology and would need to adjust their processes to meet 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), including 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 the 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, so 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 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, control manufacturers design system architecture and controller requirements during construction to meet specific requirements. This impacts data collection and flow, which could impact FDD performance. Where the FDD occurs impacts how 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 (e.g., BACnet) to provide flexibility for future system modifications or vendor changes, thereby minimizing 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 2025 Nonresidential and Multifamily Compliance Manual has language included for economizer fault detection and diagnostics. The manual specifically outlines the 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, which requires the design to specify ways to comply with the code requirements (California Energy Commission, 2025). The 2025 CEC certificate of compliance includes a checkbox indicating whether the design includes current FDD measures, with permitting officials responsible for verifying 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 ventilation levels, 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 is not included in designs, one of the biggest challenges is ensuring 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 metadata schema, mapping control points to the proper algorithms is difficult to automate and can become a tedious and time-intensive task. A stakeholder suggested requiring 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 4 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

Each measure in this CASE Report was evaluated for ESJ impacts using 4 criteria: cost, health, resiliency, and comfort. The details of that evaluation can be found in Section 1.4 and the 2028 CASE Methodology Report.

Based on a preliminary review, the Statewide CASE Team does not expect the proposed FDD measure to have significant impact on ESJ communities. The primary effect is an initial installation cost that is offset by reduced energy use over time, resulting in modest overall cost impacts, including for ESJ communities. The measure does not affect residential systems or hospitals and does not directly influence indoor conditions. As such, health impacts are not expected to be significant because indoor air quality is unaffected; resilience impacts are minimal because the measure does not alter system reliability or emergency operations; and occupant comfort is not expected to change because indoor environmental conditions remain the same.

4.4 Impacts on Jobs and Businesses

The Statewide CASE Team does not anticipate significant employment or financial impacts on any particular sector of the California economy. However, the proposed change may have modest impacts on employment in California. The Statewide CASE Team estimates the proposed change would affect statewide employment and economic output directly and indirectly through its impact on builders, designers, energy consultants, and building inspectors. Table 6 and Table 7 outline the statewide implications for these job categories. For more information on the Statewide CASE Team's economic impacts methodology, see the 2028 CASE Methodology Report.

The Statewide CASE Team does not anticipate that the proposed changes would lead to the creation of new types of jobs or the elimination of existing types of jobs. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, it would lead to modest changes in the employment of existing jobs

Table 6: Estimated Impact that Adoption of the Proposed Measure would have on the California Building Designers and Energy Consultant Sectors

Type of Economic Impact	Employment (Jobs)	Labor Income	Total Value Added	Output
Direct Effects (Additional spending by building designers and energy consultants)	0.4	$46,376	$45,912	$72,568
Indirect Effect (Additional spending by firms supporting building designers and energy consultants)	0.2	$13,809	$19,191	$30,894
Total Economic Impacts	**0.6**	**$60,185**	**$65,103**	**$103,462**

Source: Statewide CASE Team analysis of data from the IMPLAN modeling software.

Table 7: Estimated Impact that Adoption of the Proposed Measure would have on California Building Inspectors

Type of Economic Impact	Employment (Jobs)	Labor Income	Total Value Added	Output
Direct Effects (Additional spending by building inspectors)	5.7	$645,734	$765,761	$930,553
Indirect Effect (Additional spending by firms supporting building inspectors)	0.7	$59,803	$93,143	$162,223
Total Economic Impacts	**6.4**	**$705,537**	**$858,904**	**$1,092,776**

Source: Statewide CASE Team analysis of data from the IMPLAN modeling software.

The proposed change represents a modest adjustment to BAS and HVAC FDD mandatory requirements, which is not expected to excessively burden or competitively disadvantage California businesses, nor is it expected to lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not expect the proposed code changes to result in the creation of new businesses or the elimination of existing ones.

The proposed code changes would apply to all businesses operating in California, regardless of whether the business is incorporated inside or outside of the state.[3] Therefore, the Statewide CASE Team does not anticipate that the proposed changes would have an advantageous or an adverse effect on the

[3] Gov. Code, §§ 11346.3(c)(1)(C), 11346.3(a)(2); 1 CCR § 2003(a)(3) Competitive advantages or disadvantages for California businesses currently doing business in the state.

competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate that businesses located outside of California would be advantaged or disadvantaged.

The Statewide CASE Team derived a reasonable estimate of the change in investment by California businesses based on the estimated change in economic activity associated with the proposed measure and its expected effect on business income. The Statewide CASE Team's IMPLAN modeling estimated a $316,157 decrease in California business income due to the proposed code change. The Statewide CASE Team assumed that net business investment is positively correlated with business income and that a portion of business income will be allocated to net business investment.

To estimate the portion of business income that would be allocated to net investment, the Statewide CASE Team analyzed national data on corporate profits and net capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[4] As Table 8 shows, between 2020 and 2024, NPDI as a percentage of corporate profits ranged from a low of 18 percent in 2020 due to the worldwide economic slowdowns associated with the COVID-19 pandemic to a high of 28 percent in 2022, with an average of 23 percent. While only an approximation of the proportion of business income used for net capital investment, it provides a reasonable estimate of the proportion of proprietor income that business owners would reinvest into expanding their capital stock.

Table 8: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits (Percent)
2020	389	2,212	18
2021	545	2,888	19
2022	825	2,951	28
2023	836	3,069	27
2024	885	3,441	26
5-Year Average	**Intentionally blank**	**Intentionally blank**	**23**

Source: (Federal Reserve Economic Data (FRED), n.d.)

Given the estimated total increase in California business income and net business investment ratio described above, the Statewide CASE Team estimates the proposed

[4] Net private domestic investment is the total amount of investment in capital by the business sector that is used to expand the capital stock, rather than maintain or replace due to depreciation. Corporate profit is the money left after a corporation pays its expenses.

code change would result in a $74,214 decrease in net private investment by California businesses.

4.5 Economic and Fiscal Impacts

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to a significant change (increase or decrease) in investment, directly or indirectly, in any affected sectors of California's economy. The proposed change would not result in economic disruption to any sector of the California economy. For more information on the Statewide CASE Team's economic and fiscal impacts methodology, see the 2028 CASE Methodology Report.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial building industry, architects, energy consultants, and building inspectors. The Statewide CASE Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2028 code cycle regulations would result in additional spending by those businesses.

4.5.1 Effects on the State General Fund, State Special Funds, and Local Governments

The Statewide CASE Team does not expect the proposed code changes to have a measurable impact on California's General Fund, any state special funds, or local government funds.

Cost to State: The state government already has a budget for code development, education, and compliance enforcement. While the state government would be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs for the state government are small when compared to the overall cost savings and policy benefits associated with the code change proposals. The proposed code change is expected to impact large state buildings undergoing major alterations or additions, but the Statewide CASE Team has found the measure to be cost effective.

Cost to Local Governments: All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this retraining is an expense to local governments, it is not a new cost associated with the 2025 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining, including tools, training, and resources provided by the IOU Codes and Standards program (such as Energy Code Ace). As noted in Section , the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

4.5.2 Mandates on Local Agencies or School Districts

This proposed measure would require implementing HVAC FDD in new construction of large local agency and school district buildings, or undergoing major alterations or additions, which meet the proposed code language requirement. The Statewide CASE Team has found the measure to be cost effective in schools.

4.5.3 Costs to Local Agencies or School Districts

This proposed measure may result in added costs to local agencies or school districts on new construction of large local agency and school district buildings, or undergoing major alterations or additions, which meet the proposed code language requirement. This could require reimbursement pursuant to California Constitution, Government Code sections 17500 et seq., which requires "the state to reimburse local agencies and school districts for any costs that they are required to incur after July 1, 1980, as a result of a statute enacted or any executive order implementing any statute enacted on or after January 1, 1975, which mandates a new program or higher level of service of an existing program."

