DOCKETED

Docket Number:	19-BSTD-03
Project Title:	2022 Energy Code Pre-Rulemaking
TN #:	235877
Document Title:	Robert Mowris Comments - Economizer Calibration and Perimeter Gap Sealing, FDD Fan-on Correction, and Economizer Cooling to 18 kBtuh
Description:	N/A
Filer:	System
Organization:	Robert Mowris
Submitter Role:	Other Interested Person
Submission Date:	12/7/2020 5:29:32 PM
Docketed Date:	12/8/2020

Comment Received From: Robert Mowris
Submitted On: 12/7/2020
Docket Number: 19-BSTD-03

Economizer Calibration and Perimeter Gap Sealing, FDD Fan-on Correction, and Economizer Cooling to 18 kBtuh

This proposal recommends the following Heating, Ventilating Air Conditioning (HVAC) energy efficiency measures: 1) economizer calibration and perimeter gap sealing, 2) Fault Detection Diagnostic (FDD) fan-on correction, and 3) expand economizer requirements to 18 thousand British thermal units per hour (kBtuh). These low-cost measures are easy to install and apply to all nonresidential buildings regulated by the California Building Energy Efficiency Standards. Sealing the economizer perimeter gap between the economizer frame and the HVAC system cabinet reduces excess outdoor airflow, and calibrating the economizer minimum damper position to within plus or minus 5% of the design minimum outdoor airflow improves indoor air quality and occupant health during pandemics especially in office buildings, restaurants, retail buildings, grocery stores, medical facilities, and schools. FDD fan-on correction automatically detects and turns off a continuous fan-on duration control setting when the building space is unoccupied. Expand economizer requirements to 18 kBtuh requires economizers for HVAC systems with cooling capacities less than 54 kBtuh that currently do not require an economizer. Savings for all measures are 6% for fan, 12% for cooling, and 3% for heating. Each measure is cost effective, and the package of measures is cost effective in all climate zones with a benefit-cost (B/C) ratio of 5.9. The economizer calibration and perimeter gap sealing B/C ratio is 2.7, the FDD fan-on correction B/C ratio is 20.7, and the expand economizer requirements B/C ratio is 1.8. The net present value of life-cycle energy savings is worth $16.7 million per year and the Carbon Dioxide (CO2) emissions savings are 9,132 Metric Tons worth $0.967 Million per year.

Additional submitted attachment is included below.

BUILDING ENERGY EFFICIENCY MEASURE PROPOSAL TO THE

CALIFORNIA ENERGY COMMISSION

FOR THE 2022 UPDATE TO THE

CALIFORNIA ENERGY CODE, TITLE 24, PART 6

BUILDING ENERGY EFFICIENCY STANDARDS

ECONOMIZER CALIBRATION AND PERIMETER GAP SEALING, FAN-ON CORRECTION, AND EXPAND ECONOMIZER REQUIREMENTS TO 18 KBTUH COOLING CAPACITY

Nonresidential HVAC

Prepared by: VERIFIED® Inc., Robert Mowris, P.E.
and Big Ladder Software, Matthew Larson

November 2020

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Document Information

Category: Codes and Standards

Keywords: Energy Efficiency Codes and Standards, Title 24, 2023, economizer cooling, economizer calibration, economizer perimeter gap sealing, Fault Detection Diagnostics (FDD), fan-on correction, expand economizer requirements, outdoor air fraction (OAF), continuous fan-on duration, outdoor airflow, indoor air quality, health, and safety.

Citation

R. Mowris, M. Larson. 2020. Economizer Calibration and Perimeter Gap Sealing, FDD Fan-on Correction, and Economizer Cooling to 18 kBtuh. Prepared by Verified® Inc., Olympic Valley, CA, and Big Ladder Software, Denver, CO.

Abstract

This proposal recommends the following Heating, Ventilating Air Conditioning (HVAC) energy efficiency measures: 1) economizer calibration and perimeter gap sealing, 2) Fault Detection Diagnostic (FDD) fan-on correction, and 3) expand economizer requirements to 18 thousand British thermal units per hour (kBtuh). These low-cost measures are easy to install and apply to all nonresidential buildings regulated by the California Building Energy Efficiency Standards. Sealing the economizer perimeter gap between the economizer frame and the HVAC system cabinet reduces excess outdoor airflow, and calibrating the economizer minimum damper position to within plus or minus 5% of the design minimum outdoor airflow improves indoor air quality and occupant health during pandemics especially in office buildings, restaurants, retail buildings, grocery stores, medical facilities, and schools. FDD fan-on correction automatically detects and turns off a continuous fan-on duration control setting when the building space is unoccupied. Expand economizer requirements to 18 kBtuh requires economizers for HVAC systems with cooling capacities less than 54 kBtuh that currently do not require an economizer. Savings for all measures are 6% for fan, 12% for cooling, and 3% for heating. Each measure is cost effective, and the package of measures is cost effective in all climate zones with a benefit-cost (B/C) ratio of 5.9. The economizer calibration and perimeter gap sealing B/C ratio is 2.7, the FDD fan-on correction B/C ratio is 20.7, and the expand economizer requirements B/C ratio is 1.8. The net present value of life-cycle energy savings is worth \$16.7 million per year and the Carbon Dioxide (CO2) emissions savings are 9,132 Metric Tons worth \$0.967 Million per year.

EXECUTIVE SUMMARY

Introduction

This proposal presents recommendations to support the California Energy Commission (CEC or Energy Commission) effort to improve the Title 24 Standards to include or upgrade requirements for various technologies in California's Building Energy Efficiency Standards. Verified® Inc., Big Ladder Software, and GreenFan Inc., sponsored this effort. The goal of this proposal is to create new energy efficiency measures 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 Energy Commission effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies. This code change proposal recommends the following three energy efficiency measure upgrades with percentage savings from Section 4.3.1 and benefit-cost ratios from Section 5.5.

1) Economizer calibration and perimeter gap sealing to reduce excess outdoor airflow, improve indoor air quality, and save minus 1 to plus 7% on space cooling and 4 to 37% on space heating with benefit-cost ratio of 2.7;

2) Fault Detection Diagnostic (FDD) fan-on correction control to reduce or eliminate continuous fan-on operation when buildings are unoccupied, and save 5 to 6% on ventilation fan, 0 to 1% on space cooling, and 1 to 3% on space heating with benefit-cost ratio of 20.7; and

3) Expand economizer requirements to 18 kBtuh to improve indoor air quality for occupant health and safety during pandemics, and save 3 to 45% on space cooling and minus 1 to minus 7% on space heating with benefit-cost ratio of 1.8.

Scope of Code Change Proposal

The code change proposal will affect the code documents listed in Table 1 and the CEC Building Energy Efficiency Standards based on the following proposed revisions to Section 140.4 – Prescriptive Requirements for Space Conditioning Systems as follows (page 207).[1]

1) Economizer calibration perimeter gap sealing change proposal.

Revise Section 140.4(e) subsection A (page 207) as follows.

A. An air economizer capable of modulating outside-air and return-air dampers to supply ~~100 percent~~ as much as possible of the design supply air quantity as outside-air when the dampers are fully open, and economizer

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[1] California Energy Commission (CEC). 2018. Building Energy Efficiency Standards for Residential and Nonresidential Buildings for the 2019 Building Energy Efficiency Standards Title 24, Part 6 and Associated Administrative Regulations in Part 1. December 2018. CEC-400-2018-020-CMF.

perimeter gap between the economizer frame and the cabinet shall be sealed with a UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and the economizer minimum damper position must be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy;

Revise Section 140.4(e) subsection D (iii) (page 209) as follows. "Damper leakage. Economizer outdoor air and return air dampers shall have a maximum leakage rate of 10% of the design supply airflow quantity ~~10 cfm/sf at 250 Pascals (1.0 in. of water) when tested in accordance with AMCA Standard 500-D~~ and the economizer perimeter gap between the economizer frame and the cabinet shall be sealed with a UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number."

