Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

Economizer Fault Detection and Diagnostics (FDD) for Built-Up Air Handlers – Results Report

Measure Number: 2019-NR-MECH2-F

Category Name – Nonresidential Mechanical

August 2018

This report was prepared by the California Statewide Codes and Standards Enhancement (CASE) Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

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1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The Statewide CASE Team consists of the four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison, and SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power and Sacramento Municipal Utility District – which sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission evaluates proposals submitted by the Statewide CASE Team and other stakeholders and may revise or reject proposals.

In August 2017 the Statewide CASE Team submitted the CASE Report that is presented in Attachment 1 to recommend code changes related to economizer fault detection and diagnostics (FDD) for built-up air handlers. This document explains the revisions that occurred to the proposed code changes between the submittal of the Final CASE Report to the Energy Commission and the Energy Commission's adoption of the 2019 Title 24, Part 6 Standards on May 9, 2018. The document begins with a concise description of the adopted code language, followed by the estimated energy savings of the adopted requirements, with the remainder of the document outlining the evolution of the code changes and the final adopted language.

2. MEASURE DESCRIPTION

The adopted measure expands the existing mandatory code language in Section 120.2(i), which requires economizer FDD for air handling units (AHUs) on nonresidential packaged and split heating, ventilation, and air-conditioning (HVAC) systems greater than 54,000 British thermal unit per hour (Btu/hr) (4.5 tons) in nominal capacity and equipped with an air-side economizer, to also cover built-up handlers with the same characteristics. As a result, the adopted measure will expand the requirement to cover all air handlers, for packaged, split and built-up systems, that are greater than 54,000 Btu/hr in size and equipped with an air-side economizer.

FDD systems are automated systems designed to detect, diagnose, and report operational faults to help improve economizer longevity and occupant comfort. Economizer FDD systems can be standalone, such as those onboard many packaged systems, or they can be integrated into a building direct digital control (DDC) systems via sequences of operations. This adopted code change will require the detection and reporting of the following economizer faults listed in Section 120.2(i)7 for built-up systems as well as packaged systems:

- Air temperature sensor failure/fault
- Not economizing when it should
- Economizing when it should not
- Damper not modulating
- Excess outdoor air

Other related code changes include:

- Adding to Section 120.2(i)8 an exception that DDC-based FDD systems not be required to certify to the Energy Commission, due to the challenges in developing and implementing DDC systems with preconfigured FDD modules.
- Separating acceptance test NRCA-MCH-13-A into a required test for the AHU economizer FDD functional test (NRCA-MCH-13a-A) and a new test that remains a compliance credit for the AHU valve actuator and zone terminal units tests (NRCA-MCH-13b-A). Reference Appendix NA7.5.12, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units, will be modified in the same manner as the acceptance test documents.
- Improving the AHU acceptance test NRCA-MCH-13a-A for comprehensiveness and clarity, and to ensure that potential alarm delays are bypassed to accelerate the testing and commissioning process.
- Adding a prescriptive requirement in Section 140.9(a)1A that computer room AHUs are subject to the economizer FDD requirements.

Table 1 identifies sections of the Standards and Reference Appendices that were modified as a result of advocacy activities. The table also identifies if the compliance software will be updated.

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Will Compliance Software Be Modified
Economizer FDD for Built-Up Systems	Mandatory and Prescriptive	120.2(i) and 140.9(a)1A	NA7.5.12, JA6.3	No

3. Statewide Energy Impacts of Adopted Requirements

Table 2 shows the estimated energy savings of the adopted requirements over the first twelve months that are in effect. The first-year savings have not changed since submitting the Final CASE Report.

Table 2: Estimated Statewide First Year[a] Energy and Water Savings

Measure	First Year Electricity Savings (GWh/yr)	First Year Peak Electrical Demand Reduction (MW)	First Year Water Savings (million gallons/yr)	First Year Natural Gas Savings (million therms/yr)
Economizer Fault Detection and Diagnostics (Total)	0.88	1.07	N/A	0.011
New Construction	0.88	1.07	N/A	0.011
Additions	0.0	0.0	N/A	0.0
Alterations	0.0	0.0	N/A	0.0

a. First year savings from all buildings completed statewide in 2020.

4. Evolution of Code Requirements

The Statewide CASE Team submitted the final version of the CASE Report to the Energy Commission during August 2017. The Final CASE Report addresses input that was received during utility-sponsored stakeholder meetings held on September 16, 2016, and March 15, 2017, and during the Energy Commission's pre-rulemaking workshop that was held on June 20, 2017. This section describes how the code change proposal evolved between the time Final CASE Report was submitted to the Energy Commission and the time the standards were adopted.

No changes occurred between submitting the Final CASE Report and adoption. However, one section of proposed language was not adopted due to stakeholder input prior to the release of 45-Day Language.

A manufacturer stakeholder raised a question in a docketed comment letter (Braddy 2017) about language in Section 120.2(i)4C. The proposed code language replaced the *Compressor enabled* status to *Mechanical cooling enabled* status. While the stakeholder was in full support of the code change proposal, the stakeholder expressed concern that the proposed language would require making hard-coding name changes in all control platforms. The manufacturer requested confirmation that they would be in compliance with the proposed code requirement if their product documentation clarified that *Compressor enabled* and *Mechanical cooling enabled* were equivalent. The Energy Commission responded to stakeholder input by maintaining the current *Compressor enabled* status to avoid the need to make hard-coded name changes.

The Statewide CASE Team has notified the Energy Commission of the inconsistency between adopted code language and existing JA6.3 appendices language. The Statewide CASE Team expects that the appendices language will be updated to reflect adopted code language and proposed appendices language. This update will not impact energy savings.

5. Adopted Code Language

The adopted code language for the Standards and Reference Appendices are presented in the following sections. Additions to the 2016 Title 24, Part 6 code language are underlined and deletions are ~~struck~~.

5.1 Building Energy Efficiency Standards

5.1.1 Section 120.2 – Required Controls for Space-Conditioning Systems

(i) **Economizer Fault Detection and Diagnostics (FDD).** All newly installed ~~air-cooled packaged~~

~~direct- expansion units with an~~ air handlers with a mechanical cooling capacity greater than 54,000 Btu/hr and~~with~~ an installed air economizer shall include a stand- alone or integrated fault detection and diagnostics (FDD) system in accordance with Subsections 120.2(i)1 through 120.2(i)8.

1. The following temperature sensors shall be permanently installed to monitor system operation: outside air, supply air, and when required for differential economizer operation, a return air sensor; and
2. Temperature sensors shall have an accuracy of ±2°F over the range of 40°F to 80°F; and
3. The controller shall have the capability of displaying the value of each sensor; and
4. The controller shall provide system status by indicating the following conditions:
   - A. Free cooling available;
   - B. Economizer enabled;
   - C. Compressor enabled;
   - D. Heating enabled, if the system is capable of heating; and
   - E. Mixed air low limit cycle active.
5. The unit controller shall allow manual~~ly~~ initiation of~~initiate~~ each operating mode so that the operation of cooling systems~~compressors~~, economizers, fans, and heating systems can be independently tested and verified; and
6. Faults shall be reported in one of the following ways:
   - A. Reported to an Energy Management Control System regularly monitored by facility personnel.
   - B. Annunciated locally on one or more zone thermostats, or a device within five (5) feet of zone thermostat(s), clearly visible, at eye level, and meeting the following requirements:
     - i. On the thermostat, device, or an adjacent written sign, display instructions to contact appropriate building personnel or an HVAC technician; and
     - ii. In buildings with multiple tenants, the annunciation shall either be within property management offices or in a common space accessible by the property or building manager.
   - C. Reported to a fault management application which automatically provides notification of the fault to remote HVAC service provider.
7. The FDD system shall detect the following faults:
   - A. Air temperature sensor failure/fault;
   - B. Not economizing when it should;
   - C. Economizing when it should not;
   - D. Damper not modulating; and
   - E. Excess outdoor air.
8. The FDD System shall be certified by the Energy Commission as meeting requirements of Sections 120.2(i)1 through 120.2(i)7 in accordance with Section

110.0 and JA6.3.

EXCEPTION to 120.2(i)8: FDD algorithms based in Direct Digital Control systems are not required to be certified to the Energy Commission

5.1.2 Section 140.9 – Prescriptive Requirements for Covered Processes

(a) **Prescriptive Requirements for Computer Rooms.** Space conditioning systems serving a computer room with a power density greater than 20 W/ft^2 shall comply with this section by being designed with and having constructed and installed a cooling system that meets the requirements of Subsections 1 through 6.

1. **Economizers.** Each individual cooling system primarily serving computer rooms shall include either:

   A. An integrated air economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the Commission, at outside air temperatures of 55°F dry-bulb/50°F wet-bulb and below, and be equipped with a fault detection and diagnostic system as specified by Section 120.2(i); or

   B. An integrated water economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the Commission, at outside air temperatures of 40°F dry-bulb/35°F wet-bulb and below.

5.2 Reference Appendices

5.2.1 Joint Appendices

JA6.3 Economizer Fault Detection and Diagnostics (FDD) Certification Submittal Requirements.

The Joint Appendices section JA6.3 Economizer Fault Detection and Diagnostics (FDD) Certification Submittal Requirements relates to the proposed code change. The Energy Commission did not adopt the Statewide CASE Team's proposed changes to this section. The Statewide CASE Team has notified the Energy Commission of the inconsistency between adopted code language and JA6.3 language. The Statewide CASE Team expects that the appendices language will be updated to reflect adopted code language and proposed appendices language. Energy savings will not be impacted, whether the Energy Commission updates the appendices or not.

5.2.2 Nonresidential Appendices

NA7.5.12 Automatic Fault Detection and Diagnostics (FDD) for Air Handling Units and Zone Terminal Units.

5.2.2.1 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.

5.2.2.2 NA7.5.12.2 Functional Testing for Air Handling Units ~~Economizers~~

Testing of each AHU with FDD controls shall include the following tests.

(a) Bypass alarm delays.

Step 1: If applicable, bypass alarm delays to ensure that faults generate alarms immediately.

(b) Sensor ~~drift/~~failure:

Step 1: Disconnect ~~outside~~local supply air temperature sensor from unit

controller. Step 2: Verify that the FDD system reports a fault.

Step 3: Connect ~~O~~SAT sensor to the unit controller.

Step 4: Verify that FDD indicates normal system operation and clear all faults and alarms.

Step 5: If the outside air temperature sensor is local, disconnect the local OAT from the unit controller.

Step 6: Verify that the FDD system reports a fault.

Step 7: Connect the local OAT sensor to the unit controller.

Step 8: Verify that FDD indicates normal system operation and clear all faults and alarms.

(c) ~~Damper/actuator fault~~Inappropriate economizing:

Step 1: Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor below the low limit lockout.

Step 2~~1~~: From the control system workstation, override~~command~~ the ~~mixing box~~economizer dampers to ~~full open (~~100 percent outdoor air).

Step 3~~2~~: ~~Disconnect power to the actuator and v~~Verify that a fault is reported at the control workstation.

Step 4~~3~~: Remove the economizer damper override and verify that the control system indicates normal system operation.~~Reconnect power to the actuator and command the mixing box dampers to full open.~~

Step 5~~4~~: Remove all overrides and clear all faults and alarms.~~Verify that the control system does not report a fault.~~

Step 6: Override the operating state to economizer-only cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor so that free cooling is available.

Step ~~5~~7: From the control system workstation, override~~command~~ the ~~mixing box~~economizer dampers to ~~a full-closed position (~~0 percent outdoor air~~),~~.

Step ~~6~~8: ~~Disconnect power to the actuator and v~~Verify that a fault is reported at the control workstation.
Step 9~~7~~: Remove the economizer damper override and verify that the control system indicates normal system operation.~~Reconnect power to the actuator and command the dampers closed.~~

Step 10~~8~~: Remove all overrides and clear all faults and alarms.~~Verify that the control system does not report a fault during normal operation.~~

(d) ~~Valve/actuator fault:~~

~~Step 1: From the control system workstation, command the heating and cooling coil valves to full open or closed, then disconnect power to the actuator and verify that a~~

~~fault is reported at the control workstation.~~

(~~e~~d)Reinstate alarm delay.

Step 1: Reinstate alarm delays to ensure that faults generate alarms as before step (a), if applicable.

~~Inappropriate simultaneous heating, mechanical cooling, and/or economizing:~~

~~Step 1: From the control system workstation, override the heating coil valve and verify that a fault is reported at the control workstation.~~

~~Step 2: From the control system workstation, override the cooling coil valve and verify that a fault is reported at the control workstation.~~

~~Step 3: From the control system workstation, override the mixing box dampers and verify that a fault is reported at the control workstation.~~

5.2.2.3 NA7.5.12.3 Functional Testing for Air Handling Unit Valves

(a) Bypass alarm delays

Step 1: If applicable, bypass alarm delays to ensure that faults generate alarms immediately

(b) Valve/actuator fault:

Step 1: Override the operating state to occupied cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor to 90ºF.

Step 2: From the control system workstation, override the heating coil valves to the full open position (100% heating mode).

Step 3: Verify flow through the valve by differential temperature or differential

pressure method. Step 4: Verify that a fault is reported at the control workstation.

Step 5: Remove the heating coil valve override and verify that the control system indicates normal system operation.

Step 6: Remove all overrides and clear all faults and alarms.

Step 7: Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor to 40ºF.

Step 8: From the control system workstation, override the cooling coil valve to the full open position (100% cooling mode).

Step 9: Verify flow through the valve by differential temperature or differential

pressure method. Step 10: Verify that a fault is reported at the control workstation.

Step 11: Remove the cooling coil valve override and verify that the control system indicates normal system operation.

Step 12: Remove all overrides and clear all faults and alarms.

(c) Reinstate alarm delay.

Step 1: Reinstate alarm delays to ensure that faults generate alarms as before Step (a), if applicable.

6. BIBLIOGRAPHY

Braddy, B. 2017. “2019 Building Energy Efficiency Standards PreRulemaking: Trane Comments for 2019 Title 24 Non – Residential HVAC measures.” Prepared for the California Energy Commission. June. https://efiling.energy.ca.gov/URLRedirectPage.aspx?TN=TN219984_20170630T064212_Beth_Braddy_Comments_Trane_Comments_for_2019_Title_24_NonReside.pdf

ATTACHMENT 1: FINAL CASE REPORT

The final version of the CASE Report is provided in full in Attachment 1 to this report.

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

Economizer Fault Detection and Diagnostics (FDD) for Built-Up Air Handlers – Final Report

Measure Number**:** 2019-NR-MECH2-F

Nonresidential Mechanical

August 2017

This report was prepared by the California Statewide Codes and Standards Enhancement (CASE) Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

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Category:	Codes and Standards
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EXECUTIVE SUMMARY

Introduction

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

Measure Description

This CASE Report proposes expanding the existing mandatory code language in Section 120.2(i), which requires economizer fault detection and diagnostics (FDD) for nonresidential packaged and split air handling HVAC (heating, ventilation, and air-conditioning) systems greater than 54,000 Btu/hr (4.5 tons) in size with an air-side economizer, to also cover built-up handlers with these characteristics. As a result, the proposal will expand the requirement to cover all air handlers, both packaged and built-up, that are greater than 54,000 Btu/hr in size and equipped with an air-side economizer.