The extent of the costs would depend on the specific circumstances of each facility. Please see Section 5 for cost effectiveness of the measure.

4.5.4 Costs or Savings to Any State Agency

This proposed measure may result in added costs and savings to local agencies or school districts with new construction of large local agency and school district buildings, or undergoing major alterations or additions, which meet the proposed code language requirement. Please see Section 5 for cost effectiveness of the measure.

4.5.5 Other Non-Discretionary Cost or Savings Imposed on Local Agencies

This proposed measure may result in added costs and savings to local agencies or school districts with new construction of large local agency and school district buildings, or undergoing major alterations or additions, which meet the proposed code language requirement. Please see Section 5 for cost effectiveness of the measure.

4.5.6 Costs or Savings in Federal Funding to the State

There are no costs or savings to federal funding to the state due to the measure not requiring federal funding to implement.

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 estimates 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 selected the Large Office and Large School prototypes as the reference cases. The building types represent significant portions of the Large Commercial building stock subject to the proposed code change. The Statewide CASE Team ran simulations for all sixteen California climate zones.

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, et al., 2022 ; Kim, Cai, Braun, & Frank, 2018; Zhong, Calautit, & Wu, 2022):

- **Temperature sensor faults**: Temperature sensor faults occur when sensors drift from calibration or provide inaccurate readings, leading 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 during unoccupied periods, without implementing thermostat setbacks. While not a mechanical failure, this operational fault wastes significant energy by conditioning spaces when unnecessary.
- **Fan failure**: In this context, fan failure refers to the fan motor being manually overridden to a fixed speed, typically at maximum speed, rather than modulating based on system demand.

Appendix A details the assumptions used for energy and energy cost savings analysis, the modeling setups, and how these incorporate fault prevalence, temporal factors, and other modeling details. Figure 4 shows the percentage increase in whole-building energy use for each individual and aggregated fault modeled across all climate zones of Large Office prototype. 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, which represents the combination of all faults, ranges from a 5.5 percent to a 8.2 percent increase in total building energy use. Figure 5 shows the percentage increase in total energy use for Large School prototype, ranging from 8 percent to 9.3 percent under the aggregated fault scenario. The aggregated fault condition accounts for the interactive effects of each individual fault on the HVAC system and the other faults. Appendix A provides additional details on the interactive effects of the aggregated fault scenario.

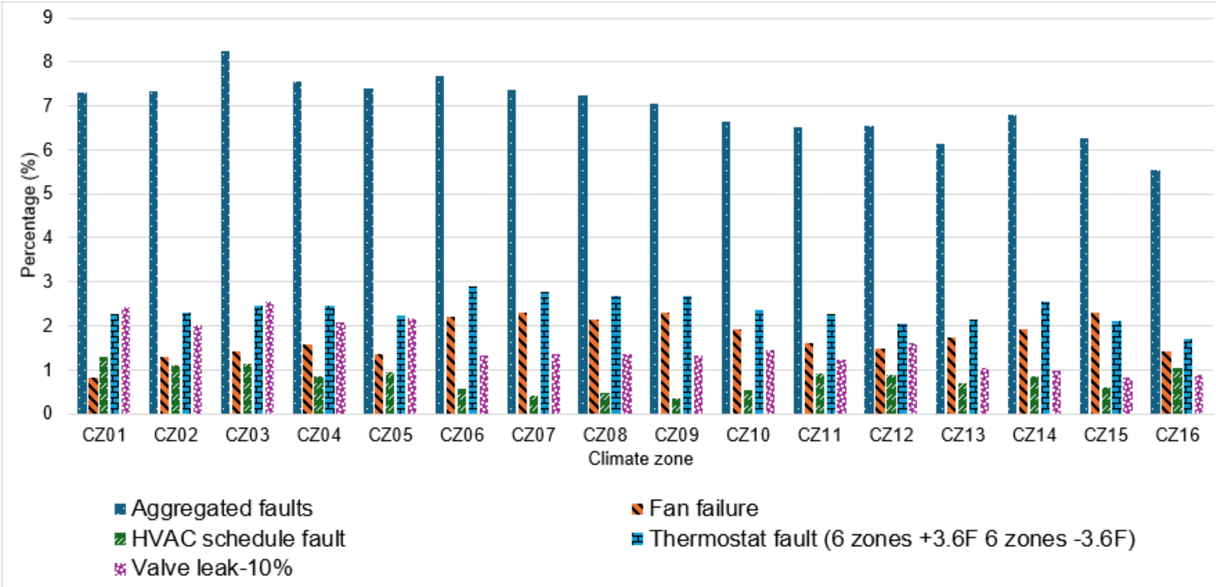

Figure 4: Percentage increase in building energy use for different fault models – OfficeLarge Prototype, all climate zones.

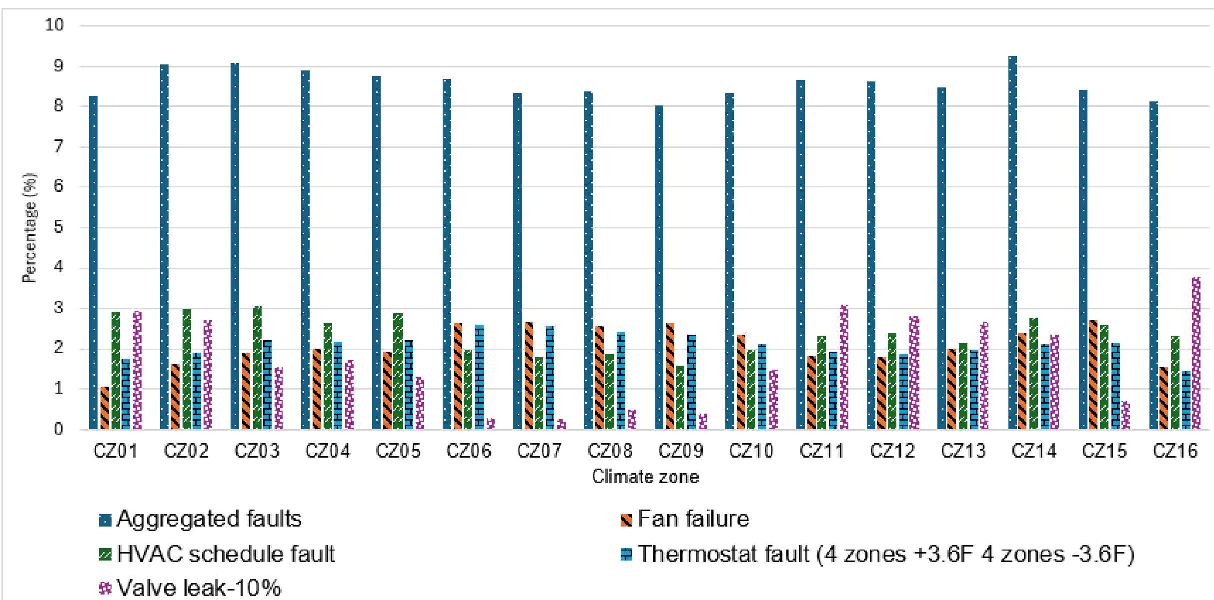

Figure 5: Percentage increase in building energy use for different fault models – SchoolLarge Prototype, all climate zones.

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 the CASE Measure Savings Estimation Template (MeasureSET) to generate energy and energy cost savings. Table 9 and Table 10 presents energy savings, peak demand reductions, natural gas savings, and source energy savings for both prototypes, respectively. First-year per-unit electricity savings range from 0.03 to 0.05 kilowatt-hour (kWh). Per-unit peak demand reductions range from 0.01 to 0.03 W. Total per-unit natural gas savings range from 0.08 to 0.23 kBtu. Per-unit site source energy savings range from 7.07 to 21.39 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 for Large Office, and $6.79 to $14.01 per square foot for Large School. The LSC methodology values peak electricity savings higher than non-peak electricity savings.