Revise Section 140.4(e) subsection D (viii) (page 210) as follows. "Relief air system. Relief air systems shall be capable of providing at least 70 ~~100~~ percent outside air without over-pressurizing the building.

2) FDD fan-on correction control change proposal.

Revise Section 140.4(m) as follows. "(m) Fan Control. Each cooling system listed in TABLE 140.4-G shall be designed to vary the indoor fan airflow as a function of load and shall comply with the following requirements:

4. DX and chilled water cooling systems and heat pump, electric resistance, hydronic, gas furnace, or hot water heating systems shall have a Fault Detection Diagnostic (FDD) fan-on correction control that automatically detects a continuous fan-on duration control setting when the building conditioned space is unoccupied and the FDD fan-on correction control automatically turns off the fan when the building conditioned space is unoccupied based on an occupancy sensor signal or a geofencing sensor signal indicating that the building conditioned space is unoccupied."

3) Expand economizer requirements to 18 kBtuh change proposal.

Revise Section 140.4(e) Economizers as follows. "1. Each cooling air handler that has a design total mechanical cooling capacity over 18,000 ~~54,000~~ Btu/hr, or chilled water cooling systems without a fan or that use induced airflow that has a cooling capacity greater than the systems listed in Table 140.4-C, shall include either: A. An air economizer capable of modulating outside-air and return-air dampers to supply at least 70 ~~100~~ percent of the design supply air quantity as outside-air; or."

Table 1 summarizes the scope of the code change proposal and which sections of the standards, Reference Appendices, Alternative Calculation Method (ACM)

Reference Manual, and compliance documents that will be modified as a result of the proposed changes.

Table 1: Scope of code change proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
Economizer Calibration and Perimeter Gap Sealing	Mandatory/ Prescriptive	120.1(d), 120.1(f), 140.4(e) D(iii), D(iv)	Nonresidential Appendix NA7	Yes, 5.7.4 Outdoor Air Controls and Economizers	NRCA-MCH-05-A NRCC-MCH-E. NRCA-MCH-02-A
FDD Fan-on Correction	Mandatory/ Prescriptive	120.1(d) 140.4(m)	Nonresidential Appendix NA7 JA6.3	Yes, 5.7.3 Fan and Duct Systems	NRCA-MCH-12-A, NRCC-MCH-E, NRCC-PRF-E
Expand Economizer Requirements to 18 kBtuh	Mandatory/ Prescriptive	120.2(i) 140.4(e)1	Nonresidential Appendix NA7 JA6.3	Yes, 5.7.4 Outdoor Air Controls and Economizers	NRCA-MCH-12-A, NRCC-MCH-E, NRCA-MCH-02-A. NRCA-MCH-05-A

Note: An (M) indicates mandatory requirements, (Ps) Prescriptive, (Pm) Performance.

Measure Description

The proposed measures include: 1) economizer calibration and perimeter gap sealing, 2) FDD fan-on correction, and 3) expand economizer requirements to 18 kBtuh. The proposed measures apply to all nonresidential buildings with cooling capacities greater than 18 kBtuh regulated by the California Building Energy Efficiency Standards. Sealing the economizer perimeter gap between the economizer frame and the HVAC system cabinet reduces uncontrolled outdoor airflow, and calibrating the economizer minimum damper position to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow (depending on occupancy) will improve indoor air quality and reduce excess outdoor airflow. The patented sealing method may be performed using tape, mastic, sealants, or other materials (Mowris and Walsh 2019).[2] The Economizer calibration requires the minimum damper position OAF be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum OAF for the building occupancy (Mowris 2018).[3] The FDD

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[2] Mowris, R., J. Walsh. 2019. Fan Controller. US Patent 9,671,125. 6 June 2019. Washington, DC: USPTO and patents pending for smart thermostat FDD fan-on correction and fan-on alarm methods. Mowris, R., J. Walsh. 2020. Fault Detection Diagnostic Variable Differential Variable Delay Thermostat. US Patent 10,712,036. 14 July 2020. Washington, DC: USPTO.

[3] Mowris, R., 2018, Apparatus and Methods to Measure Economizer Outdoor Air Fractions and Fault Detection Diagnostics of Airflow, Cooling Capacity, and Heating Capacity. US Patent 10,001,289. 18 June 2018. Washington, DC: U.S. Patent and Trademark Office (USPTO). Other US patents pending.

requirement includes checking and reporting the absolute position of the economizer damper within plus or minus 5% of the ASHRAE 62.1 minimum OAF for the building occupancy (Mowris & Walsh 2020).[4] The FDD fan-on correction measure automatically detects and turns off a continuous fan-on duration control setting when the building conditioned space is unoccupied.[5] The expand economizer requirements to 18 kBtuh requires economizer cooling for HVAC systems with cooling capacities less than 54 kBtuh that previously did not require an economizer. Requiring economizer cooling to 18 kBtuh is more cost effective with economizer calibration and perimeter gap sealing to improve indoor air quality and energy efficiency compared to a standard economizer without calibration and perimeter gap sealing.

Nonresidential packaged HVAC systems generally provide excess outdoor airflow due to uncontrolled excess outdoor airflow due to lack of calibration and perimeter gap leakage which wastes cooling and heating energy. About 13 to 78% of nonresidential buildings have fans operating continuously which wastes cooling, heating and fan energy (DNVGL 2016; Jacobs & Higgins 2003). Current CEC building standards require air-side economizers on HVAC systems with 54,000 Btuh/h or greater cooling capacities, but do not require economizers on smaller HVAC systems. The proposed code changes provide significant cooling, heating, and fan energy savings by providing prescriptive or mandatory measures to calibrate the economizer and seal the economizer perimeter gap, override the fan-on duration control setting during unoccupied periods, and the expand economizer requirements from 54,000 Btuh to 18,000 Btuh. Requiring economizers on smaller HVAC systems will improve indoor air quality and occupant health during pandemics especially in small office buildings, restaurants, retail buildings, and schools.[6]

Market Analysis and Regulatory Impact Assessment

The proposed changes include three measures described above. The measure savings are based on laboratory test measurements performed by Intertek®, and EnergyPlus building simulations performed by Big Ladder Software. The proposed changes include two patented measures: 1) economizer calibration and perimeter gap sealing, and 2) FDD fan-on correction. These two measures are widely available on the market through wholesale distributors and manufacturers. The expand economizer requirements to 18 kBtuh measure is also widely available on the market through HVAC manufacturers and wholesale distributors. These

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[4] Mowris, R., J. Walsh. 2020. Apparatus and Methods to Determine Economizer Faults. US Patent 10,663,186. 26 May 2020. Washington, DC: USPTO. Patented method determines the absolute position of the economizer damper and other faults.

[5] Ibid. Claim 26.

[6] Schoen, L., 2020. Guidance for Building Operations During COVID-19 Pandemic. ASHRAE Journal, https://www.ashrae.org/file%20library/technical%20resources/ashrae%20journal/2020journaldocuments/72-74_ieq_schoen.pdf. A. Jobson. 2020. School Ventilation for COVID-19. Collaborative for High Performance Schools. https://chps.net/sites/default/files/file_attach/CHPS_COVID-19_Whitepaper_Sep2020.pdf

measures have an effective useful life and persistence of at least 15 years. The measures do not require any additional maintenance costs.

The proposed code changes are cost effective for all climate zones and building types. The benefit-cost ratio (B/C) compares the savings benefits to the costs over a 15-year time period. Table 30 shows the total average B/C ratio is 10.27 based on a 20.65 B/C ratio for the economizer perimeter gap sealing measure, 20.68 B/C ratio for the FDD fan-on correction measure, and 2.77 B/C ratio for the expand economizer requirements to 18 kBtuh measure. The overall B/C ratio varies from 8.17 to 16.19 based on climate zone as shown in Table 30. See section 4 and section 5 for the methodology, assumptions, and results of the cost effectiveness analysis.

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. As a result this leaves more money available for discretionary and investment purposes.