FDD systems are automated systems designed to detect, diagnose, and report faults to improve economizer longevity and occupant comfort. Economizer FDD systems can be standalone, such as those onboard many packaged systems, or they can be integrated into a building direct digital control (DDC) systems via sequences of operations (SOO). This code change would require the detection and reporting of the following economizer faults listed in 120.2(i)7 for built-up systems as well as packaged systems:

- Air temperature sensor failure/fault
- Not economizing when it should
- Economizing when it should not
- Damper not modulating
- Excess outdoor air

Other related code changes include:

- Changing 120.2(i) use of "compressor cooling" to the more general "mechanical cooling."
- Adding to 120.2(i)8 an exception that DDC-based FDD systems not be required to certify to the Energy Commission, due to the challenges in developing and implementing DDC systems with preconfigured FDD modules.
- Separating acceptance test NRCA-MCH-13-A into a required test for the air handler unit (AHU) economizer FDD functional test (NRCA-MCH-13a-A) and a new test that remains a

compliance credit for the AHU valve actuator and zone terminal units tests (NRCA-MCH-13b-A). Reference Appendix NA7.5.12, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units, will be modified in the same manner as the acceptance test documents.

- Improving the AHU acceptance test NRCA-MCH-13a-A for comprehensiveness and clarity, and to ensure that potential alarm delays are bypassed to accelerate the testing and commissioning process.
- Adding a prescriptive requirement in Section 140.9(a)1A that computer room AHUs are subject to the economizer FDD requirements.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of the Standards, References Appendices, and compliance documents that will be modified as a result of the proposed change.

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Will Compliance Software Be Modified	Modified Compliance Document(s)
Economizer FDD for Built-Up Systems	Mandatory	120.2(i) and 140.9(a)1A	Nonresidential Appendix 7.5.12 JA6.3	No	NRCA-MCH-13-A

Market Analysis and Regulatory Impact Assessment

The economizer FDD in the built-up air handler market structure is not simply comprised of product manufacturers and suppliers. There are several channels through which economizer FDD in built-up systems could be implemented. The relevant market actors are:

- DDC manufacturers
- Third-party FDD vendors
- Mechanical designers
- Controls contractors

Based on stakeholder information gathered throughout CASE development, economizer FDD is a familiar concept for nearly all market actors. Market actors including DDC manufacturers, third-party FDD vendors, mechanical designers, and controls contractors are able to develop FDD SOO in response to the possible change in standards. This code proposal does not mandate a specific approach to economizer fault detection. However, *ASHRAE Guideline 36 High Performance Sequences of Operation for HVAC Systems* provides one feasible SOO that detects economizer faults in built-up air handlers.[1]

This proposal is cost-effective over the period of analysis. Overall this proposal increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure.

The proposed changes to Title 24, Part 6 have a negligible impact on the complexity of the standards and the cost of enforcement. When developing this code change proposal, the Statewide CASE Team

[1] Currently First Publication Public Review version

interviewed building officials, Title 24 energy analysts and others involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

Cost-Effectiveness

The proposed code change was found to be cost-effective for all climate zones. The benefit-to-cost (B/C) ratio compares the lifecycle benefits (cost savings) to the lifecycle costs. Measures that have a B/C ratio of 1.0 or greater are cost-effective. The larger the B/C ratio, the faster the measure pays for itself through energy savings. The B/C ratio for this measure ranges from 1.1 to 2.8, depending on the climate zone. See Section 5 for a detailed description of the cost-effectiveness analysis.

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first 12 months of implementation of the proposed code change. See Section 6 for more details.

Table 2: Estimated Statewide First-Year[a] Energy and Water Savings

Construction Type	First-Year Electricity Savings (GWh/yr)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Water Savings (million gallons/yr)	First-Year Natural Gas Savings (million therms/yr)
New Construction	0.88	1.07	N/A	0.011
Additions and Alterations	0	0	N/A	0
TOTAL	**0.88**	**1.07**	**N/A**	**0.011**

a. First-year savings from all buildings completed statewide in 2020.

Compliance and Enforcement

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process will have on various market actors. The compliance process is described in Section 2.5. The impacts the proposed measure will have on various market actors is described in Section 3.3 and Appendix B. The key recommendations related to compliance and enforcement are summarized below:

- **DDC-based systems should be exempt from certification to the Energy Commission –** Currently, packaged system economizer FDD products are required to be certified to the Energy Commission. The Statewide CASE Team recommends that DDC-based economizer FDD be exempt from certifying to the Energy Commission. Justification includes 1) there are currently no known available products that have preconfigured economizer FDD modules; 2) not all market actors may have the ability to certify to the Energy Commission; and 3) economizer FDD modules may be burdensome if they are too flexible or too inflexible.
- **Acceptance testing for economizer FDD in built-up systems should be mandatory** – Acceptance testing of a DDC based FDD would verify that the controls sensors, programming, and actuators are functioning correctly. The Statewide CASE Team recommends that the AHU functional test in NRCA-MCH-13-A be moved to NRCA-MCH-13a-A, be improved for comprehensiveness and clarity, and be made mandatory for built-up air handlers greater than 54,000 Btu/hr and with an air economizer. The remaining steps in the acceptance test should remain voluntary for a compliance credit and be moved to a new NRCA-MCH-13b-A acceptance test.

Although a needs analysis has been conducted with the affected market actors while developing the code change proposal, the code requirements may change between the time the final CASE Report is submitted and the time the 2019 Standards are adopted. The recommended compliance process and compliance documentation may also evolve with the code language. To effectively implement the adopted code requirements, a plan should be developed that identifies potential barriers to compliance when rolling-out the code change and approaches that should be deployed to minimize the barriers.

1. INTRODUCTION

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

The overall goal of this CASE Report is to propose a code change proposal for economizer fault detection and diagnostics (FDD) for built-up air handlers. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, direct digital control (DDC) manufacturers, builders, utility incentive program managers, Title 24 energy analysts, third-party FDD vendors, mechanical designers, controls contractors and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshops that the Statewide CASE Team held on September 26, 2016 and March 15, 2017.

Section 2 of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this change is accomplished in the various sections and documents that make up the Title 24, Part 6.

Section 3 presents the market analysis, including a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards such as fire, seismic, and other safety standards and whether technical, compliance, or enforceability challenges exist.

Section 4 presents the per-unit energy, demand, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate energy, demand, and energy cost savings.

Section 5 presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of additional materials and labor required to implement the measure and a qualification of the incremental cost. It also includes estimates of incremental maintenance costs. Such as, equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

Section 6 presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2019 Standards take effect. This includes the amount of energy that will be saved by California building owners and tenants, and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also considered.

Section 7 concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Reference Appendices, Alternate Calculation Manual (ACM) Reference Manual, Compliance Manual, and compliance documents.

2. MEASURE DESCRIPTION

2.1 Measure Overview

This CASE Study will propose expanding the existing mandatory code language in Section 120.2(i), which requires economizer fault detection and diagnostics (FDD) for nonresidential packaged air handling systems greater than 54,000 Btu/hr (4.5 tons) in size with an air-side economizer, to also cover built-up air handlers with these characteristics. As a result, the proposal will expand the requirement to cover all nonresidential air handlers, both packaged and built-up, that are greater than 54,000 Btu/hr in size and with an air-side economizer.

FDD systems are automated systems designed to detect, diagnose, and report faults in order to improve economizer longevity and occupant comfort. Economizer FDD systems can be standalone, such as those onboard many packaged systems, or they can be integrated into building DDC systems via sequences of operations (SOO). This code change would require the detection and reporting of the following economizer faults listed in Section 120.2(i)7 for built-up systems as well as packaged systems:

- Air temperature sensor failure/fault
- Not economizing when it should
- Economizing when it should not
- Damper not modulating
- Excess outdoor air

There are no diagnostics requirements in Section 120.2(i). Built-up equipment is currently regulated but is not required to have economizer FDD. Other related code changes include:

- Changing Section 120.2(i) use of "compressor cooling" to the more general "mechanical cooling."
- Adding to Section 120.2(i)8 an exception that DDC-based FDD systems not be required to certify to the Energy Commission, due to the challenges in developing and implementing DDC systems with preconfigured FDD modules.
- Separating acceptance test NRCA-MCH-13-A into a required test for the air handler unit (AHU) economizer FDD (NRCA-MCH-13a-A) and a new test that remains a compliance credit for the AHU valve actuator and zone terminal units tests (NRCA-MCH-13b-A). Reference Appendix NA7.5.12, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units, will be modified in the same manner as the acceptance test documents.
- Improving the AHU functional test in acceptance test NRCA-MCH-13a-A for comprehensiveness and clarity, and to ensure that potential alarm delays are bypassed to accelerate the testing and commissioning process.
- Adding a prescriptive requirement in Section 140.9(a)1A that computer room air handlers are subject to the economizer FDD requirements.

The proposed change will not modify the modeling algorithms used in the performance approach (revisions to the ACM Reference Manuals).

2.2 Measure History

Cooling energy use can be reduced in many of California's climate zones through reliable operation of air-side economizers. However, the potential savings from economizers may not be realized due to improper installation, functioning, or maintenance of economizers. A 2003 California Energy Commission report by the New Buildings Institute (NBI) showed that 62 percent of 123 economizers on rooftop heating, ventilation, and air-conditioning (HVAC) units were poorly controlled or non-functional (Energy Commission 2003). Economizer FDD enables automatic detection and diagnosis of economizer faults, such as a sensor failure, that can improve economizer operation when addressed.

The Title 24, Part 6 FDD measure was initially developed through a collaborative effort including NBI, the Western Cooling Efficiency Center, and the California Investor-Owned Utilities Codes and Standards Enhancement (CASE) program. The team developed a code proposal for the 2013 revision of the Title 24, Part 6 Building Energy Efficiency Standards, titled HVAC Controls and Economizers (also called Light Commercial Unitary HVAC) (PECI and Taylor Engineering 2011). NBI and the Northwest Energy Codes Group then proposed FDD requirements for the 2015 International Energy Conservation Code (IECC). California is among the first to implement this language, as many (if not all) other states that adopt the IECC code have not yet adopted the 2015 version. Changes in the 2016 Title 24, Part 6 included clarifications for fault reporting and an added guidance document for manufacturers when testing FDD systems for certification to the Energy Commission.

The 2019 measure proposes expanding the packaged unit FDD requirement to built-up systems because economizers in both systems:

- Are composed of the same components (sensors, control sequences, dampers, and actuators).
- Serve the same function (to conserve energy by drawing in more outside air to provide free cooling when conditions are right).
- Are prone to the same faults and thus similar energy savings potential through fault detection and diagnosis.

There are no preemption concerns with this measure, as FDD and economizers requirements are not federally regulated.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each of the Title 24, Part 6 documents will be modified by the proposed changes. See Section 7 of this report for the detailed proposed revisions to the code language.

2.3.1 Standards Change Summary

This proposal will modify the following sections of the Building Energy Efficiency Standards as shown below. See Section 7.1 of this report for the detailed proposed revisions to the code language.

SECTION 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Subsection 120.2(i): Extend mandatory economizer FDD requirements for packaged systems in Section 120.2(i) to all air handlers for systems with mechanical cooling capacity greater than 54,000 Btu/hr and an air-side economizer, including built-up systems.

SECTION 140.9 – PRESCRIPTIVE REQUIREMENTS FOR COVERED PROCESSES

Subsection 140.9(a)1A: Require that economizer FDD requirements in 120.2(i) apply to air handling units (AHUs) serving computer rooms.

2.3.2 Reference Appendices Change Summary

This proposal will modify the following sections of the Standards Appendices as shown below. See Section 7.2 of this report for the detailed proposed revisions to the text of the reference appendices.

JOINT APPENDIX

JA6.3: Clarify that economizer FDD functions are to be installed on all air handlers with a mechanical cooling capacity greater than 54,000 Btu/h and an economizer. Clarify that DDC-based FDD systems are exempted from certification to the Energy Commission.

NONRESIDENTIAL APPENDIX

NA7.5.12.1: Reflect improvements to acceptance test NRCA-MCH-13a-A, Automatic Fault Detection and Diagnostics for Air Handling Units. Improvements include addition of Construction Inspection tests, additional steps to bypass alarm delays, revision of damper and sensors referenced, and removal of redundancies. Move the remaining tests to NA7.5.12.2, which will reflect the new test NRCA-MCH-13b-A.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

The Statewide CASE Team proposes that compliance software outputs show on the NRCC-MCH-01-E document that the NRCA-MCH-13a-A document must be used for acceptance testing in built-up air handler systems with cooling capacity greater than 54,000 Btu/hr with an and economizer.

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following section of the Title 24, Part 6 Compliance Manual:

- 4.5.1.8 - Economizer Fault Detection and Diagnostics
- 13.16 - NA7.5.12 FDD for Air Handling Units and Zone Terminal Units Acceptance

Modifications will clarify that the economizer FDD requirement applies to built-up systems as well as packaged systems. Proposed modifications to the compliance manual include a reference to ASHRAE Guideline 36. The Nonresidential Compliance Manual Appendix A – Compliance Forms List will include NRCA-MCH-13a-A and NRCA-MCH-13b-A form names.

2.3.5 Compliance Documents Change Summary

The proposed code change will modify the compliance documents listed below. Examples of the revised documents are presented in Section 7.5. NRCA-MCH-13-A, Automatic Fault Detection and Diagnostics for Air Handling Units and Zone Terminal Units will be separated into two documents (NRCA-MCH-13a-A and NRCA-MCH-13b-A)

- NRCA-MCH-13a-A, renamed Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Unit Economizers, will include the AHU functional test and be made mandatory when a built-up system greater than 54,000 Btu/hr and with an air economizer is installed. Revisions will include a new Construction Inspection test, additional steps to bypass alarm delays, revision of damper and sensors referenced, and removal of redundancies.
- NRCA-MCH-13b-A, renamed Automatic Fault Detection and Diagnostics (AFDD) for AHU Valve Actuators and Zone Terminal Units, would remain a test completed for compliance credit and include the functional test for valves and zone terminal units.

2.4 Regulatory Context

2.4.1 Existing Title 24, Part 6 Standards

The existing mandatory code language in Section 120.2(i) requires economizer FDD for nonresidential air-cooled unitary direct-expansion (packaged) air handling systems greater than 54,000 Btu/h (4.5 tons) mechanical cooling capacity with an air-side economizer. The current Title 24, Part 6 language establishes specific sensor accuracy, fault detection capabilities, and reporting requirements. The FDD System must be certified by the Energy Commission as meeting requirements of Sections 120.2(i)1 through 120.2(i)7 in accordance with Section 110.0 and JA6.3.

2.4.2 Relationship to Other Title 24 Requirements

There are not significant impacts on requirements in other building codes or other requirements within Title 24, Part 6 present or planned. Potential overlaps in energy and cost savings potential may occur with other nonresidential code change proposals for the 2019 Title 24, Part 6 Standards, particularly with the other HVAC measures:

- Cooling tower minimum efficiency.
- Alignment with ASHRAE 90.1-2016 including fan system power, exhaust air energy recovery, equipment efficiency, and water-side economizer.

2.4.3 Relationship to Other State or Federal Laws

There are no federal regulations that address economizer FDD.

2.4.4 Relationship to Industry Standards

Economizer FDD was added to the 2015 IECC after being adopted in the 2013 Title 24, Part 6. California is among the first to implement this language, as many (if not all) other states that adopt the IECC code have not yet adopted the 2015 version.