Table 9: Energy and Energy Cost Savings – Per Square Foot– OfficeLarge Prototype

Climate Zone	First Year Electricity Savings (kWh)	First Year Peak Demand Reduction (W)	First Year Natural Gas Savings (kBtu)	First Year Source Energy Savings (kBtu)	Total 30-Year LSC Savings (2029 PV$)
1	0.04	0.02	0.16	15.02	9.62
2	0.04	0.02	0.15	13.99	9.06
3	0.04	0.02	0.16	15.03	9.75
4	0.04	0.02	0.14	12.41	8.30
5	0.04	0.02	0.14	12.96	8.46
6	0.05	0.02	0.10	9.36	6.67
7	0.05	0.02	0.09	8.53	6.23
8	0.05	0.02	0.10	8.93	6.42
9	0.05	0.02	0.09	8.15	6.02
10	0.04	0.03	0.10	9.58	6.75
11	0.05	0.03	0.11	10.33	7.28
12	0.04	0.02	0.13	11.77	7.97
13	0.05	0.03	0.09	8.16	5.91
14	0.05	0.03	0.10	9.38	6.86
15	0.05	0.03	0.08	7.07	5.51
16	0.04	0.03	0.11	10.06	6.90

Table 10: Energy and Energy Cost Savings – Per Square Foot – SchoolLarge Prototype

Climate Zone	First Year Electricity Savings (kWh)	First Year Peak Demand Reduction (W)	First Year Natural Gas Savings (kBtu)	First Year Source Energy Savings (kBtu)	Total 30-Year LSC Savings (2029 PV$)
1	0.03	0.02	0.23	21.39	13.55
2	0.04	0.02	0.22	20.61	13.88
3	0.04	0.02	0.19	17.03	10.67
4	0.04	0.02	0.17	15.89	10.20
5	0.03	0.02	0.17	15.27	9.91
6	0.04	0.01	0.12	10.71	7.33
7	0.04	0.01	0.11	9.99	6.79
8	0.04	0.01	0.12	11.08	7.43
9	0.04	0.01	0.11	10.23	6.93
10	0.04	0.02	0.15	13.49	9.10
11	0.04	0.03	0.20	18.46	11.95
12	0.04	0.02	0.20	17.73	12.93
13	0.04	0.02	0.17	14.83	10.65
14	0.04	0.02	0.18	16.79	11.42
15	0.05	0.03	0.13	12.00	8.30
16	0.04	0.03	0.22	19.91	14.01

Table 11 and Table 12 present the breakdown of total LSC savings from electricity and natural gas cost savings for the Large Office and Large School prototype buildings, respectively.

Table 11: 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

Table 12: 2029 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – SchoolLarge 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	0.59	12.96	13.55
2	0.66	13.22	13.88
3	0.63	10.04	10.67
4	0.64	9.56	10.20
5	0.62	9.29	9.91
6	0.67	6.66	7.33
7	0.67	6.12	6.79
8	0.67	6.76	7.43
9	0.67	6.26	6.93
10	0.67	8.43	9.10
11	0.73	11.21	11.95
12	0.68	12.25	12.93
13	0.73	9.92	10.65
14	0.81	10.62	11.42
15	0.87	7.43	8.30
16	0.76	13.25	14.01

5.3 Incremental First Cost

The Statewide CASE Team collected incremental first-cost data in November 2025, drawing on the most comprehensive study to date on FDD implementation costs (Kramer, Lin, Curtin, Crowe, & Granderson, 2020). The study, published in October 2020, reports a median incremental first cost of $0.06 per square foot for a commercial building. This cost reflects a median of $9 per data point or $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 for software installation and configuration, integration with existing BAS, and initial fault prioritization setup.

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 by building size or number of points, rather than by project type. The Statewide CASE Team assumed that 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.[5]

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 as of October 2020 (Kramer, Lin, Curtin, Crowe, & Granderson, 2020). The Statewide CASE Team collected this maintenance cost data in November 2025. 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 costs are $0.03 per square foot for the CBECC Large Office prototype building and $0.04 per square foot for the CBECC Large School prototype building. Using the same inflation rate, the Statewide CASE Team estimated that the annual maintenance costs would reach $0.04 and $0.06 per square foot for Large Office and Large School, respectively, by the time the proposed code change takes effect.[5] The annual recurring costs should be similar for new construction and alterations.

[5] 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.

The Statewide CASE Team assumed that mechanical systems or BAS would require replacement at year 16 of the 30-year analysis period, which would then necessitate FDD system replacement or reconfiguration. For this analysis, the Statewide CASE Team assumed an additional $0.09 per square foot incremental first cost to account for FDD system replacement/upgrade.

Accounting for a 3 percent discount rate per year, the total incremental maintenance costs over 30-year analysis period are $0.87 and $1.27 per square foot for Large Office and Large School prototypes, respectively.

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 the proposed residual value is greater than the 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 13 and Table 14 for new construction/additions and alterations.

Table 13: 30-Year Cost-Effectiveness Summary Per Square Foot –New Construction and Additions – OfficeLarge and SchoolLarge Prototypes

Climate Zone	Benefits LSC Savings + Other PV Savings (2029 PV$)	Costs Total Incremental PV Costs (2029 PV$)	Benefit-to-Cost Ratio
1	13.55	1.36	9.99
2	13.88	1.36	10.24
3	10.03	1.08	9.32
4	8.79	1.06	8.30
5	9.91	1.36	7.31
6	6.88	1.08	6.36
7	6.43	1.10	5.85
8	6.77	1.09	6.19
9	6.20	1.04	5.99
10	7.65	1.11	6.90
11	11.95	1.36	8.81
12	8.44	0.99	8.49
13	10.65	1.36	7.86
14	8.45	1.10	7.72
15	6.23	1.06	5.88
16	9.94	1.13	8.82
Total	**7.76**	**1.07**	**7.28**

Table 14: 30-Year Cost-Effectiveness Summary Per Square Foot – Alterations – OfficeLarge and SchoolLarge Prototypes

Climate Zone	Benefits LSC Savings + Other PV Savings (2029 PV$)	Costs Total Incremental PV Costs (2029 PV$)	Benefit-to-Cost Ratio
1	13.46	1.35	9.99
2	12.42	1.23	10.06
3	10.02	1.07	9.33
4	8.77	1.05	8.31
5	9.55	1.26	7.60
6	6.84	1.06	6.47
7	6.33	1.03	6.14
8	6.58	1.02	6.46
9	6.15	1.01	6.07
10	7.26	1.04	6.97
11	10.22	1.21	8.46
12	9.39	1.07	8.77
13	7.91	1.12	7.03
14	7.45	1.01	7.40
15	6.10	1.04	5.86
16	8.80	1.06	8.28
Total	**7.53**	**1.04**	**7.21**

6. Statewide Impacts

6.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated savings for new construction and alterations by multiplying the per-square-foot savings by the 2029 forecasts for Large Office buildings (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 for estimating the current market share, as well as statewide energy and 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 15) and alterations (Table 16) by climate zone. Table 17 presents first-year statewide savings from new construction, additions, and alterations.

Given the data regarding the 2029 forecasts, 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 1.02 gigawatt-hour (GWh) with an associated demand reduction of 0.51 MW.
    - Annual statewide natural gas and source energy use by 0.03 million therms and 268.71 million kBtu, respectively.
    - LSC savings by $183.95 million in present value.
- For alterations:
    - Annual statewide electricity use by 3.91 GWh with an associated demand reduction of 1.98 MW.
    - Annual statewide natural gas and source energy use by 0.11 million therms and 968.04 million kBtu, respectively.
    - LSC savings by $670.31 million in present value.