Statewide Energy Impacts: Energy, Water Greenhouse Gas (GHC) Emissions Impacts

Energy Savings Impacts

Table 2 shows the estimated energy savings impacts over the first twelve (12) months of implementation of the following measures: 1) economizer calibration and perimeter gap sealing, 2) FDD fan-on correction, and 3) expand economizer requirements to 18 kBtuh. First-year statewide energy and peak demand savings include electricity savings in GigaWatt-hours per year (GWh/yr), peak electricity demand savings in MegaWatts (MW), natural gas savings in million therms per year (MMTherms/yr), and time dependent valuation (TDV) energy savings in thousand (kilo) British thermal units per year (TDV kBtu/yr). See Section 2.5, 3.5, 4.5, and 5.5 for more details on the first-year statewide impacts. Sections 2.3, 3.3, 4.3, and 5.3 provide information about per-unit energy savings. Section 4.2 discusses the methodology and Section 4.3 shows the results for the per unit energy impact analysis.

Table 2: Statewide estimated first year energy savings

Measure	First Year Statewide Savings			First Year Statewide TDV Savings	
	Electricity Savings (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	TDV Electricity Savings (Million kBtu)	TDV Natural Gas Savings (Million kBtu)
Economizer Calibration Perimeter Gap Sealing	0.3	(0.1)	0.3	17.6	95.8
FDD Fan-on Correction	22.3	0.1	0.1	624.5	34.3
Expand Economizer Requirements to 18 kBtuh	8.9	0.6	(0.1)	182.0	(38.5)
TOTAL	**31.4**	**0.6**	**0.3**	**824.2**	**91.6**

Greenhouse Gas Emissions (GHC) Impacts

Table 3 provides the estimated avoided Green House Gas (GHG) emissions for the proposed code change for the first year when the standards are in effect. Avoided GHG emissions are measured in metric tons of carbon dioxide (CO2) equivalent (metric tons CO2e). Assumptions used in developing the GHG savings are provided in Appendix C. The monetary value of avoided GHG emissions is included in the TDV cost factors and in the cost-effectiveness analysis. The first-year impacts of these measures are expected to reduce GHG emissions by 9,132 Metric Tons of CO2 equivalent accounting for a monetary value of $0.967 Million US Dollars (USD) as shown in the following table.

Table 3: First-Year statewide GHG emissions impacts

Measure	First Year Statewide	
	Avoided GHG Emissions ($MTCO_2e/yr$)	Monetary Value of Avoided GHG Emissions ($2023)
Economizer Calibration and Perimeter Gap Sealing	1,726	$183,263
FDD Fan-on Correction	5,956	$632,539
Expand Economizer Requirements to 18 kBtuh	1,451	$154,057
TOTAL	**9,132**	**$969,859**

For more a detailed and extensive analysis of the possible environmental impacts from the implementation of the proposed measure(s), please refer to Section 6.2 through 6.5 and Appendix B and C of this report.

Water Use and Water Quality Impacts

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

Compliance and Enforcement

The proposed compliance and enforcement process to ensure the success of the measure is described in Section 2.5. The impacts the proposed measure will have on various market actors is described in Section 2.5. The key issues and challenges related to compliance and enforcement are summarized below:

- Working with building designers, HVAC contractors, economizer manufacturers and wholesale distributors to ensure economizers are sold and installed with the patented calibration method and patented UL-181 metal tape or other sealing materials which are manufactured or either by GreenFan® Inc. or licensed manufacturers.
- Working with building designers, HVAC contractors, wholesale distributers and HVAC contractors to provide the Smart Efficient Fan Controller® with FDD fan-on correction and also working with smart thermostat manufacturers to license the patented FDD fan-on correction software or FDD fan-on correction software algorithms on smart thermostats.
- Online portal to register building address and economizer make and model number and verification of economizer perimeter gap sealing, FDD fan-on correction, and economizer 18 kBtuh or greater by local building inspectors.

Acceptance Testing

Acceptance testing requirements for verification or commissioning are summarized below (see Section 2.5).

- Acceptance testing may include a database to register and verify building address, economizer, HVAC system make, model, serial number with patented economizer calibration and UL-181 metal tape or other sealing materials which are manufactured either by GreenFan® Inc. or licensed manufacturers.
- Acceptance testing may include a database to register and verify building address, economizer, HVAC system make, model, serial number with patented Smart Efficient Fan Controller® with FDD fan-on correction or smart thermostats that are licensed to have the patented FDD fan-on correction software or FDD fan-on correction software algorithms.

- Acceptance testing may include a database to register and verify building address, economizer, HVAC system, and thermostat make, model, serial number with economizer 18 kBtuh or greater by local building inspectors.
- Add smaller capacity 18 kBtuh or greater units to the existing acceptance testing for HVAC systems with economizers.

Cost-effectiveness

A summary of the life-cycle cost-effectiveness analysis results per square feet are provided in Table 4, based on the detailed analysis provided in Table 30 of Section 5.5. The life-cycle cost-effectiveness analysis found Benefit to Cost (B/C) ratios greater than one for each measure in every climate zone. This means that the proposed code change will provide cost savings relative to the existing conditions in every climate zone. The proposed code change measures are cost effective in every climate zone with an average B/C ratio of 4.5. As shown in Table 30 of Section 5.5, the magnitude of the life-cycle cost-effectiveness varies from a high Planning B/C ratio of 7.8 in climate zone 16 to a low Planning B/C ratio of 5.6 in climate zones 1, 3, and 5 through 9. The TDV Energy Costs Savings are the present valued energy cost savings over the 15 year time period of the analysis using the California Energy Commission's TDV methodology. The Total Incremental Cost represents the incremental initial construction and maintenance costs of the proposed measure relative to existing conditions (current minimally compliant construction practice when there are existing Title 24 Standards). Costs incurred in the future (such as periodic maintenance costs or replacement costs) are discounted by a 3 percent real discount rate, per Energy Commission's LCC Methodology. The B/C ratio is the incremental TDV energy costs savings divided by the total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is deemed to be cost effective. For a detailed description of the cost-effectiveness methodology see Section 5 of this report.

Table 4: Cost-effectiveness summary

Measure	Benefit: TDV Energy Cost Savings (2023 PV$/ft²)	Cost: Total Incremental First Cost and Maintenance Cost (2023 PV$/ft²)	Planned Benefit to Cost (B/C) Ratio
Economizer Calibration and Perimeter Gap Sealing	$1.2	$0.5	2.7
FDD Fan-on Correction	$9.4	$0.5	20.7
Expand Economizer Requirements to 18 kBtuh	$3.0	$2.1	1.4
TOTAL	**$13.7**	**$2.9**	**4.5**

Section 5.1discusses the methodology and Section 5.2 discusses the cost savings results, Section 5.3 discusses incremental costs, Section 5.4 discusses lifetime incremental maintenance costs, and Section 5.5 discusses the lifecycle cost effectiveness analysis.

1. INTRODUCTION

This proposal provides energy savings and life-cycle cost effectiveness analysis for three energy efficiency measures to enhance the California Title 24 Building Energy Efficiency Standards ("Standards") for nonresidential buildings. The goal is for the CEC to adopt the following three energy efficiency measures into the 2023 Standards: 1) economizer calibration and perimeter gap sealing, 2) Fault Detection Diagnostics (FDD) fan-on correction, and 3) Expand economizer requirements to 18 kBtuh. The proposed measures apply to all nonresidential buildings with cooling capacities greater than 18 kBtuh. Information is provided to support the code change proposal.

Section 2 of this Report provides a description of the measures, how the measures came about, and how the measures help achieve the state's zero net energy (ZNE) goals. Section 2 describes how the proposed code changes would be enforced and the expected compliance rates.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. Section 3 provides an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

Section 4 describes the key assumptions used in the energy savings analysis, the energy savings methodology and provides the per-unit energy impacts and energy savings results.