Proposed changes to the compliance manual include a reference to ASHRAE Guideline 36. Guideline 36 provides uniform sequences of operation for HVAC systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow for real-time FDD. The Statewide CASE Team assessed the most recent draft of Guideline 36 to ensure that the Title 24, Part 6 faults would be adequately addressed (see Appendix E for more detail). As part of the assessment process, the Statewide CASE Team proposed revisions to the ASHRAE 36 Guideline Project Committee to improve clarification and linkage to Title 24, Part 6 Standards.

ASHRAE SPC 207 Laboratory Method of Test of Fault Detection and Diagnostics Applied to Commercial Air-Cooled Packaged Systems is developing a laboratory test procedure for economizer faults. This committee’s work is not directly pertinent to this CASE Report proposal because it is focused on packaged systems and a broader set of economizer faults. The committee’s efforts may contribute to future code changes.

2.5 Compliance and Enforcement

The Statewide CASE Team collected input on what compliance and enforcement issues may be associated with these measures. This section summarizes how the proposed code change will modify the code compliance process. Appendix B presents a detailed description of how the proposed code changes could impact various market actors. When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced.

Currently, there are two methods of compliance for current packaged FDD requirements that may also be applicable to built-up air handlers:

1. **Certification to the Energy Commission –** Section 120.2(i)8 requires that "*the FDD System shall be certified by the Energy Commission as meeting requirements of Sections 120.2(i)1 through 120.2(i)7 in accordance with Section 110.0 and JA6.3*." In order to certify to the Energy Commission, an FDD manufacturer must submit evidence of functionality (such controller manuals or laboratory test results), as well as a signed declaration, showing that the FDD system complies with the requirements of 120.2(i)1 through 120.2(i)7. Once approved by the Energy Commission, the FDD system is listed on the Energy Commission's website.[2] There are currently over 80 economizer FDD products by 16 different manufacturers listed by the Energy Commission, suggesting a robust market. Packaged systems could have a standalone or integrated economizer FDD system, respectively meaning that the FDD system either has the sole function to provide FDD, or it also provides other functions such as controlling the economizer.
2. **Acceptance Testing -** After the FDD system is installed, it must be acceptance tested, including both a construction inspection and functional test. For packaged systems (NRCA-MCH-12-A), the construction inspection includes verification that the FDD system is certified to the Energy Commission.[3] Functional testing includes steps to introduce faults into the air handler and ensure that the FDD system detects the fault. Given the lack of precedence or recent studies, not much is currently known about compliance and enforcement of acceptance test requirements.

The Statewide CASE Team investigated which of these compliance methods would be effective and enforceable to built-up systems, which are nearly always controlled by a central DDC and SOO.

2.5.1 Recommendations for Certification to the Energy Commission for Built-Up FDD Systems

Unlike packaged systems, built-up FDD is likely to be integrated into the DDC via SOO. Based on discussions with stakeholders, this could be done by one of four market actors:

1. The **mechanical designer** includes the FDD SOO into the construction submittal as guidance to the controls contractor.
2. The **controls contractor** develops their own FDD SOO during system setup.
3. The building owner hires a **third-party FDD vendor** to remotely monitor data from the DDC system, and run it through FDD algorithms on off-site servers.
4. The **DDC manufacturer**, or their local dealer, develops a preconfigured FDD module containing SOO that require the control contractor to connect to the appropriate inputs (sensors) and outputs (alarm generation applications), but do not require the controls contractor to reconfigure or redevelop an FDD algorithm.

Mechanical designers (option one) typically develop SOO during building design, which means that SOO may be customized to a particular building. Mechanical designers do not have a laboratory to test their sequences. Because of the potential to customize SOO, and the designers' lack of laboratory facilities, it is impractical to ask designers to pre-certify their SOO to the Energy Commission during the design stage for inclusion on the Energy Commission approved list.

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[2] The declaration, testing guidance document, and list of certified economizer FDD are all available at: http://www.energy.ca.gov/title24/equipment_cert/fdd/

[3] Acceptance test forms available at: http://www.energy.ca.gov/2015publications/CEC-400-2015-033/appendices/forms/NRCA/

Option three is impractical for Energy Commission certification on a broad scale because of similar reasons to mechanical designers. FDD vendors may not typically have access to labs where they can generate the necessary evidence required for certification, and they may customize their FDD algorithms based on the system types installed. FDD vendors may be able to run tests in the field during commissioning of the systems, but results may vary from building to building. Furthermore, FDD vendor algorithms are continuously changing and being improved in off-site servers, and may make recertification necessary after software updates. Nonetheless, the Energy Commission has certified several FDD products designed to integrate with DDC systems.

Options two and four can be a realistic approach for Energy Commission certification in advance of a building project, assuming that DDC manufacturers or their local dealers (controls contractors) can provide the sufficient evidence necessary to attain certification. Multiple DDC manufacturers have suggested that they have appropriate resources to generate evidence and certify a preconfigured FDD module to the Energy Commission, and have the capability to develop preconfigured FDD modules. A product made by a large controls company is currently on the list of Energy Commission certified FDD products. The product is a fully programmable DDC system that, out of the box, does not have a preconfigured FDD module that is ready to run upon installation. Nonetheless, a California controls contractor representing the product developed economizer FDD SOO and submitted evidence to the Energy Commission for certification. The controls contractor told the Statewide CASE Team that they implement the economizer FDD in all of their installations.

Nonetheless, requiring the development and certification of a preconfigured FDD module within a broader DDC system, either by the manufacturer or controls contractor, still poses several challenges:

- There are currently no known available products from DDC manufacturers that have preconfigured economizer FDD modules, but the Statewide CASE Team is aware of several manufacturers that have stated interest in developing them.
- While one controls contractor has designed economizer FDD SOO and submitted evidence to the Energy Commission for certification, not all contractors may have the resources to do so, such as time or lab space.
- Controls contractor implementation of the FDD SOO may be refined over time and customized to each project, making it difficult to know with certainty that the SOO being implemented is the same as that certified to the Energy Commission.
- A preconfigured FDD module may pass Energy Commission certification but have the unintended consequences of causing inflexibility in the rest of the DDC capabilities, and hindering the controls contractor’s ability to customize the DDC to the broader building system.
- DDC systems must be highly flexible to meet the needs of highly complex and variable built-up systems. Thus, even preconfigured FDD modules may need further setup to integrate with a given economizer, creating opportunities for contractors to incorrectly setup the unfamiliar preconfigured module.

Due to these challenges, the Statewide CASE Team recommends that DDC-based economizer FDD be exempted from certifying to the Energy Commission. However, the Energy Commission may still certify DDC-based FDD when they are developed by a local dealer or contain a hard-coded FDD module, to give recognition to market actors that show exemplary compliance with the standards. DDC manufacturers may have incentive to certify their systems to gain market share by providing contractors with economizer FDD sequences that can easily be implemented.

2.5.2 Recommendations for Acceptance Testing for Built-Up FDD Systems

The acceptance test for built-up FDD systems (NRCA-MCH-13-A) is not currently required, and builders can earn a compliance credit by completing it. The construction inspection portion requires verification of proper installation of FDD. There is no verification that the FDD system is certified to the Energy Commission, as there is with the acceptance test for packaged economizer FDD. Based on the discussion and conclusion in Section 2.5.1, this verification will not be added.

There is a functional test for the AHU that takes approximately one hour per air handler. Functional testing includes steps to introduce faults into the air handler economizer dampers and ensure that the FDD system detects the fault. The acceptance test currently includes a functional test on the heating and cooling coil valves and zone terminal units. Because these systems are not directly related to economizers or economizer FDD, they should be moved to a separate test and remain an optional compliance credit. The Statewide CASE Team recommends that the NRCA-MCH-13-A document be split into two documents (NRCA-MCH-13a-A and NRCA-MCH-13b-A). NRCA-MCH-13a-A: Automatic Fault Detection and Diagnostics for Air Handling Unit Economizers, would retain only the air hander functional tests, and compliance document NRCA-MCH-13b-B: Automatic Fault Detection and Diagnostics for AHU Valve Actuators and Zone Terminal Units, would contain the compliance credit FDD tests for heating and cooling coil valves and zone terminal units.

Acceptance test technicians and controls contractors were unsure when the NRCA-MCH-13-A test is currently required in the standards. The Title 24, Part 6 Standards do not make clear when this test should be performed except in the Nonresidential Compliance Manual. Thus, the Statewide CASE Team proposes that compliance software outputs require, on the NRCC-MCH-01-E document, showing that the NRCA-MCH-13a-A document must be completed for acceptance testing in built-up systems with air handlers larger than 54,000 Btu/hr and with an economizer.

Nearly all stakeholders stated that the acceptance test for FDD in air handlers is crucial to ensuring proper system operation, but also stated that the current NRCA-MCH-13-A (future NRCA-MCH-13a-A) acceptance test should be clarified and improved. The Statewide CASE Team removed redundancies and improved the comprehensiveness of the test by:

- Adding an inspection test of the installed temperature sensor accuracy.
- Introducing steps to ensure that alarm delays are overridden during testing to accelerate commissioning time. Some FDD systems delay alarms until a fault persists for a certain amount of time, to avoid nuisance reporting of brief fault conditions. This proposal requires that these alarm delays be bypassed to properly perform the FDD acceptance tests, and then reinstated after the test is complete to ensure proper FDD operation.
- Disconnecting a local supply air temperature sensor, and only disconnecting a local outside air temperature (OAT) sensor. If a global OAT sensor is disconnected, it may lead to other undetected faults and provide input to several other building systems (e.g., cooling towers) and lead to undetected faults.
- Clarifying which dampers are included in “mixing box dampers,” i.e., economizer dampers.
- Clarifying how to override operating modes in order for faults to appear, and later removing them for faults to clear.
- Avoiding disconnection of actuators because it may lead to permanent physical damage and place liability on the Acceptance Test Technician. Furthermore, it is unclear what fault is intended to occur when the power is cut to the actuator. The damper position is only known if the actuator is a feedback type actuator, and is unknown if the actuator is a floating point, modulating, or spring return actuator.

The proposed revisions in Sections 7.2 and 7.5 reflect these recommendations.

2.5.3 Compliance and Enforcement Summary

This code change proposal is mandatory and will affect all nonresidential buildings with built-up air handlers greater than 54,000 Btu/hr and an air-side economizer. The key steps during the compliance process are summarized below:

- **Design Phase**: Mechanical designers will need to develop or update the SOO to include economizer FDD. Designers may also include notes in the air handler schedule and controls diagram that economizer FDD is required, so that contractors can select appropriate equipment and bid accurately. Designers will need to ensure on the NRCC-MCH-01-E document that the NRCA-MCH-13a-A acceptance test is required to be completed.
- **Permit Application Phase**: The plans examiner will need to verify that the NRCC-MCH-01-E document shows that the NRCA-MCH-13a-A acceptance test is required to be completed. Acceptance test changes should not significantly change the amount of work for building officials.
- **Construction Phase**: Controls contractors that will implement economizer FDD will need to develop or update SOO, and coordinate with the mechanical contractor to select and install the appropriate equipment such as sensors and/or actuators. Controls contractors will likely need to test the FDD SOO, and improve and refine economizer FDD SOO from project to project.
- **Inspection Phase**: Acceptance test technicians will need to become acquainted with a slightly modified acceptance test procedure on the NRCA-MCH-13a-A document, and perform the test when applicable, which would add approximately one hour per air handler.

If this code change proposal is adopted, the Statewide CASE Team recommends that information presented in this Section 2.5, Section 3, and Appendix B be used to develop a plan that identifies a process to develop compliance documentation and how to minimize barriers to compliance.

3. Market Analysis

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry players who were invited to participate in utility sponsored stakeholder meetings held on September 26, 2016 and March 15, 2017.

The Statewide CASE Team spoke with controls contractors, acceptance test technicians, mechanical designers, DDC manufacturers, and third-party FDD vendors, totaling in at least 23 stakeholders interviewed. Furthermore, on multiple occasions the Statewide CASE Team presented interim findings and recommendations to the Western HVAC Performance Alliance (WHPA) FDD Committee, and solicited feedback. The WHPA is an advisory group comprised of manufacturers, consultants, technicians, researchers, distributors, and contractors, to ensure that industry perspectives are understood in a variety of forums. Stakeholders were encouraged to attend the utility sponsored stakeholder meetings and remain active throughout the CASE development process to support a better understanding of this complex market.

3.1 Market Structure

The economizer FDD in the built-up air handler market structure is not simply comprised of product manufacturers and suppliers. There are several channels through which economizer FDD in built-up systems could be implemented, through a variety of market actors:

- **DDC manufacturers** develop fully programmable systems designed to control a variety of building systems including HVAC, lighting, and hot water. The Statewide CASE Team is aware of several manufacturers that have stated interest in developing DDC products with preconfigured FDD modules containing SOO that require the controls contractor to connect to the appropriate inputs and outputs. However, there are currently no known available products from DDC manufacturers that have preconfigured economizer FDD modules.

- **Third-party FDD vendors** remotely monitor data from the DDC system, run it through FDD algorithms in off-site servers, and report alarms back to the building operator through fault management applications.
- **Mechanical designers** provide specifications for HVAC equipment and controls operation, and may include the FDD SOO into the construction submittal as guidance to the controls contractor.
- **Controls contractors** install the controls as specified by the designer and test the system to ensure proper operation. If the designer does not specify the controls sequencing, the controls contractor would need to develop their own FDD SOO during DDC setup.

Integrated and standalone economizer FDD products that are used to meet the current FDD requirements for packaged units are not typically implemented in a built-up air handler controlled by DDC. These products may also serve built-up systems; however, contractors control built-up systems through DDC and remove or disable any onboard economizer controllers from the individual unit (including economizer FDD). While it is technically possible that a standalone FDD system could operate on a built-up system, mechanical and controls contractors are likely to face significant challenges trying to ensure that alarms are detected and reported appropriately to the DDC. Thus, contractors simplify control by removing or disabling onboard economizer controllers and FDD and instead integrate FDD directly into the DDC SOO, and FDD specific controllers are not typically installed on built-up systems.

All of these market actors have the expertise and resources to develop economizer FDD in built-up systems, as discussed in Section 3.2.

3.2 Technical Feasibility, Market Availability, and Current Practices

Based on stakeholder information gathered throughout CASE development, economizer FDD is a familiar concept for nearly all market actors. Market actors, including DDC manufacturers, third-party FDD vendors, mechanical designers, and controls contractors, are able to develop FDD SOO in response to the possible change in standards. Most DDC manufacturers are aware of the current economizer FDD requirements for packaged air handlers and understand their options to translate their current FDD algorithms to their built-up air handler controls platforms, if applicable. Mechanical designers and controls contractors currently develop and specify SOO for a variety of systems, including economizer control and alarm generation therefore economizer FDD requirements can be integrated into these practices.

This code proposal does not mandate a specific approach to economizer fault detection. However, ASHRAE Guideline 36 (anticipated for completion in fall of 2017), provides one feasible SOO that detects economizer faults in built-up air handlers. The Statewide CASE Team assessed the most recent draft of Guideline 36 to ensure that the Title 24, Part 6 faults would be adequately addressed (see Appendix E for more detail). ASHRAE Guideline 36 uses input from four air temperature sensors (supply air, return air, outside air, and mixed air) to calculate potential fault conditions. Using air temperature sensors is likely the least expensive approach to complying with the economizer fault detection requirements, but the use of feedback actuators and other types of inputs may also be used in SOO.