Table 15: 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	0.08	0.002	0.001	0	1.60	1.02
2	0.23	0.01	0.004	0.001	4.75	3.20
3	3.83	0.16	0.08	0.007	59.90	38.43
4	1.76	0.07	0.04	0.003	23.48	15.51
5	0.11	0.004	0.002	0	1.66	1.08
6	1.96	0.09	0.04	0.002	19.18	13.48
7	1.57	0.07	0.03	0.002	14.19	10.07
8	3.03	0.13	0.06	0.003	29.27	20.50
9	5.82	0.26	0.13	0.005	49.89	36.10
10	1.06	0.05	0.02	0.001	11.70	8.09
11	0.09	0.003	0.002	0	1.58	1.02
12	3.56	0.15	0.08	0.005	43.89	30.04
13	0.17	0.01	0.004	0	2.45	1.76
14	0.33	0.02	0.01	0	3.94	2.79
15	0.06	0.003	0.002	0	0.48	0.36
16	0.05	0.002	0.002	0	0.74	0.51
Total	**23.70**	**1.02**	**0.51**	**0.03**	**268.71**	**183.95**

Table 16: 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	0.17	0.01	0.003	0	3.55	2.25
2	0.61	0.02	0.01	0.001	11.42	7.62
3	12.45	0.51	0.27	0.021	194.55	124.83
4	5.82	0.24	0.12	0.008	77.25	51.06
5	0.45	0.02	0.01	0.001	6.57	4.27
6	9.41	0.42	0.21	0.010	91.30	64.34
7	6.09	0.27	0.13	0.006	53.61	38.53
8	13.38	0.60	0.29	0.013	123.90	87.99
9	23.42	1.07	0.52	0.021	198.07	144.12
10	5.28	0.23	0.13	0.006	54.99	38.30
11	0.49	0.02	0.01	0.001	7.63	5.05
12	8.17	0.34	0.18	0.012	110.03	76.67
13	0.99	0.04	0.02	0.001	10.88	7.84
14	1.57	0.08	0.05	0.002	16.27	11.73
15	0.35	0.02	0.01	0	2.82	2.12
16	0.41	0.02	0.01	0.001	5.16	3.57
Total	**89.07**	**3.91**	**1.98**	**0.11**	**968.04**	**670.31**

Table 17: 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$)
New Construction & Additions	1.02	0.51	0.03	268.71	183.95
Alterations	3.91	1.98	0.11	968.04	670.31
Total	**4.93**	**2.48**	**0.14**	**1,236.75**	**854.25**

6.2 Statewide Greenhouse Gas Emissions Reductions

Table 18 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 1,920 metric tons of carbon dioxide equivalent (CO_2e) 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 18: First-Year Statewide GHG Emissions Impacts

Measure	Reduced GHG Emissions from Electricity Savings (Metric Tons CO2e)	Reduced GHG Emissions from Natural Gas Savings (Metric Tons CO2e)	Total Reduced GHG Emissions (Metric Ton CO2e)	Total Monetary Value of Reduced GHG Emissions ($)
HVAC FDD	1,184	736	1,920	311,973
Total	**1,184**	**736**	**1,920**	**311,973**

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). New to the 2028 energy code is to *italicize defined terms* when the terms are being used in its defined context. In-line comments that are not part of the proposed code language but are used to help describe the purpose of what is proposed are included *with greyed highlight and italics.*

Markups are provided to the restructured 2025 Energy Code that the CEC developed in response to feedback that aligns the structure of Title 24, Part 6 with other parts of the California Building Standards Code (Title 24) would improve readability, usability, and navigation. New section numbers are shown as bold followed square brackets that document the section in the 2025 Title 24, Part 6 section numbers prior to the restructuring. For example, "**Section 601.1** [Section 130.0(a)] **General"** contains the content that is in the current Section 130.0(a).

Posting the proposed code language in this format is useful as it helps describe how the Energy Code changes proposed for nonresidential occupancies are isolated from the requirements for residential occupancies which are prohibited from being changed until the 2031 code cycle by Assembly Bill 130.

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)

SUBCHAPTER 2 DEFINITIONS

SECTION 201 *[Section 100.1]* **DEFINITIONS**

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.

SUBCHAPTER 4 SPACE-CONDITIONING AND VENTILATION

401.2.2.9 *[Section 120.2(i)]* **Economizer fault detection and diagnostics (FDD).**

401.2.2.10 *[New Section]*] HVAC *Fault Detection and Diagnostics (FDD)*.

A stand-alone or integrated *FDD* system shall be provided as specified by *Table 401.2-D (1)[New table]*. The provided *FDD* system shall perform all of the functions below:

1. Monitor HVAC equipment and system(s),
2. Automatically detect the following *faults*:
   2.1 HVAC operating outside of scheduled hours and outside of permitted user override
   2.2 Leaking or inoperable cooling coil valves on Air Handling Units
   2.3 Leaking or inoperable heating coil valves on Air Handling Units
   2.4 Inoperable terminal unit dampers
   2.5 Zone temperature sensor failure/fault
   2.6 Building HVAC control fan motor command at 100% or placed in manual override
3. Automatically diagnose *faults* with:
   3.1 The specific *fault* detected
   3.2 The affected equipment or system by name or identifier
   3.3 Recommended corrective actions
4. Communicate *faults* and diagnoses in at least one of the following ways:
   4.1 Report to an energy management control system regularly monitored by facility personnel
   4.2 Report to a fault management application, which automatically provides notification of the fault to a remote HVAC service provider
5. Display the *fault*, diagnosis status, and the value of each sensor being monitored in an energy management control system or a *fault* management application; and
6. Trend system performance data at least once every 15 minutes or as event-based and store data for a minimum of six months.

Exception to 401.2.2.10: Systems serving hotel/motel buildings and buildings with Group R occupancies.

TABLE 401.2-D(1) [New table] HVAC FDD APPLICATIONS AND QUALIFICATIONS

Building Status	**Applications**	**Qualifications**
Newly constructed buildings with 100,000 square feet of conditioned floor area or larger	Air-handling system and all zones served by the system	Individual systems supplying more than three zones and with design heating or cooling capacity of 300 kBtu/h and larger

Additions or alterations in buildings with 100,000 square feet of conditioned floor area or larger	Zone terminal unit such as a VAV box	Where existing zones served by the same air-handling systems have FDD
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	New or replacement air-handing units and new zones served by the system	Individual air handling units 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

401.2.2.~~10~~11 *[Section 120.2(j)]* **Direct Digital Controls (DDC)**

401.2.2.~~11~~12 *[Section 120.2(k)]* **Optimum start/stop controls.**

401.2.2.~~12~~13 *[Section 120.2(l)]* **HVAC hot water temperature.**

401.5.2.1 *[Section 141.0(b)1]* **Mandatory requirements (Alterations).**

Exception to Section 401.5.2.1 *[Section 141.0(b)1]* **:** The requirements of Section 401.2.2.10 *[new section]* shall not apply to *alterations* of *space-conditioning systems* or components.

7.4 Reference Appendices

NA 7.5.12 Automatic Fault Detection and Diagnostics (FDD) for Air Handling Units and Zone Terminal Units.