Sections 5 and 6 provide the energy and peak demand savings calculations, the benefit-cost analysis, and the environmental impact evaluation. Energy, peak demand, and environmental impacts were calculated using three metrics: (1) per unit, (2) statewide impacts during the first year when buildings complying with the 2023 Title 24 Standards are in operation, and (3) the cumulative statewide impacts for all buildings built during the 15 year time period of the analysis. Time Dependent Valuation (TDV) energy impacts, which accounts for the higher value of peak savings, are presented per unit, first year statewide and cumulative statewide. The incremental costs, relative to existing conditions are presented as are the present value of the first year TDV energy cost savings and the overall cost impacts over the first-year period of analysis.

Section 7 of the report concludes with specific recommendations for language for the Standards, Appendices, Alternate Calculation Manual (ACM) Reference Manual and Compliance Forms.

2. MEASURE DESCRIPTION

2.1 Measure Overview

The proposed code changes would require: 1) economizer calibration and perimeter gap sealing, 2) Fault Detection Diagnostic (FDD)fan-on correction, and 3) expand economizer requirements to 18 kBtuh. The proposed measures apply to all nonresidential buildings with cooling capacities greater than 18 kBtuh (or 1.5 tons). Most HVAC systems have an air-side "economizer" to provide a maximum outdoor airflow for economizer cooling when the outdoor air temperature (OAT) is less than a high-limit shut-off temperature (HST) minus a 1 to 2 degree Fahrenheit (F) dead band. If the OAT is greater than or equal to the HST, then space cooling is provided by direct expansion (DX) Air Conditioning (AC) compressors, and the economizer provides a minimum outdoor airflow to meet indoor air quality (IAQ) requirements per the American National Standards Institute (ANSI) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 (ANSI/ASHRAE 2019). Air-side economizers have movable outdoor-air and relief-air dampers with gears controlled by an actuator mounted on a frame installed in a HVAC system cabinet. Most actuator control voltages range from 2 to 10 volts (V), with 2V closed and 10V fully open. Closed position is 2V, 15% minimum is 3.1V (0.15 X 8V+ 2V), and fully open is 10V (8V + 2V).[7] A 2011 study published by Pacific Northwest National Laboratories (PNNL) reported cooling and heating savings of 24 to 32% for small office, retail, and supermarket buildings with economizer DCV and multi-speed supply fans.[8] The CEC building standards and the 2011 PNNL study are based on the EnergyPlus building simulation program.[9] The EnergyPlus program assumes zero outdoor airflow at the closed damper position, minimum outdoor airflow per ASHRAE 62.1 without economizer calibration, and 100% outdoor airflow when economizing. The models assume no continuous fan-on operation during unoccupied periods.

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[7] ASHRAE 62.1 provides minimum outdoor airflow based on building occupancy. HVAC technicians establish minimum damper positions using 1, 2, or 3 of their fingers. Digital economizers provide actuator input positions based on voltage from 2 to 10V (Honeywell 2014) or ventilation minimum positions from 0% closed to 100% fully open (Belimo 2016, Pelican 2016). Voltage or percentage positions do not correspond to OAF based on outdoor airflow (cfm) divided by total system airflow (cfm).

[8] Wang. W., Y. Huang, S. Katipamula, M. Brambley. 2011. Energy Savings and Economics of Advanced Control Strategies for Packaged Air-Conditioning Units with Gas Heat, PNNL-20955. Richland, WA: Pacific Northwest National Laboratories. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20955.pdf

[9] Crawley, D., L. Lawrie, C. Pedersen, F. Winkelmann 2000. EnergyPlus: Energy Simulation Program. ASHRAE Journal 42(4):49-56. Atlanta, GA.
https://www.researchgate.net/publication/230606369_EnergyPlus_Energy_Simulation_Program

2.1.1 Economizer Calibration and Perimeter Gap Sealing Measure

The economizer calibration and perimeter gap sealing measure includes: 1) sealing the gap between the economizer frame and the HVAC system cabinet; and 2) calibrating the economizer. This measure reduces or eliminates uncontrolled excess outdoor airflow or increases outdoor airflow to improve indoor air quality (Mowris 2018; Mowris & Walsh 2019). Figure 1 shows a ¼ to ¾ inch economizer perimeter gap before sealing with wires showing through the gap (Mowris 2016). The gap allows for easy installation, removal, and reinstallation. Figure 2 shows an economizer perimeter gap after sealing.

Figure 1: Unsealed economizer perimeter gap for a 3-ton RTU (Mowris 2016)

Figure 2: Economizer perimeter gap sealing installed before calibration

Figure 3 shows the patented economizer calibration method applied to a nonresidential building where the standard design without economizer calibration or perimeter gap sealing provides an Outdoor Air Fraction (OAF) of 30% at an economizer actuator voltage of 3.6 Volts (V). The proposed design with calibration and perimeter gap sealing provides the ASHRAE 62.1 minimum design OAF of 20% at 4.3V. Economizer calibration and perimeter gap sealing saves energy and provides proper outdoor airflow for indoor air quality.

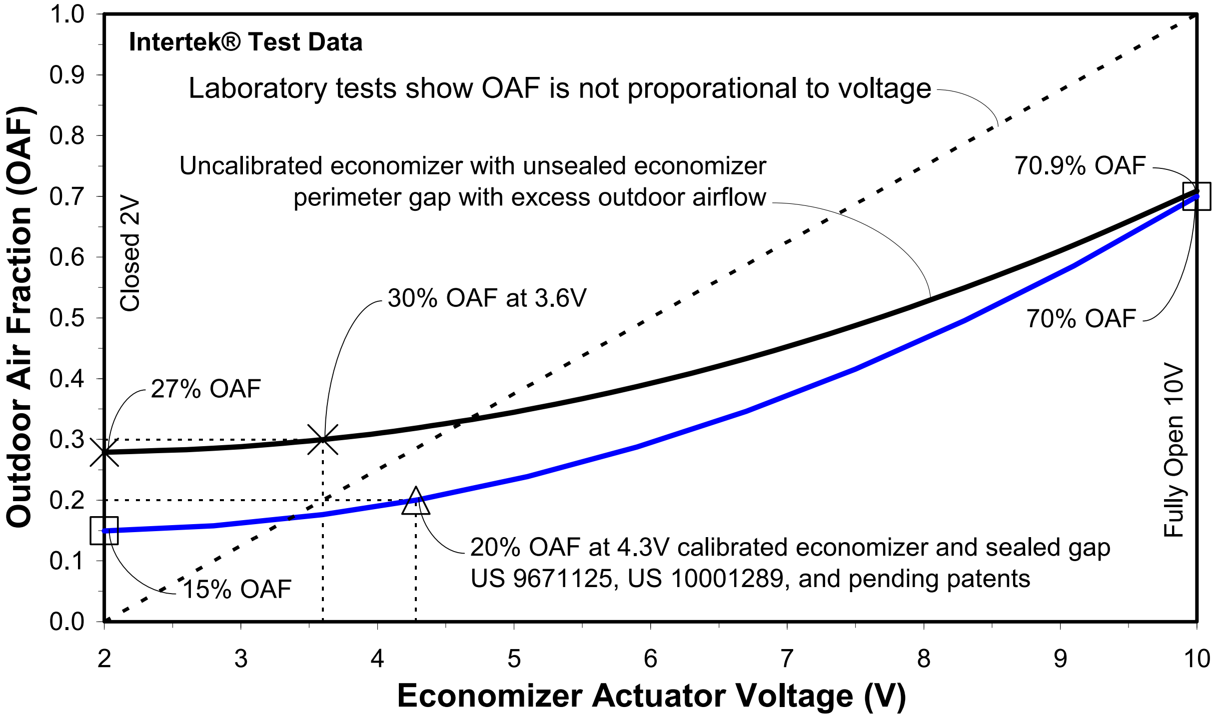

Figure 3: Economizer calibration and perimeter gap sealing

The patented economizer calibration method determines a functional relationship between the actuator voltage (x) and a corresponding damper position OAF (y). The calibration method measures a set of x-versus-y data for at least two damper positions including: a closed damper position, at least one intermediate damper position, and a fully open damper position. The coefficients of the functional relationship are calculated using the x-versus-y data. The target minimum damper position actuator voltage (x_t) is determined using the functional relationship and a required OAF (y_r) (i.e., 20% or other OAF) based on building occupancy per ASHRAE 62.1 (Mowris 2018).