Other requirements in Section 120.2(i), outside of faults required to be detected, are readily available on the built-up air handler market, including:

- Temperature sensor accuracy of +/- 2°F.
- Display of each sensor value via DDC.
- Indication of system status or mode (e.g., mechanical cooling enabled).
- Allow the individual testing of the economizer, cooling, and heating systems.
- Fault reporting to facility personnel.

The only requirement that may be challenging for the market to meet is certification to the Energy Commission, which the Statewide CASE Team recommends not be enforced for DDC-based systems, as described in Section 2.5.1. No significant changes in design, construction, or inspection are anticipated with the requirement of adding economizer FDD in built-up air handlers.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

This particular code change proposal will have a minimal impact on builders. Much of the coordination will need to occur among mechanical engineers, mechanical contractors, and controls contractors.

It is expected that builders will not be impacted significantly by any one proposed code change or the collective effect of all of the proposed changes to Title 24, Part 6. Builders could be impacted for change in demand for new buildings and by construction costs. Demand for new buildings is driven more by factors such as the overall health of the economy and population growth than the cost of construction. The cost of complying with Title 24, Part 6 requirements represents a very small portion of the total building value. Increasing the building cost by a fraction of a percent is not expected to have a significant impact on demand for new buildings or the builders' profits.

Market actors will need to invest in training and education to ensure the workforce, including designers and those working in construction trades, know how to comply with the proposed requirements. Workforce training is not unique to the building industry, and is common in many fields associated with the production of goods and services. Costs associated with workforce training are typically accounted for in long-term financial planning and spread out across the unit price of many units as to avoid price spikes when changes in designs and/or processes are implemented.

3.3.2 Impact on Building Designers and Energy Consultants

This particular revision to Title 24, Part 6 Standards will not require changes in design practices that are onerous for building designers and energy consultants. Designers may choose to develop and include economizer FDD algorithms in their SOO, but are not required to do so and can defer to the controls contractors to design the economizer FDD SOO. Some designers and energy consultants may need to be trained on the code update.

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Building code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials and ASHRAE 90.) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1 all market actors, including building designers and energy consultants, should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team is proposing for the 2019 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in requirements can be met.

3.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health. All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants, or those involved with the construction, commissioning, and maintenance of the building. By ensuring that economizers are functional, occupants will have improved indoor air quality conditions during periods when economizing is appropriate.

3.3.4 Impact on Building Owners and Occupants

As a result of economizer faults being detected and thus being more likely to be addressed, building occupants should experience increased comfort. Additionally, building owners and occupants will have increased opportunity to report faults to appropriate HVAC technicians. As a result of appropriately functioning economizers, building owners and tenants are likely to have lower energy bills.

3.3.5 Impact on Building Component Retailers (Including Manufacturers and Distributors)

Manufacturers of DDC-based economizer FDD would be exempted from certifying to the Energy Commission, but will have the option to certify to the Energy Commission when their DDC products contain a hard-coded FDD module. The Statewide CASE Team expects that some DDC manufacturers will use this approach to appeal to designers and controls contractors who have not developed economizer FDD SOO.

3.3.6 Impact on Building Inspectors

Plans examiners will need to verify that the NRCC-MCH-01-E document shows that the NRCA-MCH-13a-A acceptance test is required to be completed.

Acceptance test technicians will need to adjust to the NRCA-MCH-13a-A updates, and the new NRCA-MCH-13b-A document. By eliminating redundancy, removing any alarm delays, and clarifying intent (as described in Section 2.5.2), the Statewide CASE Team expects that the updates will reduce the time necessary to complete the acceptance test while also making it more accurate. However, because the NRCA-MCH-13a-A document will now be mandatory instead of a compliance option, the Statewide CASE Team expects that acceptance test technicians will need to spend an additional one hour per air handler to test the unit.

3.3.7 Impact on Statewide Employment

The proposed changes to Title 24, Part 6 are expected to result in positive job growth as noted below in Section 3.4. However, the Statewide CASE Team expects no impact on statewide employment from this particular measure, as manufacturing and building practices will remain essentially the same. The economizer and economizer FDD products being manufactured should not change significantly, if at all.

3.4 Economic Impacts

3.4.1 Creation or Elimination of Jobs

The building energy efficiency industry is comprised of employees who work at least part time or a fraction of their time on activities related to building efficiency. Employment in the building energy efficiency industry grew six percent between 2014 and 2015 while the overall statewide employment grew three percent (BW Research Partnership 2016). Lawrence Berkeley National Laboratory's report titled *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth* (2010) provides details on the types of jobs in the energy efficiency sector that are likely to be supported by revisions to building codes.

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.[4] Title 24, Part 6 creates jobs in all three categories with a significant amount from induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. Wei, Patadia, and Kammen (2010) estimate that energy efficiency creates 0.17 to 0.59 net job-years[5] per GWh saved. By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced. Using the mid-point for the energy efficiency range (0.38 net job-years per GWh saved) and estimates that this proposed code change will result in a statewide first-year savings of 0.88 GWh, this measure will result in approximately 0.33 jobs created during the first year the standards are in effect. See Section 6.1 for statewide savings estimates.

The Statewide CASE Team does not expect this code change to impact manufacturing or other supply chain jobs in California. The existing designers and control installation contractors, the California businesses most likely to be impacted by this measure, will not see a change in labor to meet this requirement.

3.4.2 Creation or Elimination of Businesses in California

There are approximately 43,000 businesses that play a role in California's advanced energy economy (BW Research Partnership 2016). California's clean economy grew ten times more than the total state economy between 2002 and 2012 (20 percent compared to 2 percent). The energy efficiency industry, which is driven in part by recurrent updates to the building code, is the largest component of the core clean economy (Ettenson and Heavey 2015). Adopting cost-effective code changes for the 2019 Title 24, Part 6 code cycle will help maintain the energy efficiency industry.

The Statewide CASE Team does not expect this code change to impact California businesses, either positively or negatively. Existing design and control installation businesses, the California businesses most likely to be impacted by this measure, will not see a change in costs or profits.

Table 3 lists industries that will likely benefit from the proposed code change classified by their North American Industry Classification System (NAICS) Code.

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[4] The definitions of direct, indirect, and induced jobs vary widely by study. Wei, Patadia, and Kammen (2010) describes the definitions and usage of these categories as follows: "*Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. *Indirect employment* refers to the ''supplier effect'' of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers."

[5] One job-year (or ''full-time equivalent'' FTE job) is full time employment for one person for a duration of one year.

Table 3: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Nonresidential Building Construction	2362
Electrical Contractors	23821
Plumbing, Heating, and Air-Conditioning Contractors	23822
Manufacturing	32412
Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manf.	3334
Engineering Services	541330
Building Inspection Services	541350
Environmental Consulting Services	541620
Other Scientific and Technical Consulting Services	541690

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the United States were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can be otherwise invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code changes that impact nonresidential buildings.

The Statewide CASE Team does not expect this code change to substantially impact California disadvantaged businesses, either positively or negatively. The Statewide CASE Team does not expect that disadvantage design and control installation businesses, the California businesses most likely to be impacted by this measure, will be impacted any differently than the rest of the market.

3.4.4 Increase or Decrease of Investments in the State of California

The proposed changes to the building code are not expected to impact investments in California on a macroeconomic scale, nor are they expected to affect investments by individual firms. The allocation of resources for the production of goods in California is not expected to change as a result of this code change proposal.

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

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes. The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if building owners spend additional discretionary income on taxable items. Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes will increase construction costs. As discussed in Section 3.3.1, however, there is no statistical evidence that Title 24, Part 6 drives construction costs or that construction costs have a significant impact on building price. Since compliance with Title 24, Part 6 does not have a clear impact on purchase price, it can follow that Title 24, Part 6 cannot be shown to impact revenues from property taxes.

3.4.5.1 Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will 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 to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

Cost to Local Governments

The Statewide CASE Team does not expect this code change will impact costs to local governments.

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will need to train building department staff on the revised Title 2, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2019 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 2.5 and Appendix B, 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.

3.4.6 Impacts on Specific Persons

The proposed changes to Title 24, Part 6 are not expected to have a differential impact on any groups relative to the state population as a whole including migrant workers, commuters, or persons by age, race, or religion. This measure applies to nonresidential mechanical systems, and does not directly impact any specific class or category of people.

4. ENERGY SAVINGS

4.1 Key Assumptions for Energy Savings Analysis

The Statewide CASE Team modeled the energy savings methodology based on the 2013 Light Commercial Unitary CASE Report methodology (PECI and Taylor Engineering 2011). This report addresses packaged systems only, not built up systems, but the FDD savings methodology is applicable to both system types. Overall, the Statewide CASE Team made conservative assumptions that reduce the estimate of energy savings due to this measure.

Fault incidence (column A) represents the percentage of newly installed air handlers that are expected to incur the fault during 15 years of operation. For each fault required as per Section 120.2(i), a fault incidence rate is assumed, based on AirCare Plus program 2013 through 2015 data (Table 4). Note that the AirCare Plus Program focuses on packaged AHUs, and thus the dataset may not be directly relevant to built-up AHUs. While this is a shortcoming of the dataset, it is the best and most complete dataset that the Statewide CASE Team could find despite extensive stakeholder outreach, and is a good proxy of the fault incidence rates that may be present in built-up AHUs. The derivation of the fault incidence rates is described in Appendix C.

The probability of detecting faults is not based on empirical data because the Statewide CASE Team and leading FDD experts are not aware such data exists. Because a variety of sensors and algorithms could be used to perform FDD, the Statewide CASE Team used 75 percent as the probability of FDD detecting a fault (column B). FDD experts at the WHPA FDD committee agreed that this was conservatively low assumption (a higher percentage would result in higher energy savings).

The WHPA FDD committee also agreed that 25 percent was a conservatively high assumption to use as the probability of detecting a fault without FDD (column C). Several committee members described experiences where facilities owners were unaware of an economizer fault existing in their equipment, or maintenance technicians "fixing" a comfort issue by locking the economizer damper in a position that avoids noticeable comfort issues most of the year but has negative energy impacts. Many members estimated that the reality of detecting an economizer fault without FDD is less than ten percent, but because there is very little aggregated empirical data on this issue, recommended that the Statewide CASE Team use 25 percent.

The FDD benefit represents the percentage of all air handlers that would benefit from economizer FDD by taking into account the fault incidence rate (column A) as well as the incremental increase in air handlers where the fault would be detected due to economizer FDD (column B minus column C).

Table 4: Fault Incidence Rates and FDD Benefit

Column	A	B	C	D
Title 24, Part 6 Fault	**Fault Incidence During 15 years of Operation**	**Probability of Detecting Fault With FDD**	**Probability of Detecting Fault Without FDD**	**FDD Benefit (A x (B - C))**
Air temperature sensor malfunction	19%	75%	25%	10%
Not economizing when it should	22%	75%	25%	11%
Economizing when it should not	8%	75%	25%	4%
Damper not modulating	13%	75%	25%	6%
Excess outdoor air	7%	75%	25%	4%

4.2 Energy Savings Methodology

The Statewide CASE Team assumes that only 25% of faults in a building that minimally complies with 2016 Title 24, Part 6, which does not require built-up air handler economizer FDD, are likely to be detected (as per Column C in Table 4). Building energy simulations used in the performance compliance path assume that the HVAC system operates with no faults. To assess the energy, demand, and energy cost impacts, the Statewide CASE Team developed energy simulation inputs designed to emulate economizer fault conditions required in Section 120.2(i) and simulated them in CBECC-Com. The energy savings were multiplied by FDD benefit percentages (discussed in Section 4.1) to attain net savings due to economizer FDD.

Economizer faults were simulated individually in the following ways, where SAT is Supply Air Temperature and RAT is Return Air Temperature. RATs are assumed to be constant at 75°F:

1. **Air temperature sensor failure:** Adjust SAT +/- 1°F and adjust economizer upper limit by +/- 1°F (to mimic OAT sensor drift).
2. **Not economizing when it should:** High limit set point = RAT - 10°F.
3. **Economizing when it should not:** High limit set point = RAT + 10°F.
4. **Damper not modulating:** No economizer (stuck closed).
5. **Excess outdoor air:** 80 percent outside air system (stuck open).

The FDD benefit for each fault in Table 4 was multiplied by the expected energy impact of the simulated faults, to attain the net energy benefit for each fault. The energy benefits for all faults were summed to yield energy and cost-effectiveness results in this report.

The Energy Commission provided guidance on the type of prototype buildings that must be modeled. Only the large office prototype was use in simulations, as detailed in Table 5. The energy savings from this measure varies by climate zone. As a result, the energy impacts and cost-effectiveness were evaluated by climate zone. Energy savings, energy cost savings, and peak demand reductions were calculated using a time dependent valuation (TDV) methodology.

Table 5: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Occupancy Type (Residential, Retail, Office, etc.)	Area (Square Feet)	Number of Stories	Statewide Area (Million Square Feet)
Large Office	498,000	13	30.821

The Statewide CASE Team used the energy savings per square foot from the large office simulations to estimate savings in new construction college buildings, which are typically served by central plants and thus are likely to have built-up air handlers. Detailed methodology is in Appendix A.

The code proposal includes a prescriptive requirement that AHUs serving computer room process spaces with integrated air economizers also meet the requirements of 120.2(i), when applicable (i.e., the AHU is greater than 54,000 Btu/hr). The Statewide CASE Team did not perform analysis specifically on a computer room space type. Under the assumption that computer rooms have higher cooling loads than offices per ft^2 of floorspace, the Statewide CASE Team estimates that computer rooms have higher potential for cooling energy savings due to economizer FDD.

4.3 Per-Unit Energy Impacts Results

Energy savings and peak demand reductions per unit for new construction are presented in Table 6. The per-unit energy savings estimates do not take naturally occurring market adoption or compliance rates into account.

Per square foot savings for the first year are expected to range from a high of 0.058 kilowatt-hours per year ($kWh/yr/ft^2$) and 0.003 $therms/yr/ft^2$ to a low of 0.021 $kWh/yr/ft^2$ and 0 $therms/yr/ft^2$ depending upon climate zone. Demand reductions/increases are expected to range between 0.068 Watts per square foot (W/ft^2) and 0.002 W/ft^2 depending on climate zone.

Table 6: First-Year Energy Impacts Per Square Foot of New Construction

Climate Zone	Electricity Savings (kWh/yr/ft²)	Peak Electricity Demand Reductions (W/ft²)	Natural Gas Savings (therms/yr/ft²)	TDV Energy Savings (TDV kBtu/yr/ft²)
1	0.028	0.002	0.001	1.1
2	0.034	0.060	0.001	1.4
3	0.033	0.027	0.000	0.9
4	0.035	0.035	0.001	1.1
5	0.033	0.013	0.000	0.9
6	0.035	0.045	0.000	1.0
7	0.038	0.040	0.000	1.0
8	0.036	0.068	0.000	1.2
9	0.041	0.035	0.000	1.6
10	0.038	0.058	0.000	1.3
11	0.039	0.048	0.001	1.8
12	0.034	0.059	0.001	1.4
13	0.038	0.056	0.001	1.7
14	0.046	0.006	0.001	2.0
15	0.058	0.038	0.000	2.2
16	0.021	0.034	0.003	1.1

Per square foot TDV energy cost savings over the 15-year period of analysis are presented in Table 7. These are presented as the discounted present value of the energy cost savings over the analysis period.