NA7.5.12.1 Construction Inspection for Air Handling Units

Prior to Functional Testing, verify and document the following:

a) Verify on the submittal documents or sensor specifications that locally installed supply air, outside air, and return air (if applicable) temperature sensors have an accuracy of ±2ºF over the range of 40ºF to 80ºF.

b) Verify there is an FDD system, and document the FDD system has the capability of displaying the following:

  1. HVAC system schedule
  2. Zone temperature sensors
  3. AHU temperature sensors
  4. AHU heating and cooling valve commands

5. Building HVAC control fan motor command and status

NA7.5.12.3 Functional Testing for Air Handling Unit Schedule and Overrides

a) HVAC operating outside of schedule:

Step 1: Schedule the HVAC system to be scheduled as unoccupied

Step 2: Override the AHU to be operating at 100%

Step 3: Verify the FDD system displays the fault information and provides a recommended corrective action

Step 4: Return the system to normal operations

Step 5: FDD system indicates normal operation

b) Fan command override:

Step 1: Verify the FDD system indicates normal operation

Step 2: Override the fan to be operating at 100%

Step 3: Verify the FDD system displays the fault information and provides a recommended corrective action

Step 4: Return the fan command to automated through the sequence of operations

Step 6: FDD system indicates normal operation

NA7.5.12.4~~3~~ Functional Testing for Air Handling Unit Valves

Testing shall be performed on each cooling “and” heating valve in the system that is monitored by the FDD.

d) Leaking or inoperable cooling coil valves:

Step 1: Verify the FDD system indicates normal operation

Step 2: Command the cooling coil valve be fully closed

Step 3: Physically lower the temperature being read by the sensor after the cooling coil by at least five degrees

Step 4: Verify the FDD system displays the fault information and provides a recommended corrective action

Step 5: Return the temperature sensor to normal operations

Step 6: FDD system indicates normal operation

e) Leaking or inoperable heating coil valves:

Step 1: Verify the FDD system indicates normal operation

Step 2: Command the heating coil valve be fully closed

Step 3: Physically raise the temperature being read by the sensor after the heating coil by at least five degrees

Step 4: Verify the FDD system displays the fault information and provides a recommended corrective action

Step 5: Return the temperature sensor to normal operations

Step 6: FDD system indicates normal operation

NA7.5.12.54Functional Testing for Zone Terminal Units

Testing shall be performed on one of each type of terminal unit (VAV box) in the project. A minimum of 5 percent of the terminal boxes shall be tested.

g) Zone temperature sensor:

Step 1: Verify the FDD system indicates normal operation

Step 2: Disconnect the zone temperature sensor from the control system

Step 3: Verify the FDD system displays the fault information and provides a recommended corrective action

Step 4: Return the terminal unit controls back to automated through the sequence of operations

Step 5: FDD system indicates normal operation

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)

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Appendix A: Assumptions for Cost-Effectiveness Analysis

Key Assumptions for Energy Savings Analysis

This measure proposes that new construction and building additions/alterations with 100,000 or more square feet of conditioned space, and 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, et al., 2022 ; Kim, Cai, Braun, & Frank, 2018; Zhong, Calautit, & 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, thereby addressing the energy impact of the fault. These durations represented typical processes for how the facility team traditionally detects faults, including addressing occupant comfort complaints, analyzing trend data, and analyzing utility bills. These fault-persistence assumptions served as a baseline 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 that faults occur at the same rate 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 that the FDD can detect all co-occurring faults simultaneously when they occur 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 estimates 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 assumed that each fault occurs at its respective prevalence rate across affected systems or zones, based on a literature review. Because these fault prevalence rates reflect observations across a population of buildings rather than individual buildings, the Statewide CASE Team applied these portfolio-level rates and scaled them to prototype size to estimate the number of faulty systems or zones. 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 that the relative energy impact of each fault at 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 using 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 whole-building-level annual energy savings by combining 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 for prototypical buildings and units. 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 it includes an operational fault class for modeling of HVAC faults, while CBECC does not currently support fault modeling. The Statewide CASE Team exported the input data file from a CBECC standard prototype model for use in EnergyPlus fault simulations. This section details the energy modeling results and energy savings analysis. Table 19 presents the prototype buildings used in the analysis. The Statewide CASE Team modeled the Large Office and Large School prototype buildings.

Table 19: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (Square Feet)	Description
CBECC Large Office	13	498,589	12-story + 1 basement office building with 5 zones and a ceiling plenum on each floor.
CBECC Large School	2	210,866	High school with WWR-35% and SRR-1.4%

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 five modeled thermal zones. With a fivefold multiplier, each modeled floor represents 25 actual zones, although the CBECC prototype handles these multipliers internally during load calculations. In total, the CBECC Large Office prototype comprises 13 AHUs (each with one supply fan and one cooling coil) 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[6]
    - 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

[6] CBECC Standard Design includes heating coils as part of the VAV system

The CBECC Large School prototype represents a 2-story building, and CBECC models these two floors directly without any multipliers. The CBECC Large School prototype represents 2 AHUs (each with one supply fan and one cooling coil, serving one floor), and 46 thermal zones, each served by one ATU. The first floor has 25 thermal zones, and the second floor has 21 zones. The HVAC system in the CBECC Large School prototype includes:

- AHU:
  - The following design supply airflow rates:
    - Floor 1: 128,116 cfm
    - Floor 2: 73,892 cfm
  - Each AHU contains:
    - One main heating coil and one cooling coil[7]
    - One supply fan
    - A set of economizer dampers
    - Temperature sensors for outdoor air, return air, mixed air, and supply air
  - The AHU on the first floor serves 25 ATUs, and the second-floor AHU serves the rest 21 ATUs.
- Two 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:
  - Forty-six ATUs with hot water reheat coils
  - Forty-six zone thermostats for temperature control

This system configuration is representative of typical large commercial 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 malfunctions. The Statewide CASE Team did not simulate damper faults as they overlap with the economizer FDD requirements. The Statewide CASE Team simulated each fault individually using the following approaches for the Standard Design:

[7] CBECC Standard Design includes heating coils as part of the VAV system

- Temperature sensor faults: Temperature sensor faults occur when thermostats provide inaccurate readings, leading the HVAC system to believe the zone temperature differs from actual conditions. The Statewide CASE Team modeled this fault by applying offsets of ±3.6°F (±2°C) to the affected thermostats, meaning that the system believed that the zone temperature was 3.6°F higher or lower than it actually was. The Statewide CASE Team assumed a 20 percent failure rate for thermostats (Crowe, 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. For Large Office, 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. For the Large School, the Statewide CASE Team applied thermostat faults to 8 of 46 zones, assigning positive offsets to the first-floor faulty zones and negative offsets to the second-floor faulty zones.
- Valve leakage: Valve leakage occurs when cooling-coil valves fail to fully close, 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, et al., 2022). Applying this prevalence rate to the Large Office prototype model with 13 AHUs, the Statewide CASE Team modeled five AHUs with cooling coil valve leakage. However, the Large School prototype's two discrete AHUs created a modeling constraint. Applying a fault to one AHU resulted in 50 percent system prevalence, exceeding the lower target prevalence. To address this, the Statewide CASE Team applied a prevalence-adjustment approach during post-processing (detailed in this Appendix). For the Large School, the Statewide CASE Team applied the fault to one AHU's cooling coil valves.
- HVAC scheduling: HVAC scheduling faults occur when systems fail to implement setback controls during unoccupied periods. In the Large Office prototype model Proposed Design, the HVAC system maintained occupied thermostat setpoints (70-75°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 (60-85°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. For the Large School prototype, in the Proposed Design, the HVAC system set back and maintained unoccupied thermostat setpoints (60-

85°F) from 10 p.m. to 6 a.m. Monday through Friday. In the Standard Design, the Statewide CASE Team assumed no HVAC set back controls from 1 a.m. to 6 a.m. on weekdays, with the system maintaining occupied thermostat setpoints (70-75°F) during that window. This ensures consistent daily fault persistence across both prototypes. As with the Large Office, the Large School retains setback controls during weekends and holidays. Based on a NREL report on common faults prevalence, the Statewide CASE Team assumes a 23 percent prevalence rate as the share of equipment that experiences scheduling faults (Kim, Cai, Braun, & Frank, 2018). Applying this prevalence rate to the Large Office prototype model with 13 AHUs, the Statewide CASE Team modeled three AHUs with HVAC scheduling faults. For Large School prototype, the same prevalence constraint applied to HVAC scheduling faults. The Statewide CASE Team modeled one AHU with the scheduling fault and applied the prevalence adjustment during post-processing.