2.1.2 FDD Fan-on Correction Measure

The patented FDD fan-on correction measure automatically detects and turns off a continuous fan-on duration control setting when the building conditioned space is unoccupied (Mowris & Walsh 2019).[10] Figure 4 shows the standard design with a

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[10] Ibid. Claim 26.

continuous fan-on setting increases HVAC energy use for 13 to 78% of buildings with this fault. The proposed design FDD fan-on correction detects, reports, and overrides continuous fan-on settings to reduce HVAC energy use.

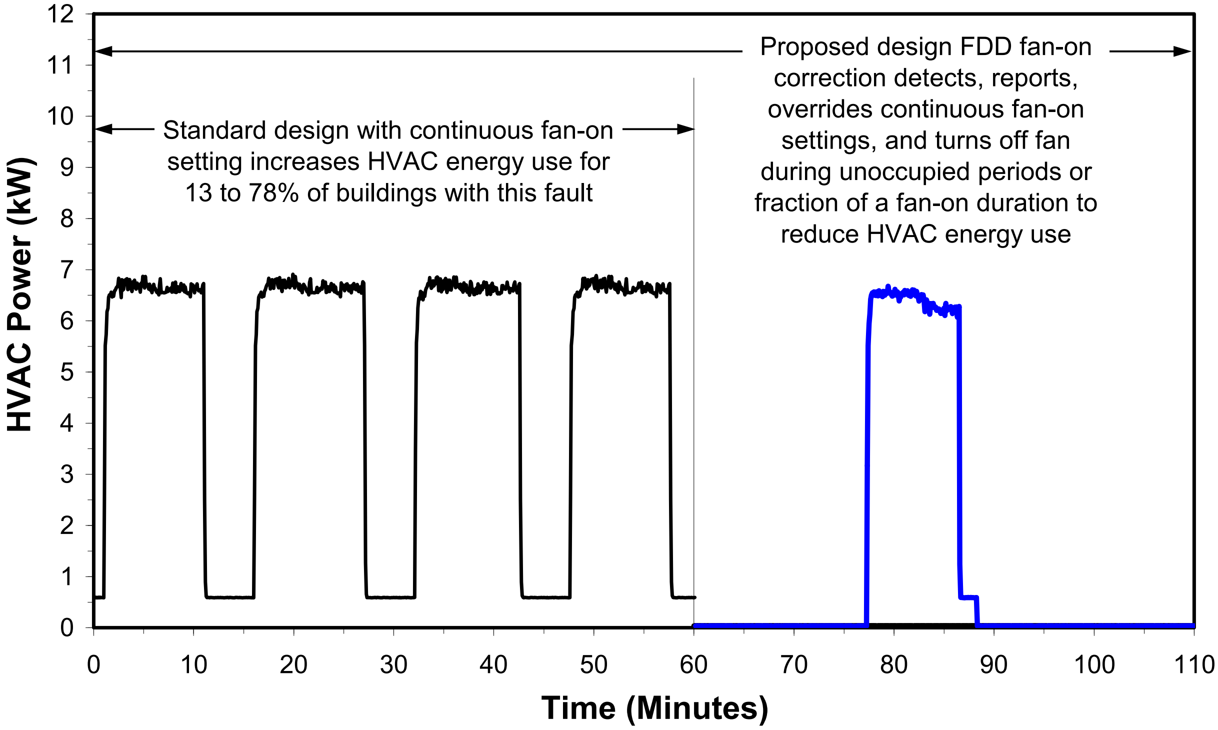

Figure 4: FDD Fan-on correction detects, reports, and overrides continuous fan-on faults to reduce HVAC energy use for 13 to 78% of buildings

The FDD fan-on correction measure would expand on existing CEC FDD requirements for HVAC systems to automatically detect and turn off a continuous fan operation when a building is unoccupied or provide a continuous fan-on fault alarm message for a building operator to turn off the fan during unoccupied periods (Mowris 2018). The measure provides continuous fan-on operation during occupied periods to provide the ASHRAE 62.1 minimum outdoor airflow based on building occupancy to maintain indoor air quality for health and safety especially during pandemics (Mowris & Walsh 2019; Mowris, R., J. Walsh. 2020). FDD Fan-on correction code change proposal is applicable to 13 to 78% of buildings per previously published evaluation studies (DNVGL 2016; Jacobs & Higgins 2003).[11]

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[11] DNVGL 2016. Impact Evaluation of 2013-14 HVAC3 Commercial Quality Maintenance Programs. San Francisco, CA: CPUC. http://www.calmac.org/publications/HVAC3ImpactReport_0401.pdf. Pages 68-69 of DNVGL reported: "78% of them show the fan running continuously in the as-found case, see Figure 17." "PG&E Commercial HVAC implementer reported, finding base case fan-on only 13% of the time." Figure 18 shows "the measure is implemented in only 2.8% of the cases where supply fan was found on. Furthermore, in 45% of cases where the fan was found in the auto or off state the implementer adjusted the fan to on, see Figure 19."
Jacobs, P., and C. Higgins. 2003. Small HVAC System Design Guide. P500-03-082-A12. Sacramento, CA: CEC. Jacobs reported 30% of HVAC systems having continuous fan operation during unoccupied periods. https://newbuildings.org/sites/default/files/A-12_Sm_HVAC_Guide_4.7.5.pdf.

Savings for the FDD fan-on correction are weighted assuming 13% of buildings have this fault.

2.1.3 Expand Economizer Requirements to 18 kBtuh Measure

The expand economizer requirements to 18 kBtuh provides economizer cooling for HVAC systems with cooling capacities less than 54 kBtuh that previously did not require an economizer. Requiring economizers on smaller HVAC systems will improve indoor air quality and occupant health and safety during pandemics especially in small office buildings, restaurants, retail buildings, and schools. Savings for expand economizer requirements are 0% for fan, 15% for cooling, and -5% for heating based on EnergyPlus simulations.

2.1.4 Overview of Proposed Code Changes

The proposed code changes will apply to all nonresidential buildings and packaged HVAC systems regulated by the California Building Energy Efficiency Standards. The proposed code changes will impact the mandatory, prescriptive, and performance requirements (compliance options) and modify the modeling algorithms used in the performance approach (revisions to the ACM Reference Manuals). The proposed code changes will strengthen and improve building standards for systems or equipment which were inadequate or not sufficiently regulated previously.

The code change proposal will affect the code documents listed in Table 1 (above) and the CEC Building Energy Efficiency Standards based on the following proposed revisions to Section 140.4 – Prescriptive Requirements for Space Conditioning Systems as follows (page 207-214).[12]

1) Economizer Calibration and Perimeter Gap Sealing change proposal

    Revise Section 102.2(i) section (i) (i) Economizer Fault Detection and Diagnostics (FDD) (page 144) subsection 7.

    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[[,]];

    F. <u>Economizer perimeter gap has not sealed; and</u>

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[12] California Energy Commission (CEC). 2018. Building Energy Efficiency Standards for Residential and Nonresidential Buildings for the 2019 Building Energy Efficiency Standards Title 24, Part 6 and Associated Administrative Regulations in Part 1. December 2018. CEC-400-2018-020-CMF.

G. Economizer minimum damper position has not been calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

Revise Section 140.4(e) subsection D (iii) (page 209) as follows. "Damper leakage. Economizer outdoor air and return air dampers shall have a maximum leakage rate of 10% of the design supply airflow quantity ~~10 cfm/sf at 250 Pascals (1.0 in. of water) when tested in accordance with AMCA Standard 500-D~~ and the economizer perimeter gap between the economizer frame and the cabinet shall be sealed with a UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number."