5. Lifecycle Cost and Cost-Effectiveness

5.1 Energy Cost Savings Methodology

TDV energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in 2020 present value (PV) dollars based on net present value (NPV) conversion factors of $0.0890/TDV, $2.45/kWh, and $16.00/therm. The TDV energy estimates are based on present valued cost savings but are normalized in terms of "TDV kBtu." Peak demand reductions are presented in peak power reductions (kW). The Energy Commission derived the 2020 TDV values that were used in the analyses for this report (Energy + Environmental Economics 2016).

The Statewide CASE Team used CBECC-Com to quantify energy savings and peak electricity demand reductions resulting from built-up air handler economizer FDD, as described in Section 4.2.

5.2 Energy Cost Savings Results

As presented in Table 7, it is estimated that the per square foot TDV energy cost savings over the 15-year evaluation period for newly constructed homes ranges between 0.20 and 0.08 NPV $/ft² depending on the climate zone. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. Economizer hours can be during both on-peak and off-peak hours, though the majority of economizing hours are off-peak because there are by definition more temperature conditions outside, which result in lower mechanical cooling loads than peak cooling conditions.

Table 7: TDV Energy Cost Savings Over the 15-Year Period of Analysis – Per Square Foot of New Construction

Climate Zone	15-Year TDV Electricity Cost Savings (2020 NPV $/ft^2)	15-Year TDV Natural Gas Cost Savings (2020 NPV $/ft^2)	Total 15-Year TDV Energy Cost Savings (2020 NPV $/ft^2)
1	0.08	0.01	0.10
2	0.11	0.01	0.12
3	0.07	0.01	0.08
4	0.09	0.01	0.10
5	0.07	0.01	0.08
6	0.09	0.00	0.09
7	0.09	0.00	0.09
8	0.11	0.00	0.11
9	0.14	0.00	0.14
10	0.11	0.01	0.12
11	0.14	0.01	0.16
12	0.12	0.01	0.13
13	0.14	0.01	0.15
14	0.16	0.01	0.18
15	0.20	0.00	0.20
16	0.06	0.04	0.10

5.3 Incremental First Cost

The Statewide CASE Team estimated the current incremental construction costs, which represents the incremental cost of the measure if a building meeting the proposed standard were built today, including materials and labor.

Per the Energy Commission's guidance, design costs are not included in the incremental first cost. Design costs cover the development of economizer FDD SOO, which could take several days, by mechanical designers, third-party FDD vendors, controls contractors, or DDC manufacturers. However, the programming and testing of economizer FDD SOO by controls contractors is not considered a design cost because it typically happens during building construction and is specific to the building.

The Statewide CASE Team assumed compliance through the method outlined in ASHRAE Guideline 36, which detects fault conditions through the use of inputs from the outdoor air and supply air temperature sensors (OAT and SAT, respectively), as well as the return air and mixed air temperature sensors (RAT and MAT, respectively). Among these sensors, the OAT and SAT are already required in Section 120.2(i). Thus, the material and labor for installing an RAT and MAT must be included in order to meet the hardware requirements for this measure, even though the code proposal does not include requiring these sensors because DDC-based FDD can be setup differently through a variety of inputs (e.g., feedback actuator input).

The RAT sensor can be a simple point sensor. However, an averaging MAT sensor is necessary because the mixing box, which mixes outside air and return air in the air handler, is subject to non-uniform and fluctuating air temperatures. An averaging MAT sensor gathers data from several temperature sensors mounted in the mixed air plenum.[6]

[6] Several data points in the mixing box develops a more accurate temperature estimate in the presence of heterogeneous air temperatures than a point MAT sensor. In larger air handlers, multiple MATs may be necessary (approximately one linear foot per square foot of fan area.)

Other material costs associated the sensors include wiring to the controller, as well as a potential controller upgrade. A controller with eight inputs can typically accommodate a built-up air handler. The Statewide CASE Team made the conservative assumption that the controller would need to be upgraded to accommodate the RAT and MAT sensors.

Based on stakeholder input (detailed in the Appendix D), current incremental construction cost components are summarized in Table 8. The NRCA-MCH-13a-A acceptance test must be completed by a mechanical acceptance test technician. The acceptance test is expected to take one hour per air handler, at an average rate of $150 per hour. The large office prototype has 13 air handlers that range in size from 70 to 110 tons each, thus individual air handler costs must be multiplied by 13 to attain whole building costs.

Table 8: Current Incremental Construction Cost for Economizer FDD in Built-Up Systems

Component	Cost	Source
Contractor Implementation of RAT, MAT, and FDD SOO	$2,604	3 Mechanical Designer and 2 Control Contractor Interviews (see Appendix)
Acceptance Testing	$150	2 Acceptance Test Technician Interviews
Total Cost Per Air Handler	$2,754	
Total Cost for 13 Air Handlers	$35,804	

5.4 Lifetime Incremental Maintenance Costs

FDD SOO is unlike other efficiency measures – it does not have an expected useful life or need to be replaced as is the case for other measures such as lighting. Energy savings will persist as long as FDD adequately detects and reports economizer faults. Assuming that FDD SOO function appropriately for the life of the AHU, they will detect more faults over the life of the AHU than if there was no FDD. Although there may be more attention paid to economizer faults and increased maintenance resulting due to FDD, the Statewide CASE Team is not assuming an increase in maintenance costs, because of the fact that built-up air handlers are typically maintained either by on-site facilities engineers or through a service contract with a maintenance company. In either case, costs are unlikely to increase because:

- On-site facilities engineers are typically paid an annual salary or hourly wage based on a set schedule. More frequent economizer maintenance is expected to be within their normal job description and not a catastrophic failure that would invoke overtime pay.
- Service contract agreements with a maintenance company are typically “all-embracing” or “full parts and labor” for large facilities that would have built-up air handlers. These contracts stipulate that the maintenance technician make a set number of site visits per year (typically two) to replace filters and check fan belts, and address other maintenance issues as needed. Economizer faults are likely to be addressed during these scheduled visits unless a building owner specifically requests that an additional visit be made on a time and materials basis. Based on discussions with stakeholders, building owners do not prioritize economizer fault remediation unless there are significant comfort issues.

5.5 Lifecycle Cost-Effectiveness

This measure proposes a mandatory HVAC requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 15-year period of analysis. The Energy Commission establishes the procedures for calculating lifecycle cost-effectiveness. The Statewide CASE Team collaborated with the Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. In this case, incremental first cost and incremental maintenance costs over the 15-year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were also included in the evaluation.

Design costs were not included nor was the incremental cost of code compliance verification. According to the Energy Commission's definitions, a measure is cost-effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the total present lifecycle cost benefits by the present value of the total incremental costs. Results of the per-unit lifecycle cost-effectiveness analyses are presented in Table 9 for new construction. The measure is found to be cost-effective in every climate zone.

Table 9: Lifecycle Cost-Effectiveness Summary – Large Office Prototype New Construction

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $)	Costs Total Incremental Present Value (PV) Costs[b] (2020 PV $)	Benefit-to-Cost Ratio
1	$47,504	$35,804	1.3
2	$60,025	$35,804	1.7
3	$40,330	$35,804	1.1
4	$48,282	$35,804	1.3
5	$39,567	$35,804	1.1
6	$45,275	$35,804	1.3
7	$45,202	$35,804	1.3
8	$53,866	$35,804	1.5
9	$72,163	$35,804	2.0
10	$57,791	$35,804	1.6
11	$78,119	$35,804	2.2
12	$64,121	$35,804	1.8
13	$77,266	$35,804	2.2
14	$88,172	$35,804	2.5
15	$99,593	$35,804	2.8
16	$50,916	$35,804	1.4

a. **Benefits: TDV Energy Cost Savings + Other Present Valued Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53)). Other savings are discounted at a real (nominal minus inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement, and maintenance over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present valued costs, the B/C ratio is infinite.

As described in Section 4.2, the Statewide CASE Team did not perform energy analysis on a computer room space type under the assumption that computer rooms would have much higher potential for cooling energy savings due to economizer FDD than office spaces. Assuming the same costs for built-up FDD integration, integrated air-side economizer FDD on computer room AHUs should be more cost-effective than the results in Table 9. Similarly, the 2013 Light Commercial Unitary CASE Report found economizer FDD to be cost-effective on packaged units serving office spaces (PECI and Taylor Engineering 2011), and thus would be cost-effective on computer rooms as well. This CASE Report and the 2013 CASE Report provide justification for prescriptive requirements on economizer FDD on computer room AHUs greater than 54,000 Btu/hr with an integrated air economizer.

6. First-Year Statewide Impacts

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per square foot savings, presented in Section 4.3, by the statewide new construction forecast for 2020 for large office buildings and college buildings. The 2020 new construction forecast data is presented in more detail in Appendix A. College buildings were assumed to be most often located on campuses that are served by central plant systems, and consequently built-up air handlers controlled by DDC. The first-year energy impacts represent the first-year annual savings from all buildings that were projected to be completed in 2020. The lifecycle energy cost savings represent the energy cost savings over the entire 15-year analysis period. Results are presented in in Table 10 for new construction.

Given data regarding the new construction forecast for 2020, the Statewide CASE Team estimates that the proposed code change will reduce annual statewide electricity use by 0.88 GWh with an associated demand reduction of 1.07 megawatts (MW). Natural gas use is expected to be reduced by 0.011 million therms. The energy savings for buildings constructed in 2020 are associated with a present valued energy cost savings of approximately $2.75 million in (discounted) energy costs over the 15-year period of analysis.

Table 10: Statewide Energy and Cost Impacts – New Construction

Climate Zone	Statewide New Construction in 2020 (million square feet)		First-Year[a] Electricity Savings (GWh)	First-Year[a] Peak Electrical Demand Reduction (MW)	First-Year[a] Natural Gas Savings (million therms)	Lifecycle[b] Present Valued Energy Cost Savings (PV$ million)
	College	Office				
1	0.02	0.03	0.00	0.00	0.000	0.00
2	0.09	0.52	0.02	0.04	0.001	0.07
3	0.41	3.46	0.13	0.11	0.002	0.31
4	0.21	1.17	0.05	0.05	0.001	0.13
5	0.04	0.23	0.01	0.00	0.000	0.02
6	0.26	2.18	0.08	0.11	0.000	0.22
7	0.21	1.10	0.05	0.05	0.000	0.12
8	0.36	3.20	0.13	0.24	0.001	0.38
9	0.42	4.31	0.19	0.16	0.001	0.69
10	0.31	1.09	0.05	0.08	0.001	0.16
11	0.08	0.21	0.01	0.01	0.000	0.04
12	0.38	2.25	0.09	0.16	0.002	0.34
13	0.16	0.39	0.02	0.03	0.000	0.09
14	0.05	0.27	0.01	0.00	0.000	0.06
15	0.04	0.14	0.01	0.01	0.000	0.04
16	0.09	0.62	0.01	0.02	0.002	0.07
TOTAL	**3.1**	**21.2**	**0.88**	**1.07**	**0.011**	**2.75**

a. First-year savings from all buildings completed statewide in 2020.

b. Energy cost savings from all buildings completed statewide in 2020 accrued during 15-year period of analysis.

6.2 Statewide Water Use Impacts

The proposed code change will not result in water savings. This is a conservative assumption as this measure could potentially provide water savings for built-up systems that have central plants (such as cooling towers) and faults that result in mechanical over-cooling are detected and fixed.

6.3 Statewide Material Impacts

In the context of the new construction of a built-up air handler, material impacts for two sensors and wiring are negligible.

6.4 Other Non-Energy Impacts

Occupants are expected to be more comfortable with improved economizer performance.

7. PROPOSED REVISIONS TO CODE LANGUAGE

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

7.1 Standards

SECTION 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Nonresidential, high-rise residential, and hotel/motel buildings shall comply with the applicable requirements of Sections 120.2(a) through 120.2(k).

(i) **Economizer Fault Detection and Diagnostics (FDD).** All newly installed ~~air-cooled packaged direct expansion units with an~~ air handlers with a mechanical cooling capacity greater than 54,000 Btu/hr ~~with~~ and an installed air economizer shall include a stand alone or integrated Fault Detection and Diagnostics (FDD) system in accordance with Subsections 120.2(i)1 through 120.2(i)8.

1. The following temperature sensors shall be permanently installed to monitor system operation: outside air, supply air, and when required for differential economizer operation, a return air sensor; and
2. Temperature sensors shall have an accuracy of ±2°F over the range of 40°F to 80°F; and
3. The controller shall have the capability of displaying the value of each sensor; and
4. The controller shall provide system status by indicating the following conditions:
   A. Free cooling available;
   B. Economizer enabled
   C. ~~Compressor~~ Mechanical cooling enabled;
   D. Heating enabled, if the system is capable of heating; and
   E. Mixed air low limit cycle active.
5. The unit controller shall allow manual~~ly~~ ~~initiate~~ initiation of each operating mode so that the operation of ~~compressors~~ cooling systems, economizers, fans, and heating systems can be independently tested and verified; and
6. Faults shall be reported in one of the following ways:
   A. Reported to an Energy Management Control System regularly monitored by facility personnel.

B. Annunciated locally on one or more zone thermostats, or a device within five (5) feet of zone thermostat(s), clearly visible, at eye level, and meeting the following requirements:
   i. On the thermostat, device, or an adjacent written sign, display instructions to contact
   ii. In buildings with multiple tenants, the annunciation shall either be within property management offices or in a common space accessible by the property or building manager.

C. Reported to a fault management application which automatically provides notification of the fault to remote HVAC service provider.

7. The FDD system shall detect the following faults:
   A. Air temperature sensor failure/fault;
   B. Not economizing when it should;
   C. Economizing when it should not;
   D. Damper not modulating; and
   E. Excess outdoor air.
8. The FDD System shall be certified by the Energy Commission as meeting requirements of Sections 120.2(i)1 through 120.2(i)7 in accordance with Section 110.0 and JA6.3.
   EXCEPTION to 120.2(i)8: FDD algorithms based in Direct Digital Control systems are not required to be certified to the Energy Commission.

SECTION 140.9 – PRESCRIPTIVE REQUIREMENTS FOR COVERED PROCESSES

(a) **Prescriptive Requirements for Computer Rooms.** Space conditioning systems serving a computer room with a power density greater than 20 W/ft^2 shall comply with this section by being designed with and having constructed and installed a cooling system that meets the requirements of Subsections 1 through 6.

1. Economizers. Each individual cooling system primarily serving computer rooms shall include either:

A. An integrated air economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the Energy Commission, at outside air temperatures of 55°F dry-bulb/50°F wet-bulb and below, and with fault detection and diagnostics as specified by Section 120.2(i); or

B. An integrated water economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the Energy Commission, at outside air temperatures of 40°F dry-bulb/35°F wet-bulb and below.

7.2 Reference Appendices

7.2.1 Joint Appendices

JA6.3 Economizer Fault Detection and Diagnostics (FDD) Certification Submittal Requirements.