- Fan failure: Fan failure occurs when supply fans become stuck at full 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, & Charles, 2017), representing a fan operating continuously at maximum 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 Large Office prototype model with 13 AHUs, the Statewide CASE Team modeled three of them with fan failure. For Large School prototype, the Statewide CASE Team modeled one supply fan with fan failure and applied the prevalence-adjustment approach during post-processing.

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 capacity/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 in 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 as FDD enabled, allowing detection and correction of a higher percentage of faults 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 20 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 20: 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	Thermostat setpoint maintained at: 70°F for heating and 75°F for cooling 24 hours/day M-F	Setback thermostat setpoint to 60°F for heating and 85°F for cooling 12 a.m.-5 a.m. 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)
CBECC Large School	All	Temperature sensor fault (+ offset)	4 zones on the first story	Added FaultModel	ThermostatOffset	+3.6°F (+2 °C)	0 (No offset)
CBECC Large School	All	Temperature sensor fault (- offset)	4 zones on the second story	Added FaultModel	ThermostatOffset	-3.6°F (-2 °C)	0 (No offset)

Prototype ID	Climate Zone	Measure name	Equipment/ Zone Modified	Objects Modified	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
CBECC Large School	All	Fan failure	Second-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 School	All	HVAC scheduling	Second-floor AHU	Set back HVAC Schedule	Heating and cooling thermostat setpoints	Thermostat setpoint maintained at: 70°F for heating and 75°F for cooling 1 a.m.- 6 a.m. M-F	Setback thermostat setpoint to 60°F for heating and 85°F for cooling 10 p.m.- 6 a.m. M-F
CBECC Large School	All	Valve leakage	Second-floor AHU	Water coil controller	Minimum Actuated flow	10% leakage (10% of design flow rate)	0 (No leakage)

At any given time in a building, faults may occurring, and some may have been ongoing 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 control 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 included 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 accounting for the incremental reduction in fault duration that the proposed HVAC FDD system provides. All individual-fault and combined-faults energy models incorporated fault prevalence rates by applying each fault to only a fraction of the applicable equipment, devices, and zones. Table 21 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 21: Fault Prevalence, Persistence and Recurrence Assumptions

Fault Type	Prevalence Rate	Duration – No FDD	Duration – FDD	Fault recurrence frequency
Temperature sensor fault	20 percent	2 months	1 month	Once per year
HVAC scheduling	40 percent	3 months	1 month	Once per year
Fan failure	23 percent	3 months	1 month	Once per year
Valve leakage	20 percent	3 months	1 month	Once per year

To account for differences in fault duration and recurrence frequency, the Statewide CASE Team developed a methodology to estimate the relative energy impact of each fault in the combined fault model, thereby adjusting 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-fault 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:

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

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

Where:

- $E_{baseline}$: Total annual building energy use under fault-free baseline conditions (kBtu)
- E_i: Total annual building energy use with individual fault i present (kBtu)
- $\Delta E_{individual,i}$: Annual energy penalty from individual fault i (kBtu)
- $E_{combined}$: Total annual building energy use with all faults present simultaneously (kBtu)
- $\Delta E_{combined}$: Annual energy penalty from combined fault scenario (kBtu)

Then, the Statewide CASE Team calculated the interaction factor IF to quantify how faults interact when co-occurring. If faults were simply additive, the combined penalty would equal the sum of individual penalties. However, when faults co-occur, they can interact and amplify or offset each other’s effects, causing the combined penalty to exceed or fall below the simple sum. The Statewide CASE Team calculated the interaction factor IF as the ratio of the combined scenario energy penalty to the sum of all individual fault penalties. 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. The Statewide CASE Team used this interaction factor in subsequent post-processing steps to proportionally disaggregate the combined scenario into individual fault components, because each fault type has different persistence assumptions. The equation to calculate interaction factor IF is:

$$IF = \frac{\Delta E_{combined}}{\sum \Delta E_{individual,i}}$$

Where $\Delta E_{combined}$ is the energy penalty when all faults occur simultaneously (kBtu), and $\sum \Delta E_{individual,i}$ is the sum of energy penalties from each fault occurring individually (kBtu).

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

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

Where $\Delta E_{component,i}$ is the energy penalty for each fault type i after disaggregating the combined scenario using the interaction factor IF.

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:

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

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

- With FDD:

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

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

Where:

- $\Delta E_{NoFDD,i}$: annual energy penalty for fault type i without FDD (kBtu)
- $t_{NoFDD,i}$: persistence duration for fault type i without FDD (month)

- ΔE_{NoFDD}: total annual energy penalty without FDD, summed across all faults (kBtu)
- $\Delta E_{FDD,i}$: annual energy penalty for fault type i with FDD (kBtu)
- $t_{FDD,i}$: persistence duration for fault type i with FDD (month)
- ΔE_{FDD}: total energy penalty with FDD, summed across all faults (kBtu)

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 occurred only once per year on affected equipment, meaning each fault has a recurrence rate ρ_{rec} of one. This means that after a fault occurs and persists for its specified duration, it recurs the following year with the same prevalence rate and persistence duration throughout the analysis period. The Statewide CASE Team then used the following equation to calculate the final adjusted energy penalty ΔE_{final}:

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

Where:

- ΔE_{final}: final annual energy penalty after post-processing (kBtu)
- ρ_{rec}: fault recurrence rate, equal to one in this analysis

Large School modeling results require an additional prevalence adjustment post-processing step. The Large School prototype has only two AHUs, so the Statewide CASE Team could not directly represent these population-level prevalence rates into a single Large School model due to discrete system configurations. Applying a fault to one AHU results in 50 percent system prevalence, while target prevalences are lower (23 percent for scheduling faults, 20 percent for fan failures, 40 percent for valve leakage). To address this constraint, the Statewide CASE Team applied a building portfolio approach that stacks multiple building models to achieve the target prevalence. This statistical approach captures fault occurrences observed across the building population and scales them to represent individual prototype buildings.

For example, the fan fault target prevalence is 20 percent, but the Large School model, with one failed, produced 50 percent prevalence. The Statewide CASE Team stacked two faulty buildings (one fan failed in each) with three baseline buildings (no failed fans). This approach produced two faulty fans out of ten total fans, achieving the 20 percent prevalence. The building portfolio establishes the relationship between the modeled building-level prevalence (50 percent, one fan out of two) and the target system-level prevalence (20 percent, two fans out of ten across the portfolio). This ratio determines the adjustment factor that weights the faulty building's energy penalty to reflect the lower system-level prevalence. For this fan fault, the adjustment factor is 0.4 (20 percent/50 percent), which scales the energy penalty to 40 percent to reflect the energy impact at the targeted prevalence level.

The adjustment factor AF equals target prevalence P_{target} divided by modeled prevalence $P_{modeled}$, representing the weighted average of faulty and fault-free buildings that achieves the target prevalence across the building population:

$$AF = \frac{P_{target}}{P_{modeled}}$$

The Statewide CASE Team then applied the adjustment factor AF to the energy difference of the individual fault scenario i:

$$\Delta E_{individual,i}^{adjusted} = AF \times \Delta E_{individual,i}$$

Where $\Delta E_{individual,i}^{adjusted}$ represents the adjusted energy penalty for individual fault type i after applying the prevalence adjustment factor.