Revise Section 140.4(e) subsection D (viii) (page 210) as follows. "Relief air system. Relief air systems shall be capable of providing at least 70 ~~100~~ percent outside air without over-pressurizing the building.

2) FDD Fan-on Correction Control change proposal

Revise Section 110.2(c) for thermostats to add the FDD fan-on correction control capability to detect, report, and override a continuous fan-on duration setting when the space is unoccupied. Revise Section 120.2(e) for controls to require automatically turning off the ventilation fan when the building is unoccupied. Revise Section 140.4(m) (page 214) as follows. "(m) Fan Control. Each cooling system listed in TABLE 140.4-G shall be designed to vary the indoor fan airflow as a function of load and shall comply with the following requirements:

4. DX and chilled water cooling systems and heat pump, electric resistance, hydronic, gas furnace, or hot water heating systems shall have a Fault Detection Diagnostic (FDD) fan-on correction control that automatically detects a continuous fan-on duration control setting when the building conditioned space is unoccupied and the FDD fan-on correction control automatically turns off the fan when the building conditioned space is unoccupied based on an occupancy sensor signal or a geofencing sensor signal indicating that the building conditioned space is unoccupied."

3) Expand Economizer Requirements to 18 kBtuh change proposal

Revise Section 140.4(e) (page 207) Economizers as follows. "1. Each cooling air handler that has a design total mechanical cooling capacity over 18,000 ~~54,000~~ Btu/hr, or chilled water cooling systems without a fan or that use induced airflow that has a cooling capacity greater than the systems listed in Table 140.4-C, shall include either: A. An air economizer capable of modulating outside-air and return-air dampers to supply at least 70 ~~100~~ percent of the design supply air quantity as outside-air; or."

2.2 Measure History

This economizer calibration and perimeter gap sealing code change is being proposed to reduce uncontrolled outdoor airflow at the closed and minimum economizer damper positions to save cooling and heating energy. The FDD fan-on correction code change is being proposed to reduce or eliminate continuous fan-on operation when buildings are unoccupied to save fan, cooling, and heating energy. The expand economizer requirements to 18 kBtu/hr code change is proposed to increase cooling energy savings, improve indoor air quality, and improve occupant health during pandemics especially in small office buildings, restaurants, retail buildings, and schools. Occupants in these small nonresidential buildings represent hard-to-reach populations which face adverse risks from pandemics and infectious diseases due to lack of access to indoor air quality measures provided by increased outdoor airflow and natural cooling provided by economizers.

The economizer calibration and perimeter gap sealing measure and FDD fan-on correction code changes have not been proposed previously. The FDD fan-on correction measure would expand on existing CEC FDD requirements for HVAC systems to automatically detect and turn off a continuous fan operation when a building is unoccupied or provide a continuous fan-on fault alarm for a building operator or maintenance personnel to turn off a continuous fan-on operation during unoccupied periods (Mowris & Walsh 2020). FDD Fan-on correction code change proposal is applicable to 13 to 78% of buildings per previously published evaluation studies (DNVGL 2016; Jacobs & Higgins 2003). Savings for the FDD fan-on correction are weighted assuming 13% of buildings have this fault. Canfab Inc. Is one of the largest economizer manufacturers in the United States located in Corona, CA (https://canfab.com). Canfab manufacturers economizers for Bryant®, Carrier®, Day & Night®, Trane®, York®, and Sigler® (https://canfab.com/about). Canfab Indicated they are willing to sell the patented GreenSeal® UL-181 listed metal tape to seal the economizer calibration and perimeter gap as an optional performance upgrade for their economizers, if economizer calibration and perimeter gap sealing is specified by building designers, engineers, architects, and HVAC contractors in California.[13]

The CEC is currently considering nonresidential duct sealing code changes which have similar impacts on HVAC energy use.[14] The economizer 18 kBtu/hr code change proposal is also being proposed by the CASE team but only to 33,000 Btu/hr which represents about 50% of the HVAC systems that are less than 54,000

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[13] Bourdon, John. Canfab Inc. 2020. Personal communication regarding including GreenSeal® UL-181-FX metal tape for economizer perimeter gap sealing as a performance upgrade for economizer products. June 4, 2020. Corona, CA: Cannon Fabrication Inc. (Canfab Inc.).

[14] C. Worth, B. Zank, S. Wang, E, Martin. 2020. Air Distribution: High Performance Ducts and Fan Systems. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/09/2022_T24-Final-CASE-Report_Air-Distribution.pdf

Btu/hr and greater than 18,000 Btu/hr.[15] The prescriptive requirements for air-side economizers were previously updated with two 2013 CASE reports: 1) Fan Control and Economizers (CASE: Fan Control and Economizer 2011), and 2) Light Commercial Unitary 2022 Title 24, Part 6 Final CASE Report – 2022-NR-HVAC4-F 72 HVAC (CASE: Light Commercial Unitary 2011). These changes were adopted in June 2012. At that time, three changes were made: 1. cooling capacity requirements for economizers were reduced from 75,000 Btu/h to 54,000 Btu/h. 2. Minimum compressor displacement required package units to have multiple stages for economizing (Table 140.4-F). 3. FDD code changes were introduced.

There are no preemption concerns.

Investor Owned Utilities (IOUs) in California have offered financial incentives to HVAC contractors since 2014 to adjust thermostat fan control settings to "AUTO" from "ON." The patented FDD fan-on correction measure turns the fan-on duration control off automatically whenever the building is unoccupied. Current practices in California were evaluated by DNVGL in a 2016 Impact Evaluation report prepared for the California Public Utilities Commission (CPUC) (pp. 68-69) indicating: "78% of them show the fan running continuously in the as-found case, see Figure 17 (of DNVGL 2016). "PG&E Commercial HVAC implementer reported, finding base case fan-on only 13% of the time." Figure 18 (of DNVGL 2016) shows "the measure is implemented in only 2.8% of the cases where supply fan was found on. Furthermore, in 45% of cases where the fan was found in the auto or off state the implementer adjusted the fan to on, see Figure 19 (of DNVGL 2016)." A 2003 CEC report by Jacobs and Higgens found 30% of HVAC systems having continuous fan operation during unoccupied periods (Jacobs & Higgins 2003).

No other requirements in Title 24 are impacted by the code change proposal. Table 5 provides the following building simulation modeling changes to model the proposed code changes.

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[15] Minezaki, T., S. Wang, E. Martin, N. Bulger. 2020. Nonresidential HVAC Controls. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report-HVAC-Controls.pdf

Table 5: Modeling changes to simulate proposed code changes

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
Small office	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 26.5%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 19.51%/70,2%
Small office	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small office	All	Economizer ≥ 18 kBtuh	No economizer operation	Fixed dry bulb economizer control
Medium retail	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 28.4%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 24.54%/70.2%
Medium retail	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small school	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 32.5%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 34.5%/70.2%
Small school	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small school	All	Economizer ≥ 18 kBtuh	No economizer operation for 9 of 11 RTUs	Differential dry bulb economizer control 9 of 11

The modeling changes will improve the current modeling results by providing more accurate baseline and measure savings estimates for compliance based on field and laboratory test data of actual packaged Roof Top Units (RTUs). Laboratory tests were performed at Intertek®, an ISO-certified laboratory used by manufacturers and USDOE to test HVAC equipment for compliance with Federal energy efficiency standards. Laboratory tests were performed on six new packaged HVAC units with DX Air Conditioning (AC) compressors, gas furnace or heat pump heating, and new economizers.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each of the Title 24 documents will be modified by the proposed changes to the code documents. See Section 7. 1 for proposed changes to the standards language, Section 7.2 for proposed changes to the Reference Appendices, Section 7.3 for proposed changes to the Alternative Calculation Method (ACM) Reference Manuals, Section 7.4 for proposed changes to the Compliance Manuals, and Section 7.5 for proposed changes to the Compliance Forms.