Title 24, Part 6, Section 120.2(i) requires that economizer FDD functions be installed on all ~~air-cooled unitary air conditioning systems with an~~ air handlers with a mechanical cooling capacity ~~over~~ greater than 54,000 Btu/hr ~~cooling capacity~~ and an economizer, with the ability to detect the faults specified in Section 120.2(i). Each air conditioning system manufacturer, controls supplier, or FDD supplier wishing to certify that their FDD analytics conform to the FDD requirements of Title 24, Part 6, may do so in a written declaration. This requires that a letter be sent to the California Energy Commission declaring that the FDD conforms to Title 24, Part 6, Section 120.2(i). The declaration at the end of this section shall be used to submit to the California Energy Commission. FDD algorithms based in Direct Digital Control systems are not required to be certified to the California Energy Commission, but manufacturers, controls suppliers, or other market actors can choose to apply for certification.

7.2.2 Nonresidential Appendices

NA7.5.12 is currently split into two functional test sections, NA7.5.12.1 (for air handling units) and NA7.5.12.2 (for zone terminal units). The Statewide CASE Team recommends adding a new construction inspection section at the beginning, and moving the valve actuator tests into their own section, as shown below. The valve actuator test is to remain a compliance credit, along with the zone terminal unit test.

NA7.5.12 Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units (AHUs) 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 +/2°F over the range of 40°F to 80°F.

NA7.5.12.~~1~~2 Functional Testing for Air Handling Unit Economizers

Testing of each AHU with FDD controls shall include the following tests.

(a) Bypass alarm delays

Step 1: If applicable, bypass alarm delays to ensure that faults generate alarms immediately.

(~~a~~b) Sensor ~~drift/~~failure:

Step 1: Disconnect ~~outside air~~ local supply air temperature sensor from unit controller.
Step 2: Verify that the FDD system reports a fault.
Step 3: Connect S~~O~~AT sensor to the unit controller.
Step 4: Verify that FDD indicates normal system operation and clear all faults and alarms.
Step 5: If the outside air temperature sensor is local, disconnect the local OAT from the unit controller.
Step 6: Verify that the FDD system reports a fault.
Step 7: Connect the local OAT sensor to the unit controller.
Step 8: Verify that FDD indicates normal system operation and clear all faults and alarms.

(~~b~~c) ~~Damper/actuator fault~~ Inappropriate economizing:

Step 1: Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor below the low limit lockout.
Step ~~1~~2: From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~full open (~~100% outdoor air mode~~)~~.
Step ~~2~~3: ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.
Step ~~3~~4: ~~Reconnect power to the actuator and command the mixing box dampers to full open~~ Remove the economizer damper override and verify that the control system indicates normal system operation.

Step ~~4~~5: ~~Verify that the control system does not report a fault~~ Remove all overrides and clear all faults and alarms.
Step 6: Override the operating state to economizer-only cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor so that free cooling is available.
Step ~~5~~7: From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~a full-closed position (~~0% outdoor air mode~~)~~.
Step ~~6~~8: ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.
Step ~~7~~9: ~~Reconnect power to the actuator and command the dampers closed~~ Remove the economizer damper override and verify that the control system indicates normal system operation.
Step ~~8~~10: ~~Verify that the control system does not report a fault during normal operation~~ Remove all overrides and clear all faults and alarms~~.~~

~~(c) Valve/actuator fault:~~

~~Step 1: From the control system workstation, command the heating and cooling coil valves to full open or closed, then disconnect power to the actuator and verify that a fault is reported at the control workstation.~~

The Statewide CASE Team recommends item (c) Valve/actuator fault be moved from this test to Section NA 7.5.12.3. Furthermore, the Statewide CASE recommends that the Valve/actuator test be modified in a similar way as the newly proposed item (c) Inappropriate economizing above.

The Statewide CASE Team also recommends that item "(d) Inappropriate simultaneous heating, mechanical cooling, and/or economizing" be eliminated due to redundancy with the proposed changes.

~~(d) Inappropriate simultaneous heating, mechanical cooling, and/or economizing:~~

~~Step 1: From the control system workstation, override the heating coil valve and verify that a fault is reported at the control workstation.~~
~~Step 2: From the control system workstation, override the cooling coil valve and verify that a fault is reported at the control workstation.~~
~~Step 3: From the control system workstation, override the mixing box dampers and verify that a fault is reported at the control workstation.~~

(d) Reinstate alarm delay

Step 1: Reinstate alarm delays to ensure that faults generate alarms as before Step (a), if applicable.

NA7.5.12.3 Functional Testing for Air Handling Unit Valves

(a) Bypass alarm delays

Step 1: If applicable, bypass alarm delays to ensure that faults generate alarms immediately

(b) Valve/actuator fault:

Step 1: Override the operating state to occupied cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor to 90°F.
Step 2: From the control system workstation, override the heating coil valves to the full open position (100% heating mode).

Step 3: Verify flow through the valve by differential temperature or differential pressure method.
Step 4: Verify that a fault is reported at the control workstation.
Step 5: Remove the heating coil valve override and verify that the control system indicates normal system operation.
Step 6: Remove all overrides and clear all faults and alarms.
Step 7: Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor to 40°F.
Step 8: From the control system workstation, override the cooling coil valve to the full open position (100% cooling mode).
Step 9: Verify flow through the valve by differential temperature or differential pressure method.
Step 10: Verify that a fault is reported at the control workstation.
Step 11: Remove the cooling coil valve override and verify that the control system indicates normal system operation.
Step 12: Remove all overrides and clear all faults and alarms.

(c) Reinstate alarm delay

Step 1: Reinstate alarm delays to ensure that faults generate alarms as before Step (a), if applicable.

NA7.5.12.24 Functional Testing for Zone Terminal Units

[…]

7.3 ACM Reference Manual

The Statewide CASE Team proposes that compliance software outputs always show, on the NRCC-MCH-01-E document, that the NRCA-MCH-13a-A document must be used for acceptance testing in built-up systems greater than 54,000 Btu/hr with air handlers and an economizer.

The valve/actuator portion of the AHU functional test, and the zone terminal unit functional test, should remain optional compliance credits in NRCA-MCH-13b-A. The compliance credits for these portions of the test must be recalculated.

7.4 Compliance Manuals

7.4.1 Chapter 4 – Mechanical Systems

Chapter 4, Section 4.5.1.8, of the Nonresidential Compliance Manual will need to be revised according to the changes to the standard. Example 4-38 and Table 4-23 will also need to be revised accordingly. In addition to changes reflecting the standards, the Statewide CASE Team proposes adding the following language at the end of Section 4.5.1.8:

For air handlers controlled by direct digital controls (DDC), including packaged systems, FDD sequences of operations (SOO) must be developed to adhere with the requirements of 120.2(i)1 through 7.

ASHRAE Guideline 36-2017 is the recommended reference for developing SOO specifically for the faults listed in 120.2(7). The purpose of Guideline 36 is to provide uniform sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow for real-time fault detection and diagnostics. To properly adhere to Guideline 36, all SOO design elements in Sections 5.N.14 and/or Sections 5.P.11 must be implemented, including defining operating states, the use an alarm delay, and the installation of an averaging mixed air temperature (MAT) sensor. If a designer wishes to use Guideline 36 to detect the required economizer faults in Title 24 Section 120.2(i)7, the SOO should include Guideline 36 Fault Conditions #2, 3, and 5 through 13 at a minimum. Other Title 24 FDD requirements in Section 120.2(i) and acceptance tests are not met by including these fault conditions into SOO.

FDD systems controlled by DDC are not required to be certified to the California Energy Commission, but manufacturers, controls suppliers, or other market actors can choose to apply for certification.

7.4.2 Chapter 10 – Process Energy

The Statewide CASE Team proposes adding the following language at the end of Section 10.4.3.1.

This section requires integrated air or water economizer. If an air economizer is used to meet this requirement, it must be designed to provide 100% of the expected system cooling load at outside conditions of 55°F Tdb with a coincident 50°F Twb. This is different from the non-computer room economizer regulations (§140.4(e)), which require that an air economizer must supply 100 percent of the supply-air as outside air. The air economizer must also have fault detection and diagnostics (FDD) if it is on an air-handler that has a mechanical cooling capacity greater than 54,000 Btu/hr. A computer room air economizer does not have to supply any outside air if it has an air-to-air heat exchanger that can meet the expected load at the conditions specified and can be shown (through modeling) to consume no more energy that the standard air economizer.

The Statewide CASE Team proposes the following modification to Example 10-6.

Question

A new data center is built with chilled water CRAH units sized to provide 100% of the cooling for the IT equipment. The building also has louvered walls that can open to bring in outside air and fans on the roof that can exhaust air. Does this design meet the requirements of §140.9(a)1?

Answer

Yes, provided that all of the following are true:

• The economizer system moves sufficient air so that it can fully satisfy the design IT equipment loads with the CRAH units turned off and the outside air dry-bulb temperature at 55°F. And,

• The control system provides integrated operation so that the chilled water coils in the CRAH units are staged down when cool outside air is brought into the data center. And,

• The economizer system is provided with a high limit switch that complies with §140.4(e). Although fixed dry-bulb switches are allowed in §140.4(e) they are not recommended ~~recommend~~ in this application as the setpoints were based on office occupancies. A differential dry-bulb switch would provide much larger energy savings.

This system is not required to have economizer fault detection and diagnostics because the economizer is not located on any of the air handlers.

7.4.3 Chapter 13 – Acceptance Requirements

Due to the proposed changes to the Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units acceptance test, Chapter 13 Acceptance Tests will also need to be revised according to proposals in Section 7.5 below.

7.5 Compliance Documents

The existing acceptance document for NRCA-MCH-13-A, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units, is revised and renamed to NRCA-MCH-13a-A, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Unit Economizers, according to proposed changes in 7.2. Several parts of this test are recommended to be moved to NRCA-MCH-13b-A.

7.5.1 NRCA-MCH-13a-A

A. Construction Inspection	**Results**
1. Instrumentation to perform test includes, but not limited to:	
a. No instrumentation is required – changes are implemented at the building automation system control station	N/A
2. Installation	
b. 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 +/2°F over the range of 40°F to 80°F. ~~The functional testing verifies proper installation of the controls for FDD for air handling units and zone terminal units. No additional installation checks are required.~~	Yes/No

B. Functional Testing for Air Handling Unit~~s~~ Economizers	**Results**
Testing of each AHU with FDD controls shall include the following tests:	
Step 1: Bypass alarm delays	
a. If applicable, bypass alarm delays to ensure that faults generate alarms immediately	Yes/No /Not Applicable
Step ~~1~~2: Sensor ~~drift/~~failure	
a. Disconnect ~~outside air~~ local supply air temperature sensor from unit controller.	Yes/No
b. Verify that the FDD system reports a fault.	Yes/No
c. Connect S~~O~~AT sensor to the unit controller.	Yes/No
d. Verify that FDD indicates normal system operation and clear all faults and alarms.	Yes/No
e. If local, disconnect local outside air temperature sensor from unit controller.	Yes/No
f. Verify that the FDD system reports a fault.	Yes/No
g. Connect OAT sensor to the unit controller.	Yes/No
h. Verify that FDD indicates normal system operation and clear all faults and alarms.	Yes/No
Step ~~2~~3: ~~Damper/actuator fault~~ Inappropriate economizing	

a. Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor below the low limit lockout.	Yes/No
~~a~~b. From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~full open (~~100% outdoor air mode~~)~~.	Yes/No
~~b~~c. ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.	Yes/No
~~c~~d. ~~Reconnect power to the actuator and command the mixing box dampers to full open~~ Remove the economizer damper override and verify that the control system indicates normal system operation.	Yes/No
~~d~~e~~. Verify that the control system does not report a fault.~~ Remove all overrides and clear all faults and alarms	Yes/No
f. Override the operating state to economizer-only cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor so that free cooling is available.	Yes/No
~~e~~g. From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~a full-closed position (~~0% outdoor air mode~~)~~.	Yes/No
~~f~~h. ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.	Yes/No
~~g~~i. ~~Reconnect power to the actuator and command the dampers closed.~~ Remove the economizer damper override and verify that the control system indicates normal system operation.	Yes/No
~~h~~j. ~~Verify that the control system does not report a fault during normal operation~~. Remove all overrides and clear all faults and alarms.	Yes/No

The Statewide CASE Team recommends Step 3 (valve/actuator faults) be removed from this test and onto a new NRCA-MCH-13b-A compliance document (see Section 7.5.2). Furthermore, the Statewide CASE Team proposes that this step be modified in the same way as Step 2 above, to improve clarity. The faults introduced in the valve actuator test, if detected, will improve fault diagnosis and economizer operation.

The Statewide CASE Team recommends that "Step 4: Inappropriate simultaneous heating…" be eliminated due to redundancy with the proposed acceptance test changes.

~~Step 4: Inappropriate simultaneous heating, mechanical cooling, and/or economizing~~	
~~a. From the control system workstation, override the heating coil valve and verify that a fault is reported at the control workstation.~~	~~Yes/No~~
~~b. From the control system workstation, override the cooling coil valve and verify that a fault is reported at the control workstation.~~	~~Yes/No~~
~~c. From the control system workstation, override the mixing box dampers and verify that a fault is reported at the control workstation.~~	~~Yes/No~~
Step 4: Reinstate alarm delay	

a. Reinstate alarm delays to ensure that faults generate alarms as before Step 1, if applicable	Yes/No /Not Applicable

The Statewide CASE Team recommends Part C (functional test for zone terminal units) be removed from this test and onto a new NRCA-MCH-13b-A compliance document. Because Part C is not directly related to economizers, it is out of the scope of this proposal.

~~C. Functional Testing for Zone Terminal Units~~	~~Results~~
~~Testing of each AHU with FDD controls shall include the following tests:~~	

7.5.2 NRCA-MCH-13b-A

B. Functional Testing for Air Handling Unit~~s~~ Valves	Results
Testing of each AHU with FDD controls shall include the following tests:	
Step 1: Bypass alarm delays	
a. If applicable, bypass alarm delays to ensure that faults generate alarms immediately.	Yes/No /Not Applicable
Step 2~~3~~: Valve/actuator fault	
a. Override the operating state to occupied cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor to 90°F.	Yes/No
~~a~~b. From the control system workstation, ~~command~~ override the heating coil valves to the full open position (100% heating mode).	Yes/No
c. Verify flow through the valve by differential temperature or differential pressure method.	Yes/No
~~b~~d. ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.	Yes/No
~~c~~e. ~~Reconnect power to the actuator and command the heating coil valve to full open~~ Remove the heating coil valve override and verify that the control system indicates normal system operation.	Yes/No
~~d~~f~~. Verify that the control system does not report a fault.~~ Remove all overrides and clear all faults and alarms.	Yes/No
g. Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor to 40°F.	Yes/No
~~e~~h. From the control system workstation, ~~command~~ override the cooling coil valve to the full open position (100% cooling mode).	Yes/No

i. Verify flow through the valve by differential temperature or differential pressure method.	Yes/No
~~f~~j. ~~Disconnect power to the actuator and v~~Verify that a fault is reported at the control workstation.	Yes/No
~~g~~k. ~~Reconnect power to the actuator and command the cooling coil valve to full open.~~ Remove the cooling coil override and verify that the control system indicates normal system operation.	Yes/No
~~h~~l. ~~Verify that the control system does not report a fault during normal operation~~. Remove all overrides and clear all faults and alarms.	Yes/No
Step 3: Reinstate alarm delay	
a. Reinstate alarm delays to ensure that faults generate alarms as before Step 1, if applicable.	Yes/No /Not Applicable

C. Functional Testing for Zone Terminal Units	**Results**
Testing of each AHU with FDD controls shall include the following tests:	

[…]

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Appendix A: STATEWIDE SAVINGS METHODOLOGY

The projected nonresidential new construction forecast that will be impacted by the proposed code change in 2020 is presented in Table 11. This measure is only expected to impact new construction, not alterations.