The aggregated fault scenario required integration of prevalence adjustments with interaction factors IF. The calculation proceeded in three steps: 1) calculate prevalence-adjusted individual fault savings using the stacking method described above, 2) sum the adjusted individual differences to determine the combined effects across the building stock, and 3) apply the interaction factor IF from the aggregated fault model to account for overlapping effects when multiple faults co-occur within individual buildings. This methodology ensures aggregated savings reflect both fault distribution across the building stock and physical interactions within individual buildings. The following equation represents the adjusted energy difference $\Delta E_{combined}^{adjusted}$ between the aggregated fault scenario and baseline scenario:

$$\Delta E_{combined}^{adjusted} = IF \times \sum \Delta E_{individual,i}^{adjusted}$$

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

Using the Large Office results as an example, Figure 6: Climate Zone 7 – monthly energy use for aggregated-fault and baseline models – OfficeLarge Prototype and Figure 7 show monthly electricity and natural gas usage of the Large Office prototype 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. The winter months saw peak natural gas consumption for heating, while the summer months saw elevated electricity use for cooling.

The composition of energy savings varies by climate zone and season. In CZ 7, electricity savings dominated, ranging from 40,000 to 70,000 kBtu per month, with the greatest savings during the 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 dramatic 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.

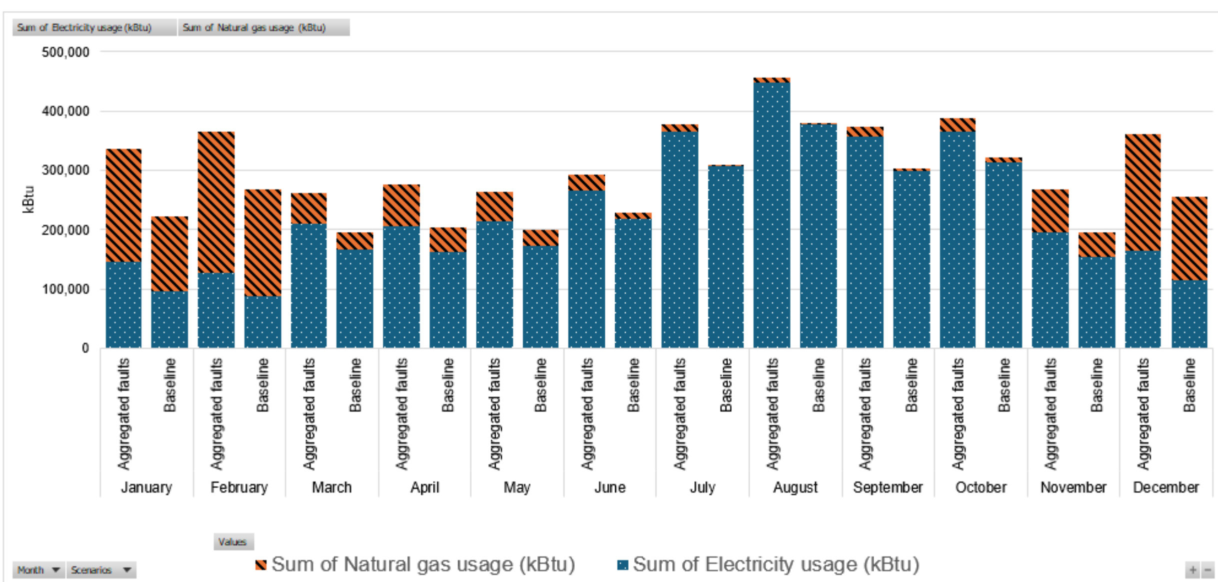

Figure 6: Climate Zone 7 – monthly energy use for aggregated-fault and baseline models – OfficeLarge Prototype

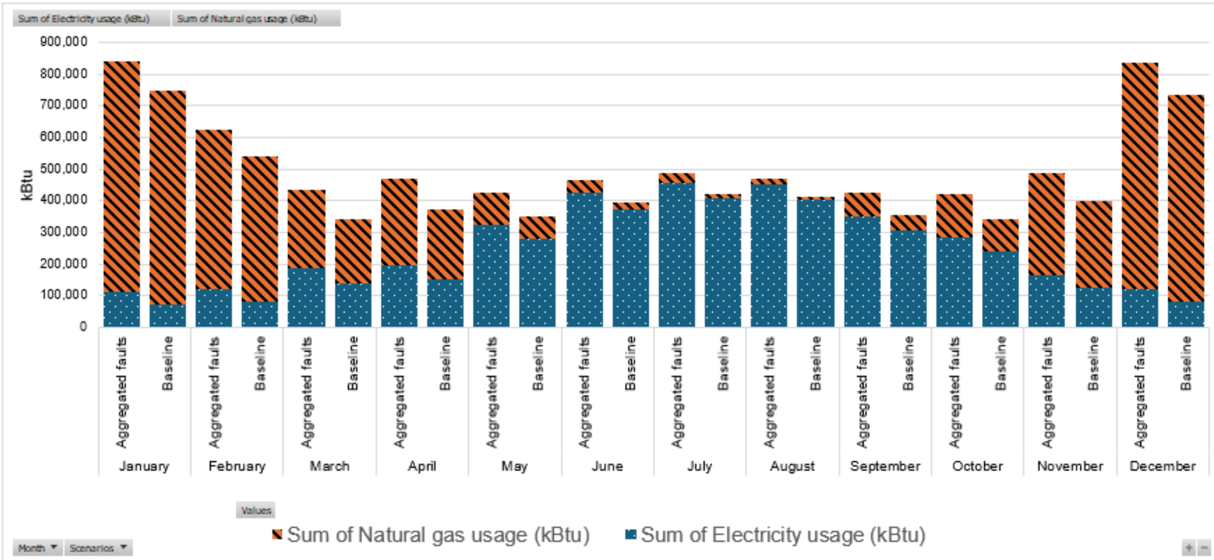

Figure 7: Climate Zone 12 – monthly energy use for aggregated-fault and baseline models – OfficeLarge Prototype.

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 with a certain square footage (100,000 SF) and a certain equipment heating and/or cooling capacity (300,000 Btu/h).

Necessity: The necessity for this change is to provide the FDD requirements 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 criteria for mechanical systems when they need to include FDD.

Purpose and Necessity of Changes to the Reference Appendices

Section: NRCA-MCH-12-A Fault Detection and Diagnostics (FDD) – Packaged Units (Certificate of Acceptance)

Purpose: The purpose of this change is to include further testing of baseline functional requirements of FDD in packaged units.

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

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.

Appendix C: Assumptions for Statewide Savings Estimates

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-foot 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, Lin, Curtin, Crowe, & Granderson, 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 to establish 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 percentage of impacted existing buildings, the Statewide CASE Team assumed that 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 22 presents the projected nonresidential new construction that the proposed code change will impact in 2026. Table 23 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 24 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 25 presents the assumed percentage of affected floorspace by climate zone.