2.3.1 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency standards. Section 110.2(c) for thermostats is modified to add the FDD fan-on correction control capability to detect, report, and override a continuous fan-on duration setting when the space is unoccupied. Section 120.2(e) for controls is modified to automatically shut off the ventilation fan when the building is unoccupied. Section 120.2(i) is modified to require air-side economizers on systems with a mechanical cooling capacity greater than or equal to 18,000 Btu/hr from 54,000 Btu/hr, and require the economizer perimeter gap to be sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number. Section 140.4(c) is modified to require all fan systems to be controlled by a thermostat that has a FDD fan-on correction control capability to detect and override a continuous fan-on duration setting when the conditioned space is unoccupied. Section 140.4(e) is modified to require air-side economizers on systems with a mechanical cooling capacity greater than or equal to 18,000 Btu/hr from 54,000 Btu/hr. Section 140.4(e) A and B are modified to require modulating outside-air and return-air dampers to supply as much as possible of the design air quantity as outside air from 100 percent which is not currently impossible to economizer and relief damper leakage.

2.3.2 Reference Appendices Change Summary

This proposal would modify the following sections of the Reference Appendices. Appendix JA5 is modified in Sections JA5.2.1, JA 5.2.6, and JA6.1.1.6.2.4 to require Occupant Controlled Smart Thermostats (OCST) include a FDD fan-on correction control capability to detect and override a continuous fan-on duration setting when the conditioned space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied. Section JA6.3 and JA6.3.1 are modified to require economizer FDD functions on air handlers with mechanical cooling capacity greater than or equal to 18,000 Btu/hr and also include verification of economizer perimeter gap sealing and FDD fan-on correction. Acceptance tests described in Appendix NA7 and NA7.5.1.1.2 (functional testing) are modified to verify the economizer perimeter gap is sealed and verify the supply fan turns off when the occupancy sensor signal is removed and verify the supply fan turns on continuously again after the occupancy sensor signal is reconnected.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

This proposal would modify the following sections of the Alternative Calculation Method (ACM) Reference Manual. Section 5.7.2.2 Schedules is modified to describe the FDD fan-on correction capability to detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a continuous fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied. Section 5.7.4.1 Outside Air Controls is modified to describe the standard design maximum outside air ratio of 0.69 for all systems greater than or equal to 18,000 Btu/h cooling capacity and unoccupied minimum outside air ratio in the closed position 0.13 for all systems. The existing building maximum outside air ratio of 0.70 for all systems greater than or equal to 18,000 Btu/h cooling capacity and unoccupied minimum outside air ratio in the closed position 0.218 for all systems based on Intertek® laboratory tests. Section 5.7.4.2 Air Side Economizer: Control Type and Section 5.7.4.2 Air Side Economizer: Integration Level are modified to describe the control should be no economizer when the standard design total cooling capacity < 18,000 Btu/hr.

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following sections of the Compliance Manuals. Chapter 4 Mechanical Section 4.5.2.2, Section 4.5.1.1.1.13 Economizer Fault Detection and Diagnostics, Section 4.5.1.1.1.18 Economizers, Section 4.9.1.1.1.3 Mandatory Measures – Additions and Alterations, and Section 10.4.3.1 Economizers are modified in three locations. The first describes the change in the economizer requirement threshold from 54,000 Btu/h to 18,000 Btu/h. The second requires the economizer calibration and perimeter gap sealing between the system cabinet and the economizer frame. The third requires the OCST include FDD fan-on correction capability.

2.3.5 Compliance Forms Change Summary

The proposed code change will modify the compliance forms for Chapter 4 Mechanical. The compliance document CEC-NRCC-MCH-E would need to be revised to verify economizers and economizer perimeter gap sealing on HVAC Systems with mechanical cooling capacity greater than or equal to 18,000 Btu/hr. Section 4.5.1.1.1.13 (e) would be modified to require mandatory FDD for all newly installed air handlers with a mechanical cooling capacity greater than or equal to 18,000 Btu/hr, and describe excess outdoor airflow due to improper damper position or economizer perimeter gap leakage. Section 4.5.1.1.1.13(f) would be modified to require an FDD entry to indicate the economizer perimeter gap is sealed. Section 5.5.1.1.1.18 would be modified in §140.4(e) and §140.4(e) 2D to require an economizer and perimeter gap sealing for each individual cooling air handler system with total mechanical cooling capacity over 18,000 Btu/h.

2.4 Regulatory Context

2.4.1 Existing Standards

Existing California Building Code requirements (Title 24, Part 6 2019): Section 120.2(i) and Section 140.4(e) require economizers for HVAC systems with mechanical cooling over 54,000 Btu/h, but do not require economizer perimeter gap sealing or FDD fan-on correction. Existing standards would be revised in Section 110.2(c) for smart thermostats to add the FDD fan-on correction control capability to detect, report, and override a continuous fan-on duration setting when the space is unoccupied. Existing standards would be revised in Section 120.2(e) for controls to require automatically turning off the ventilation fan when the building is unoccupied. Existing standards would be revised to require an economizer in Section 140.4(e) and include economizer perimeter gap sealing in Section 120.2(i). If comfort cooling systems have a cooling efficiency that meets or exceeds the cooling efficiency improvements in Table 140.4-D then the HVAC systems do not require an economizer. These energy efficiency measures are not included in other model building codes (e.g., ASHRAE 90.1, ASHRAE 189.1, IECC, local ordinances).

2.4.2 Relationship to Other Title 24 Requirements

Prescriptive requirements for economizers are included under the California Mechanical Code (Title 24, Part 4 2019) as part of Appendix E – Sustainable Practices. However, these requirements are not mandatory and are superseded by the California Energy Code (Title 24, Part 6 2019). There overlaps with other Title 24 code change proposals for the 2022 cycle to require an economizer for HVAC systems with mechanical cooling capacities greater than 33,000 Btu/hr from 54,000 Btu/hr.

2.4.3 Relationship to Federal Laws

HVAC equipment that would be impacted by the proposed code change have standards, certification, and testing regulated as part of the U.S. federal Energy Policy Act of 2005 (EPCA 2005). However, economizers, economizer perimeter gap sealing, and FDD fan-on correction measures are not included in any specific federal requirements.

2.4.4 Relationship to Industry Standards

Existing industry standards for economizers are set by ASHRAE in Standard 90.1. The ASHRAE standards are adopted into model codes by the International Code Council which publishes the International Energy Conservation Code (IECC) and the International Green Construction Code (IGCC). A summary of economizer requirements by each code or standards body is presented in the following table.

Table 6: Economizer and fan control requirements for existing standards

Proposed Requirement	Title 24, Part 6 (2019)	ASHRAE Std 90.1 (2019)	(IECC 2018)	IGCC 2018 ASHRAE 189.1	Title 24 Part 6 (Proposed)
Capacity threshold to require economizer	54,000 Btu/h	54,000 Btu/h	54,000 Btu/h	33,000 Btu/h	18,000 Btu/h
Economizer calibration and Perimeter gap sealing	NA	NA	NA	NA	Required
FDD fan-on correction	NA	NA	NA	NA	Required

2.5 Compliance and Enforcement

The proposed code changes considered methods to streamline the compliance and enforcement process regarding mitigating negative impacts on market actors who are involved in the process. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E describes how the proposed changes could impact various market actors.

The activities that need to occur during each phase of a building project are described below.

- **Design Phase:** During the design phase, the mechanical engineers would ensure that small HVAC package units with mechanical cooling capacity greater than or equal to 18,000 Btu/hr include the proposed measures including economizer, economizer perimeter gap sealing, and smart thermostat FDD fan-on correction requirements or have an exception.
- **Permit Application Phase:** At this phase, plan-checkers with authority and jurisdiction would ensure that HVAC package units with mechanical cooling capacity greater than or equal to 18,000 Btu/hr require the proposed measures or have an exception. Under this phase, NRCC-MCH-E Certificate of Compliance would be completed to verify the equipment meets the economizer, economizer perimeter gap sealing, and smart thermostat FDD fan-on correction requirements.
- **Construction Phase:** During this phase, the general/installing contractor must complete the NRCI-MCH-01-E form to verify equipment was installed properly and meets or exceeds HVAC requirements documented in the NRCC. Under this phase, aftermarket economizers would be installed if they are not included in the package HVAC unit.
- **Inspection Phase:** Under this phase, an acceptance testing technician will complete acceptance testing and fill out the NRCA-MCH-05 form. Economizers and Smart thermostats currently require functional testing and economizer

testing includes FDD. The FDD fan-on correction requires functional testing under NA7.5.12.3, NA7.5.13.2, and NA7.5.17.1.