The Energy Commission Demand Analysis Office provided the Statewide CASE Team with the nonresidential new construction forecast for 2020, broken out by building type and forecast climate zones (FCZ). The raw data from the Energy Commission is not provided in this report, but can be available upon request.

The Statewide CASE Team completed the following steps to refine the data and develop estimates of statewide floorspace that will be impacted by the proposed code changes:

1. Translated data from FCZ data into building standards climate zones (BSCZ). Since Title 24, Part 6 uses BSCZ, the Statewide CASE Team converted the construction forecast from FCZ to BSCZ using conversion factors supplied by the Energy Commission. The conversion factors, which are presented in Table 12 represent the percentage of building square footage in FCZ that is also in BSCZ. For example, looking at the first column of conversion factors in Table 12, 22.5 percent of the building square footage in FCZ 1 is also in BSCZ 1 and 0.1 percent of building square footage in FCZ 4 is in BSCZ 1. To convert from FCZ to BSCZ, the total forecasted construction for a specific building type in each FCZ was multiplied by the conversion factors for BSCZ 1, then all square footage from all FCZs that are found to be in BSCZ 1 are summed to arrive at the total construction for that building type in BSCZ 1. This process was repeated for every climate zone and every building type. See Table 14 for an example calculation to convert from FCZ to BSCZ. In this example, construction BSCZ 1 is made up of building floorspace from FCZs 1, 4, and 14.
2. Redistributed square footage allocated to the “Miscellaneous” building type. The building types included in the Energy Commissions’ forecast are summarized in Table 13ootage from nonresidential new construction in 2020 and the nonresidential existing building stock in 2020 to the miscellaneous building type, which is a category for all space types that do not fit well into another building category. It is likely that the Title 24, Part 6 requirements apply to the miscellaneous building types, and savings will be realized from this floorspace. The new construction forecast does not provide sufficient information to distribute the miscellaneous square footage into the most likely building type, so the Statewide CASE Team redistributed the miscellaneous square footage into the remaining building types in such a way that the percentage of building floorspace in each climate zone, net of the miscellaneous square footage, will remain constant. See Table 15 for an example calculation.
3. Made assumptions about the percentage of nonresidential new construction in 2020 that will be impacted by proposed code change by building type and climate zone. The Statewide CASE Team’s assumptions are presented in Table 16 and Table 17 and discussed further below.
4. Made assumptions about the percentage of the total nonresidential building stock in 2020 that will be impacted by the proposed code change by building type and climate zone. The Statewide CASE Team’s assumptions are presented in Table 16 and Table 17 and discussed further below.
5. Calculated nonresidential floorspace that will be impacted by the proposed code change in 2020 by building type and climate zone for new construction. Results are presented in Table 11.

Table 11: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2020, by Climate Zone and Building Type (Million Square Feet)

Climate Zone	New Construction in 2020 (Million Square Feet)											
	OFF-SMALL	REST	RETAIL	FOOD	NWHSE	RWHSE	SCHOOL	COLLEGE	HOSP	HOTEL	OFF-LRG	TOTAL
1	0	0	0	0	0	0	0	0.016	0	0	0.034	**0.050**
2	0	0	0	0	0	0	0	0.092	0	0	0.522	**0.614**
3	0	0	0	0	0	0	0	0.411	0	0	3.464	**3.875**
4	0	0	0	0	0	0	0	0.207	0	0	1.171	**1.379**
5	0	0	0	0	0	0	0	0.040	0	0	0.227	**0.268**
6	0	0	0	0	0	0	0	0.257	0	0	2.183	**2.441**
7	0	0	0	0	0	0	0	0.212	0	0	1.100	**1.312**
8	0	0	0	0	0	0	0	0.361	0	0	3.196	**3.557**
9	0	0	0	0	0	0	0	0.424	0	0	4.312	**4.736**
10	0	0	0	0	0	0	0	0.310	0	0	1.085	**1.395**
11	0	0	0	0	0	0	0	0.078	0	0	0.206	**0.284**
12	0	0	0	0	0	0	0	0.380	0	0	2.252	**2.632**
13	0	0	0	0	0	0	0	0.156	0	0	0.395	**0.550**
14	0	0	0	0	0	0	0	0.055	0	0	0.272	**0.327**
15	0	0	0	0	0	0	0	0.041	0	0	0.136	**0.177**
16	0	0	0	0	0	0	0	0.094	0	0	0.624	**0.717**
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3.135**	**0**	**0**	**21.179**	**24.315**

Table 12: Translation from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ)

		Building Standards Climate Zone (BSCZ)																
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**
Forecast Climate Zone (FCZ)	**1**	22.5%	20.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.8%	33.1%	0.2%	0.0%	0.0%	13.8%	100%
	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.0%	75.7%	0.0%	0.0%	0.0%	2.3%	100%
	3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	20.9%	22.8%	54.5%	0.0%	0.0%	1.8%	100%
	4	0.1%	13.7%	8.4%	46.0%	8.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.8%	0.0%	0.0%	0.0%	0.0%	100%
	5	0.0%	4.2%	89.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.6%	0.0%	0.0%	0.0%	0.0%	100%
	6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100%
	7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	75.8%	7.1%	0.0%	17.1%	100%
	8	0.0%	0.0%	0.0%	0.0%	0.0%	40.1%	0.0%	50.8%	8.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	100%
	9	0.0%	0.0%	0.0%	0.0%	0.0%	6.4%	0.0%	26.9%	54.8%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	5.8%	100%
	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	74.9%	0.0%	0.0%	0.0%	12.3%	7.9%	4.9%	100%
	11	0.0%	0.0%	0.0%	0.0%	0.0%	27.0%	0.0%	30.6%	42.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
	12	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	4.2%	95.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	100%
	13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	69.6%	0.0%	0.0%	28.8%	0.0%	0.0%	0.0%	1.6%	0.1%	0.0%	100%
	14	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	97.1%	100%
	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	99.9%	0.0%	100%
	16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

Table 13: Description of Building Types and Sub-types (Prototypes) in Statewide Construction Forecast

Energy Commission Building Type ID	Energy Commission Description	Prototype Description			
		Prototype ID	Floor Area (ft^2)	Stories	Notes
OFF-SMALL	Offices less than 30,000 square feet	Small Office	5,502	1	Five zone office model with unconditioned attic and pitched roof.
REST	Any facility that serves food	Small Restaurant	2,501	1	Similar to a fast food joint with a small kitchen and dining areas.
RETAIL	Retail stores and shopping centers	Stand-Alone Retail	24,563	1	Stand Alone store similar to Walgreens or Banana Republic.
		Large Retail	240,000	1	Big box retail building, similar to a Target or Best Buy store.
		Strip Mall	9,375	1	Four-unit strip mall retail building. West end unit is twice as large as other three.
		Mixed-Use Retail	9,375	1	Four-unit retail representing the ground floor units in a mixed-use building. Same as the strip mall with adiabatic ceilings.
FOOD	Any service facility that sells food and or liquor	N/A	N/A	N/A	N/A
NWHSE	Non-refrigerated warehouses	Warehouse	49,495	1	High ceiling warehouse space with small office area.
RWHSE	Refrigerated Warehouses	N/A	N/A	N/A	N/A
SCHOOL	Schools K-12, not including colleges	Small School	24,413	1	Similar to an elementary school with classrooms, support spaces and small dining area.
		Large School	210,886	2	Similar to high school with classrooms, commercial kitchen, auditorium, gymnasium and support spaces.
COLLEGE	Colleges, universities, community colleges	Small Office	5,502	1	Five zone office model with unconditioned attic and pitched roof.
		Medium Office	53,628	3	Five zones per floor office building with plenums on each floor.
		Medium Office/Lab		3	Five zones per floor building with a combination of office and lab spaces.
		Public Assembly		2	TBD
		Large School	210,886	2	Similar to high school with classrooms, commercial kitchen, auditorium, gymnasium and support spaces.
		High Rise Apartment	93,632	10	75 residential units along with common spaces and a penthouse. Multipliers are used to represent typical floors.
HOSP	Hospitals and other health-related facilities	N/A	N/A	N/A	N/A
HOTEL	Hotels and motels	Hotel	42,554	4	Hotel building with common spaces and 77 guest rooms.
MISC	All other space types that do not fit another category	N/A	N/A	N/A	N/A
OFF-LRG	Offices larger than 30,000 square feet	Medium Office	53,628	3	Five zones per floor office building with plenums on each floor.
		Large Office	498,589	12	Five zones per floor office building with plenums on each floor. Middle floors represented using multipliers.

Table 14: Converting from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ) – Example Calculation

Climate Zone	**Total Statewide Small Office Square Footage in 2020 by FCZ** (Million Square Feet) **[A]**	**Conversion Factor FCZ to BSCZ 1 [B]**	**Small Office Square Footage in BSCZ 1** (Million Square Feet) **[C] = A x B**
1	0.204	22.5%	0.046
2	0.379	0.0%	0.000
3	0.857	0.0%	0.000
4	1.009	0.1%	0.001
5	0.682	0.0%	0.000
6	0.707	0.0%	0.000
7	0.179	0.0%	0.000
8	1.276	0.0%	0.000
9	0.421	0.0%	0.000
10	0.827	0.0%	0.000
11	0.437	0.0%	0.000
12	0.347	0.0%	0.000
13	1.264	0.0%	0.000
14	0.070	2.9%	0.002
15	0.151	0.0%	0.000
16	0.035	0.0%	0.000
Total	**8.844**		**0.049**

Table 15: Example of Redistribution of Miscellaneous Category - 2020 New Construction in Climate Zone 1

Building Type	**2020 Forecast** (Million Square Feet) **[A]**	**Distribution Excluding Miscellaneous Category [B]**	**Redistribution of Miscellaneous Category** (Million Square Feet) **[C] = B × 0.11**	**Revised 2020 Forecast** (Million Square Feet) **[D] = A + C**
Small Office	0.049	12%	0.013	0.062
Restaurant	0.016	4%	0.004	0.021
Retail	0.085	20%	0.022	0.108
Food	0.029	7%	0.008	0.036
Non-Refrigerated Warehouse	0.037	9%	0.010	0.046
Refrigerated Warehouse	0.002	1%	0.001	0.003
Schools	0.066	16%	0.017	0.083
College	0.028	7%	0.007	0.035
Hospital	0.031	7%	0.008	0.039
Hotel/Motel	0.025	6%	0.007	0.032
Miscellaneous	0.111	---	-	---
Large Offices	0.055	13%	0.014	0.069
Total	**0.534**	**100%**	**0.111**	**0.534**

Table 16: Percent of Floorspace Impacted by Proposed Measure, by Building Type

Building Type *Building Sub-Type*	**Composition of Building Type by Sub-Types[a]**	**Percent of Square Footage Impacted[b]**	
		New Construction	**Existing Building Stock (Alterations)[c]**
Small office		0%	0%
Restaurant		0%	0%
Retail		0%	0%
Stand-Alone Retail	*10%*	*0%*	*0%*
Large Retail	*75%*	*0%*	*0%*
Strip Mall	*5%*	*0%*	*0%*
Mixed-Use Retail	*10%*	*0%*	*0%*
Food		0%	0%
Non-Refrigerated Warehouse		0%	0%
Refrigerated Warehouse		N/A	N/A
Schools		0%	0%
Small School	*60%*	*0%*	*0%*
Large School	*40%*	*0%*	*0%*
College		45%	0%
Small Office	*5%*	*45%*	*0%*
Medium Office	*15%*	*50%*	*0%*
Medium Office/Lab	*20%*	*100%*	*0%*
Public Assembly	*5%*	*50%*	*0%*
Large School	*30%*	*50%*	*0%*
High Rise Apartment	*25%*	*50%*	*0%*
Hospital		N/A	N/A
Hotel/Motel		0%	0%
Large Offices		0%	0%
Medium Office	*50%*	*0%*	*0%*
Large Office	*50%*	*100%*	*0%*

a. Presents the assumed composition of the main building type category by the building sub-types. All 2019 CASE Reports assumed the same percentages of building sub-types.

b. When the building type is comprised of multiple sub-types, the overall percentage for the main building category was calculated by weighing the contribution of each sub-type.

c. Percent of existing floorspace that will be altered during the first-year the 2019 Standards are in effect.

Table 17: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone

Climate Zone	Percent of Square Footage Impacted	
	New Construction	Existing Building Stock (Alterations)[a]
1	100%	0%
2	100%	0%
3	100%	0%
4	100%	0%
5	100%	0%
6	100%	0%
7	100%	0%
8	100%	0%
9	100%	0%
10	100%	0%
11	100%	0%
12	100%	0%
13	100%	0%
14	100%	0%
15	100%	0%
16	100%	0%

a. Percent of existing floorspace that will be altered during the first year the 2019 Standards are in effect.

Appendix B: Discussion of Impacts of Compliance Process on Market Actors

This section discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. The Statewide CASE Team asked stakeholders for feedback on how the measure will impact various market actors during public stakeholder meetings that were held on September 26, 2016 and March 15, 2017 (Statewide CASE Team 2016, 2017). The Statewide CASE Team also interviewed several DDC manufacturers, controls contractors, mechanical designers, FDD vendors, acceptance test technician trainers, and commissioning agents to gather information about how the proposed code change will impact them. The key results from feedback received during stakeholder meetings and other target outreach efforts are detailed below.

Table 18 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. Generally, the new requirements of DDC-based FDD and mandatory acceptance test for the FDD system will fit within the current work flow of the market actors. There will likely be improved coordination among various market actors to meet the measure requirements, but no specialized training or skills are necessary to meet the code requirement. Writing FDD SOO will require additional time to develop, but after development and refinement, the SOO will be replicable across projects. However, the FDD SOO will need to be acceptance tested at each individual AHU to ensure functionality, with the proposed NRCA-MCH-13a-A Automated Fault Detection and Diagnostics (AFDD) for Air Handling Units Acceptance Test.

While DDC-based FDD will not be required to be certified to the Energy Commission, some market actors may choose to certify their SOO for marketing purposes. The Statewide CASE Team has considered this possibility in Table 18.