Table 22: 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	2.69	1.31	0.00	1.35	1.01	2.00	4.65	0.65	0.00	3.22	0.00	0.22	0.04	0.03	17.15
Large School	0.08	0.23	1.15	0.46	0.11	0.61	0.56	1.03	1.17	0.40	0.09	0.34	0.17	0.11	0.02	0.02	6.54
Total	**0.1**	**0.2**	**3.8**	**1.8**	**0.1**	**2.0**	**1.6**	**3.0**	**5.8**	**1.0**	**0.1**	**3.6**	**0.2**	**0.3**	**0.1**	**0.1**	**23.7**

Table 23: 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	0.19	8.76	4.39	0.11	7.03	4.93	11.33	20.02	4.14	0.18	5.84	0.57	1.37	0.27	0.30	69.44
Large School	0.16	0.43	3.69	1.43	0.34	2.38	1.15	2.05	3.41	1.14	0.31	2.33	0.42	0.20	0.07	0.11	19.63
Total	**0.2**	**0.6**	**12.5**	**5.8**	**0.4**	**9.4**	**6.1**	**13.4**	**23.4**	**5.3**	**0.5**	**8.2**	**1.0**	**1.6**	**0.3**	**0.4**	**89.1**

Table 24: Percentage of Nonresidential Floorspace Impacted by Proposed Code Change in 2029, by Building Type

Building Type	New Construction Impacted (Percent Square Footage)	Existing Building Stock (Alterations) Impacted (Percent Square Footage)
Large Office	100%	6.7%
Medium Office	0%	0%
Small Office	0%	0%
Large Retail	0%	0%
Medium Retail	0%	0%
Strip Mall	0%	0%
Mixed-Use Retail	0%	0%
Large School	100%	6.7%
Small School	0%	0%
Non-refrigerated Warehouse	0%	0%
Hotel	N/A	N/A
Assembly	0%	0%
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%

Table 25: Percentage of Nonresidential Floorspace Impacted by Proposed Measure, by Climate Zone

Climate Zone	New Construction Impacted (Percent Square Footage)	Existing Building Stock (Alterations) Impacted (Percent Square Footage)
1	12%	0%
2	6%	0%
3	19%	1%
4	13%	1%
5	6%	0%
6	15%	1%
7	15%	1%
8	15%	1%
9	19%	1%
10	6%	1%
11	2%	0%
12	20%	1%
13	3%	0%
14	9%	1%
15	3%	0%
16	4%	0%

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 Final 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 2028 code cycle. The goal of these meetings is to solicit early stakeholder input on proposals, ensuring the proposals and 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 two stakeholder meetings for NR HVAC Fault Detection and Diagnostics via webinar, as described in Table 26. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting, such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography section of this report.

Table 26: Utility-Sponsored Stakeholder Meetings

Meeting Name and Link to Materials	Meeting Date	Summary of Items Discussed
First Round of Nonresidential Water Heating, HVAC, Utility-Sponsored Stakeholder Meeting	Thursday, October 23, 2025	Expected baseline requirements, current market penetration, most impactful FDD algorithms, code barriers, and compliance requirements.
Second Round of Nonresidential Water Heating, HVAC, Utility-Sponsored Stakeholder Meeting	April 21, 2026	Same discussion items as the first meeting, with updated information, to provide an overall summary of the measure. Additional emphasis on compliance requirements.

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 2028 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for 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 in April 2026 and provided updated details on proposed code changes. These meetings introduced results from 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. 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 27.

Table 27: Engaged Stakeholders

Organization/Individual Name	Market Role	CASE Report Sections Influenced by Stakeholder Feedback
Hwakong Cheng and Steve Taylor (Taylor Engineers)	Engineering and Consulting	2.1, 4.1.2, 4.2.1, 4.2.3, 7.3, Appendix E
Paul Ehrlich (Building Intelligence Group)	Smart Building Consulting	4.1.2, 4.2.1, 4.2.3
Nicholas Gayeski (Clockworks Analytics)	FDD Provider	2.1, 4.1.2, 4.2.3, 5.3, 7.3, Appendix E
James Lee, Dean Taylor (Cimetrics)	FDD Provider	4.1.2, 4.2.3, 5.3, 7.3, Appendix E
Colin Hensel, Jonathan Carosh, Wayne Stoppelmoor (Schneider Electric)	Controls Manufacturer	2.1, 4.1.2, 4.2.1, 4.2.3
Eliot Crowe, John House (LBNL)	Research Laboratory	2.3, 4.1.1, Appendix C
Sia Diabiri (Altura)	Smart Building Implementer	2.3, 7.3
David Sellers, Larry Lister, Tony Pierce (Facility Dynamics Engineering)	Consulting Engineering and Commissiong	3.4, 5.3, 7.3
Brian Clark (US Army Corps of Engineers)	Government Engineering Organization	2.2, 2.3, 7.3, 7.4, Appendix E
California Energy Alliance	Energy Stakeholders	2.1, 4.1.2, 4.2.1, 4.2.3, 5.3, 7.3

The Statewide CASE Team received valuable stakeholder feedback during the engagement process. Most comments expressed support for the proposed FDD requirement and offered constructive suggestions to clarify technical details, implementation approaches, and cost assumptions. The Statewide CASE Team incorporated many of these suggestions into the measure development. Notable stakeholder comments also include suggestions related to additional FDD functionality and fault conditions that stakeholders felt should be included in the proposed code language. Although these suggestions were generally deemed valid, the proposed measure does not incorporate them at this time because additional research is needed to support their inclusion. A summary of the suggested functionality and fault types, along with the rationale for exclusion, is below:

- **Fault prioritization** was not included because it is hard to define in the code for compliance, and hard to verify during acceptance testing. It is also typically provided as a feature in FDD products that are separate from the BAS, which the Statewide CASE Team has tried to avoid requiring a facility manager to use.
- **Control point naming requirements** were not included because they are difficult for ATTs during acceptance testing and require further research to determine market impacts. Further research is needed to understand the potential market impacts associated with imposing standardized control-point naming conventions.
- **Energy recovery system faults** were not included because they can be written as a separate measure that applies to smaller buildings and systems, similar to the economizer FDD measure. This requires a separate measure with more research into market and technical impacts.
- **Simultaneous heating and cooling faults** were not included because they can occur for reasons dependent on AHU size and configuration. Although it is a common fault in systems, it is difficult to provide a clear compliance verification pathway without more information. More research is needed to determine market and technical impacts.

Appendix F: Code Language Markup (Non-restructured)

The language below is from the Draft CASE Report and in the non-restructured 2025 Title 24 Part 6 Code Language.

F.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).

F.2 Administrative Code (Title 24, Part 1)

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

F.3 Energy Code (Title 24, Part 6)

Section 100.1 DEFINITIONS

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.

SUBCHAPTER 4 SPACE-CONDITIONING AND VENTILATION

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 perform all of the functions below:

1. Monitor HVAC equipment and system(s),
2. Automatically detect the following *faults*:
    A. HVAC operating outside of scheduled hours and outside of permitted user override
    B. Leaking or inoperable cooling coil valves on Air Handling Units
    C. Leaking or inoperable heating coil valves on Air Handling Units
    D. Inoperable terminal unit dampers

E. Zone temperature sensor failure/fault
F. Building HVAC control fan motor command at 100% or placed in manual override

3. Automatically diagnose *faults* with:
    A. The specific *fault* detected
    B. The affected equipment or system by name or identifier
    C. Recommended corrective actions
4. Communicate *faults* and diagnoses in at least one of the following ways:
    A. Report to an energy management control system regularly monitored by facility personnel
    B. Report to a fault management application, which automatically provides notification of the fault to a remote HVAC service provider
5. Display the *fault*, diagnosis status, and the value of each sensor being monitored in an energy management control system or a *fault* management application; and
6. Trend system performance data at least once every 15 minutes or as event-based and store data for a minimum of six months.

Exception to Section 120.2(i).2: Systems serving hotel/motel buildings and buildings with Group R occupancies.

TABLE 120.2(i)2-A HVAC FDD APPLICATIONS AND QUALIFICATIONS

Building Status	**Applications**	**Qualifications**
Newly constructed buildings with 100,000 square feet of conditioned floor area or larger	Air-handling system and all zones served by the system	Individual systems supplying more than three zones and with design heating or cooling capacity of 300 kBtu/h and larger
Additions or alterations in buildings with 100,000 square feet of conditioned floor area or larger	Zone terminal unit such as a VAV box	Where existing zones served by the same air-handling systems have FDD
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	New or replacement air-handing units and new zones served by the system	Individual air handling units 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

Section 141.0(b)1 Mandatory requirements (Alterations).

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