Table 18: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Mechanical Designer	• Select equipment • Develop design drawings and specifications while coordinating with other architects, structural engineers, and installers/contractors. • Develop custom sequences of operation (SOO) as necessary.	• A design that meets the energy and comfort needs of owner/occupants. • The design intent is properly installed, and passes plan check and acceptance tests.	• May choose to develop customized economizer FDD SOO for large built-up AHUs with economizers. • May need to coordinate with controls contractor to ensure appropriate SOO setup.	• Use ASHRAE Guideline 36 to develop FDD SOO. • Check FDD setup and implementation during construction administration process. • Refine FDD SOO over time. • To avoid confusion during construction, ensure on the NRCC-MCH-01-E document that the NRCA-MCH-13a-A acceptance test is required to be completed.
Energy Consultant	• Coordinate with the mechanical designer and architect. • Complete compliance documents related to energy.	• Building a model that meets the compliance criteria and is accurate to the building to pass plan check • Ensuring AHU size and type, and economizer type is modeled correctly.	• May need to become familiar with new compliance credit for AFDD for Zone Terminal Units	• To avoid confusion during construction, ensure on the NRCC-MCH-01-E document that the NRCA-MCH-13a-A acceptance test is required to be completed.
AHU, Economizer, and DDC Manufacturers	• Building HVAC equipment – economizer dampers, control logic, and economizer FDD -- sometimes in response to what building code requires. • Coordinate with designers and installers through product guides, distributors and local representatives, and installation manuals.	• Unit/component operates as designed and in accordance with T24 Part 6.	• May need to develop new economizer FDD algorithms for built up systems. • May need to coordinate with controls contractors to ensure appropriate SOO for accurate fault detection.	• Use ASHRAE Guideline 36 or packaged economizer FDD algorithms to develop built up FDD SOO. • Check FDD setup and implementation during construction administration process. • Refine FDD SOO over time.
HVAC Controls Subcontractor	• Coordinate with mechanical designer to properly select and install equipment according to specifications.	• Installing a properly working economizer and economizer FDD, including writing FDD controls sequence if none are	• May choose to develop customized FDD SOO for large built-up AHUs with economizers.	• Use ASHRAE Guideline 36 to develop FDD SOO. • Check FDD setup and implementation during

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
	• Potentially complete, or assist with acceptance tests.	provided. • Equipment that meets the specification provided, installation that passes acceptance tests, building owner satisfaction, and no warranty issues post construction.	• May need to coordinate with DDC manufacturer or mechanical designer to ensure appropriate SOO setup.	construction administration process. • Refine FDD SOO over time.
Acceptance Test Technicians	• One or more site visits to verify code compliant and proper installation of equipment, signing certificate of acceptance. • Coordinate with the installer primarily, possibly the mechanical designer.	• Checking air economizer controls equipment and FDD installation and functionality according to Title 24, Part 6 procedures. • Verifying economizer and FDD installation, identifying incorrectly installed economizer FDD, and issuing a certificate of acceptance with as few re-inspections as possible.	• Will need to become accustomed to new NRCA-MCH-13a-A document being mandatory, rather than a compliance credit.	• Will need to become accustomed with new procedures on NRCA-MCH-13a-A document to ensure on-site tests do not take longer than necessary.

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Building Enforcement Agency	• Review the permit submittal for code compliance, issue construction permit, issue occupancy permit, review construction installation • Coordinate with the mechanical designer and energy consultant (sometimes through architect or owner) and acceptance tester for certificate of acceptance during the permitting process • Paper review of permit application submission, and review installation	• Confirming plans are compliant with Title 24, Part 6 and energy model was completed correctly • Need to get things right the first time to avoid re-inspection	• The plans examiner will need to verify that the NRCC-MCH-01-E document shows that the NRCA-MCH-13a-A acceptance test is required to be completed. • May need to check plans for specification of economizer FDD.	• Become acquainted with when economizer FDD is required • Check plans for specification of economizer FDD
Building Owner / Facility Personnel	• Maintain systems and ensure efficient building operation • A handoff with the commissioning agent or mechanical designer on instructions manuals for equipment	• An efficiently run and functional building, lowering operational costs and maintaining operational costs • Ensure that FDD system is working, without sending out too many alarms or too little alarms	• Will need to be educated on economizer FDD alarms and appropriate course of action (servicing the system or contacting a maintenance technician)	• Training on how to appropriately fix economizer faults

Appendix C: AirCare Plus Data Analysis to Determine Economizer Fault Incidence

Fault incidence rates represent how often faults occur in AHUs. Incidence rates help the Statewide CASE Team provide an estimate of the savings potential of economizer FDD that detects and reports faults, ostensibly because faults that are detected and reported will be remediated rather than persist. The use of fault incidence rates in the energy savings analysis is described in Section 4. Based on the precedence that AirCare Plus Program data was used to determine fault incidence rates for the packaged economizer FDD CASE proposal for the 2013 Title 24, Part 6 code cycle, Pacific Gas and Electric Company provided the Statewide CASE Team with more recent AirCare Plus Program data to support the development of updated economizer fault incidence rate estimates for the 2019 Title 24, Part 6 code cycle.

Note that the AirCare Plus Program focused on packaged or split rooftop AHUs up to 60 tons, and thus the dataset may not be directly relevant to built-up AHUs. While this is a shortcoming of the dataset, it is the best and most complete dataset that the Statewide CASE Team could find despite extensive stakeholder outreach, and is a good proxy of the fault incidence rates that may be present in built-up AHUs.

The Statewide CASE Team received the latest three years of AirCare Plus Program data, from 2013 to when the program ended in 2015. The program provided incentives to commercial building owners to make packaged AHUs operate more efficiently through a series of maintenance measures. The program was not designed to enroll only malfunctioning packaged or split AHUs. Economizer-specific measures were split into high and low cost options, with higher incentives provided for high cost repairs – it is unclear if/how this may have affected the type of economizer repairs performed. Program coverage included data from a variety of hot and mild climate zones in northern California.

The AirCare Plus Program dataset contains a total of 34,911 entries for all HVAC related repairs on packaged units for three years (2013 through 2015). The Statewide CASE Team reviewed and cleaned the data, developed a unique identifier comprised of the packaged AHU serial number and the date serviced, and removed duplicative data entries. The unique identifier has a combined metric of “AHUs × fault occurrence.”

As shown in Table 19, the cleaned dataset contained a total of 13,494 HVAC related fault entries with 9,603 unique packaged AHUs. Of the unique air handlers, 3,662 (38 percent) are greater than 4.5 tons and thus relevant to this code proposal. Of the 3,662 packaged AHUs greater than 4.5 tons, 1,403 (38 percent) had economizer related faults. The data were then categorized based on different criteria into one or more of the five Title 24, Part 6 economizer fault types.

Table 19: Count of Fault Entries and Packaged AHUs in AirCare Plus Program (2013-2015)

Type	Total	Packaged AHUs > 4.5 Tons	Packaged AHUs > 4.5 Tons with Economizer Related Faults
Fault Entries	13,494	5,296	1,824
Unique Packaged AHUs	9,603	3,662	1,403

The economizer fault prevalence rate of 38 percent is lower than previous literature on this topic, but aligns well with recent surveys by Dr. Kristin Heinemeier. Dr. Heinemeier (2014) conducted a meta-analysis containing 12 research studies on economizer failure rates between 1993 and 2013 that showed failure rates ranging from 43 to 100 percent. In 2014 Dr. Heinemeier also surveyed twenty commercial building contractors and found that specific economizer failure prevalence range from 5 to 40 percent, depending on the fault type.

The AirCare Plus Program data has general information on the type of repair that was performed, and has no correlation with the economizer FDD faults required in Section 120.2(i). The Statewide CASE Team assessed whether a particular data entry corresponded to a fault type shown in Table 20 by using two key parameters. The first parameter to understanding the type of fault is the 'POST Economizer Repair Technician Comments,' and the second parameter is the pre- and post-repair changeover set-points (also known as the high-limit set-point).

Table 20: Fault Types

Type	Fault Description
Type 1	Air temperature sensor failure/fault
Type 2	Not economizing when it should
Type 3	Economizing when it should not
Type 4	Damper not modulating
Type 5	Excess outdoor air

Using these two key parameters, the Statewide CASE Team categorized the faults as described below:

- **High limit set point**: If the high limit set-point was increased post repair, then it was characterized as a Type 2 fault (i.e., not economizing when it should). Alternatively, if the high limit set-point was decreased post repair, then it was characterized as a Type 3 fault (i.e., economizing when it should not). This was implemented both using excel formulas as well as a manual review where required.
- **Sensor related comments**: Sensor related faults, including relocation or replacement, were categorized as a Type 1 fault (i.e., air temperature sensor failure/fault). Although air temperature sensor failure/faults are very likely to result in inappropriate economizing, the Statewide CASE Team did not count the sensor repairs towards other faults to be conservative.
- **Damper/actuator related comments**: Other mechanical faults were related to dampers, actuators, motors, or linkages. All of the damper related repairs such as replacements and adjustments are categorized as a Type 4 fault (i.e., damper not modulating). It is possible that a malfunctioning damper would also translate into a Type 2 or Type 3 fault depending on where the damper got stuck. Because of a lack of description on the position in which the damper/actuator malfunctioned, the Statewide CASE Team categorized half of the Type 4 faults as Type 2 and Type 3 each.

The Type 5 fault count is assumed to be equal to the Type 3 fault, because they represent the same condition (economizing when it should not indicate that there is excess outdoor air). Table 21 below summarizes the fault conditions, and the types of comments that were categorized as the fault.

Table 21: Overview of Fault Categorization of AirCare Plus Data

Type	Fault Description	AirCare Plus Data Interpretation
Type 1	Air temperature sensor failure/fault	Relocation, replacement or installation of supply or outside air sensor
Type 2	Not economizing when it should	High limit set point is increased post repair (plus half of the Type 4 faults)
Type 3	Economizing when it should not	High limit set point is decreased post repair (plus half of the Type 4 faults)
Type 4	Damper not modulating	Relocation or fixing of dampers, linkages, actuators or fixing of low voltage wiring
Type 5	Excess outdoor air	(Equal to Type 3)

The Statewide CASE Team calculated the fault incidence rate for each year by counting the number of faults under a specific category (Type 1 through Type 5) and dividing it by the number of unique air handlers that are greater than 4.5 tons in that year. The average incidence rate for the dataset was determined by calculating the average of each annual incidence rate for each fault type, as per Table 22 below. Table 23 lists the 2013 Light Commercial Unitary CASE Report (PECI and Taylor Engineering 2011) incidence rates as compared to the 2013-2015 findings. All incidence rates appear to have reduced from the 2013 CASE dataset, except air temperature sensor failure/fault. The Statewide CASE Team was not able to access to the 2013 CASE dataset. Through discussions with the 2013 CASE author and the program data available, the Statewide CASE Team determined the need to revise the data analysis approach for this CASE proposal. Without access to the 2013 CASE dataset, the Statewide CASE Team could not determine why incidence rates appear to have fluctuated.

Table 22: Annual and Average Incidence Rates from AirCare Plus Data

Fault	2013	2014	2015	Average
Air temperature sensor failure/fault	26%	20%	11%	19%
Not economizing when it should	29%	11%	25%	22%
Economizing when it should not	11%	5%	7%	8%
Damper not modulating	17%	9%	11%	13%
Excess outdoor air	11%	5%	6%	7%

Table 23: Comparison of 2013 CASE Fault Incidence Rates with 2013-2015 AirCare Plus Data

Fault	2013 CASE Incidence Rates	2013-2015 AirCare Plus Incident Rates
Air temperature sensor failure/fault	2%	19%
Not economizing when it should	30%	22%
Economizing when it should not	No data	8%
Damper not modulating	24%	13%
Excess outdoor air	24%	7%

Appendix D: COST DATA COLLECTION

The Statewide CASE Team collected costs for adding RAT and MAT sensors to the air handler primarily from two sources: mechanical designers and controls contractors. Mechanical designers provided a rule-of-thumb meant to represent the cost of an additional control point, summarized below in Table 24. Designers also noted that MATs and RATs are more often installed in built-up air handlers, if not for control then for monitoring and trending. Nonetheless, the CASE Team conservatively assumed that RATs and MATs represented entirely additional control points.

Table 24: Mechanical Designer Costs Per Additional Control Point

Designer	Minimum of Range	Maximum of Range	Average
#1	$1,000	$2,000	$1,500
#2	$500	$2,000	$1,250
#3	$1,000	$1,500	$1,250
Average Cost			**$1,333**

Based on Table 24, the average cost for adding two control points (the RAT and MAT) would be $2,666 per air handler, or $34,658 for the 13 air handlers in the large office prototype. The Statewide CASE Team also spoke with two controls contractors to attain itemized costs for adding the two control points, summarized in Table 25. Costs include all markups.

Table 25: Current Incremental Construction Cost for Economizer FDD in Built-Up Systems

		Control Contractor #1			**Control Contractor #2**		
Row	**Cost Component**	**Number of Units Per Air Handler**	**Cost Per Unit**	**Cost Per Air Handler**	**Number of Units Per Air Handler**	**Cost Per Unit**	**Cost Per Air Handler**
A	Averaging MAT Sensor	4	$238	$952	4	$170	$680
B	RAT Sensor	1	$78	$78	1	$50	$50
C	Upsized Controller	1	$700	$700	1	$350	$350
D	Control and Electrical Contractor Installation and Wiring (Hours and Materials)	5	$105	$525	-	-	$1,150
E	Control Contractor Implementation, Startup, and Testing (Hours)	1	$75	$75	4	$125	$500
F	**Total Cost Per Air Handler (A+B+C+D+E)**			**$2,355**			**$2,730**
G	**Total Cost for 13 Air Handlers (F x 13)**			**$30,610**			**$35,490**
H	**Average Cost for RAT, MAT, and FDD SOO**			**$33,050**			

Based on Table 25, the average cost for adding the RAT and MAT and programming the FDD SOO would be $33,050. The overall average of the mechanical design estimate and the control contractor cost estimates for implementing the necessary sensors and controls to complete economizer FDD is $33,854, or $2,604 per air handler.

Appendix E: GUIDELINE 36 AND TITLE 24, PART 6

Table 26 below depicts how the Statewide CASE Team believes that the Title 24, Part 6 fault detection requirements align with the Guideline 36 fault conditions. ASHRAE Guideline 36 is still under development, though significant changes to the fault condition equations are not anticipated based on the first round of public comments. Shaded cells on the fault conditions rows indicate irrelevant conditions to economizers and/or operating states.

Table 26. Assessment of Guideline 36 Fault Conditions that Align with Title 24, Part 6 Fault Detection Requirements

Operating States, Defined by Commanded Position of Valves and Dampers

1 - Heating only

2 - Economizer cooling only

3 - Economizer and mechanical cooling

4 - Mechanical cooling only

Title 24, Part 6 Fault to be Detected (120.2(i)7)	A. Air Temp Sensor				B. Not Economizing When It Should				C. Economizing When It Should Not				D. Damper Not Modulating				E. Excess Outdoor Air			
Guideline 36 Operating State #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Guideline 36 Fault Condition Description																				
1 - Duct static pressure too low																				
2 - MAT too low; should be between OAT and RAT	X	X	X	X																
3 - MAT too high; should be between OAT and RAT	X	X	X	X																
4 - Too many changes in operating state																				
5 - SAT too low; should be higher than MAT	X																			
6 - OA fraction not equal to %OAmin	X			X					X			X	X			X	X			X
7 - SAT too low in full heating	X								X				X				X			
8 - SAT and MAT should be approximately equal		X																		
9 - OAT too high for economizer cooling only		X																		
10 - OAT and MAT should be approximately equal			X				X													
11 - OAT too low for 100% cooling			X				X								X					
12 - SAT too high; should be less than MAT			X	X																
13 - SAT too high in full cooling			X	X								X				X				X
14 - Temperature drop across inactive cooling coil																				
15 - Temperature rise across inactive heating coil																				

ATTACHMENT 2: PUBLIC COMMENTS SUBMITTED BY THE STATEWIDE CASE TEAM

The Statewide CASE Team did not submit any comments to the Energy Commission's docket that were relevant to this measure.