As outlined above, this measure would have limited changes to the existing design and construction process. Therefore, the implementation of this measure is not expected to add substantial changes to the existing code compliance process.

3. MARKET ANALYSIS

Market Analysis is from the 2020 Statewide CASE Nonresidential HVAC Controls Report (Minezaki et al 2020 or CASE 2020). [16] CASE 2020 provides a market analysis identifying current technology availability, current product availability, and market trends. CASE 2020 describes how the proposed standard may impact the market in general and individual market players. Information is provided about the incremental cost of complying with the proposed measure. Verified® provides incremental cost information about the economizer perimeter gap sealing measure and the FDD fan-on correction measure. Estimates of market size and measure applicability are based on research with industry stakeholders, Energy Commission, and a range of industry players who were invited to participate in stakeholder meetings held in 2020.

3.1 Market Structure

The primary market actors for these measures are HVAC system manufacturers, design engineers, and HVAC contractors. The primary impacts associated with reducing the HVAC system mechanical cooling capacity requirements for economizers from 54,000 Btu/hr to 18,000 Btu/hr are HVAC designers and HVAC contractors based on modifying current design practices and encouraging placement of smaller HVAC systems closer to exterior walls to comply with the economizer requirements. This may be important for additions and alterations which may exclude replacement in buildings with no return ducting systems or buildings with limited space. The proposed code changes do not include an exception for Dedicated Outdoor Air Systems recommended by the Codes and Standards Enhancement (CASE) Program.[17]

HVAC system manufacturers will not be impacted by the proposal since most existing HVAC systems incorporate economizers and are not expected to require significant changes. The timing of this proposal coincides with new requirements from the California Air Resources Board regarding low global warming potential (low GWP) refrigerants and new federal minimum efficiency requirements which will occur in 2023, which will motivate manufacturers to revise product offerings.

Secondary market actors include building operators and code enforcement professionals. The main impact for building operators is smaller capacity units

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[16] Minezaki, T., S. Wang, E. Martin, N. Bulger. 2020. Nonresidential HVAC Controls. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report-HVAC-Controls.pdf. See pages 77-87

[17] Minezaki, T., S. Wang, E. Martin, N. Bulger. 2020. Nonresidential HVAC Controls. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report-HVAC-Controls.pdf. See pages 171-174 regarding an exception to exempt the economizer requirement if the Dedicated Outdoor Air Systems (DOAS) prescriptive requirements are met for the same space.

require economizers with FDD which will require changes to maintenance plans. Most buildings have larger HVAC systems which already require economizers so this shouldn't be an issue. The main impacts for plan checkers will be learning the new code requirements and product specifications including validating smaller units with an economizer with FDD, economizer perimeter gap sealing, and smart thermostats with FDD fan-on correction. HVAC contractors will need to conduct functional testing related to economizers on smaller sized units. For units that use the economizer trade-off table or the new exception for DOAS units, plans checkers and designers will need to be aware of the new language which will no longer feature a particular efficiency metric.

3.2 Technical Feasibility, Market Availability and Current Practices

Air-side economizers have movable metal outdoor-air, return-air, and relief-air dampers and gears mounted in a metal frame of a HVAC system cabinet. The gears are connected to an actuator shaft controlled by an economizer controller. The economizer controller actuator voltage typically ranges from 2 to 10 volts (V), with 2V closed and 10V fully open. The economizer controller receives occupancy sensor signal measurements, a first-stage (or multiple-stage) thermostat call for cooling signal, and temperature sensor measurements to operate the actuator and open or close the outdoor-air and return-air dampers which provide outdoor air to a conditioned space to improve indoor air quality (IAQ) and reduce the electricity required for mechanical cooling. Economizers have been required as part of ASHRAE 90.1 since 1975.[18] Economizers have been required on smaller units and are offered as an option by most manufacturers on HVAC systems with mechanical cooling capacities greater than or equal to 18,000 Btu/hr.

The 2020 Statewide CASE Nonresidential HVAC Controls (CASE 2020) states that "some stakeholders have expressed concerns about the persistence of savings from economizers because of historic reports that economizers do not function as intended for long periods of time, and the savings are lost or energy use increases when broken economizer systems are not fixed. The Statewide CASE Team expects the savings from this submeasure to persist so long as the economizer is functioning properly. While economizers have been around for decades, several cycles of incremental code changes to Title 24, Part 6, have increased the performance over time. As of the 2019 code cycle, economizers are required to come with a warranty, damper reliability testing, damper leakage testing, and include FDD. Market changes toward advanced digital economizer controllers

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[18] ASHRAE 1975. Standard 90-75 - Energy Conservation in New Building Design. New York, NY: ASHRAE. See Section 5.6 Cooling with Outdoor Air (Economizer Cycle), pp. 24-25. "Each fan system shall be designed to use up to and including 100 percent of the fan system capacity for cooling with outdoor air automatically whenever its use will result in lower usage of energy. Activation of economizer cycle shall be controlled by sensing outdoor air enthalpy and dry-bulb temperature jointly or outdoor air dry-bulb temperature alone to accomplish the above. Exceptions for fan systems less than 5,000 cfm (2.36 m3/s(or 134,0000 Btu/hr total mechanical cooling capacity www.ashrae.org)."

and gear-based actuators (rather than older-style rod-linkages) have also improved performance and reliability. Additionally, this measure includes the FDD measure which will improve measure persistence and reduce overall operational costs."[19]

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by new energy efficiency measures proposed in this report and similar economizer measures proposed by the CASE 2020 Report. These businesses adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training to offer competitive design and construction services consistent with the latest building standards codes.

The following table from the CASE 2020 report shows that California's construction industry includes about 17,273 businesses and 343,513 employees.[20] In 2018, total payroll was $27.8 billion in the commercial building sector.

Table 7: California construction industry, businesses, employment, and payroll (CASE 2020)

Construction Sectors	Businesses	Employment	Annual Payroll (billions $)
Commercial	**17,273**	**343,513**	**$27.8**
Commercial Building Construction	4,508	75,558	$6.9
Foundation, Structure, & Building Exterior	2,153	53,531	$3.7
Building Equipment Contractors	6,015	128,812	$10.9
Building Finishing Contractors	4,597	85,612	$6.2

Source: (State of California, Employment Development Department n.d.)

The proposed measures including: 1) economizer calibration and perimeter gap sealing, and 2) FDD fan-on correction, and 3) economizers for mechanical cooling capacities greater than or equal to 18,000 Btu/hr would likely affect commercial builders and nonresidential electrical, HVAC, and plumbing contractors, but will

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[19] Minezaki, T., S. Wang, E. Martin, N. Bulger. 2020. Nonresidential HVAC Controls. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report-HVAC-Controls.pdf. See pages 77-87

[20] Average total monthly employment in California in 2018 was 18.6 million; the construction industry represented 4.5 percent of 2018 employment.

not significantly impact other building trades. According to the CASE 2020 report, the effects on the commercial building industry would not be felt by all firms and workers, but would be concentrated in specific industry subsectors. The following table provides the commercial building subsectors impacted by the changes proposed in this report as they are related directly related to the purchase and installation of HVAC equipment. The total annual payroll is $6.9 billion representing 4,508 businesses and 75,558 employees.

Table 8: California specific subsectors of the commercial building industry impacted by proposed change to code (CASE 2020)

Construction Subsector	Establishments	Employment	Annual Payroll (billions $)
Commercial Building Construction	4,508	75,558	$6.9
Nonresidential Electrical Contractors	3,115	66,951	$5.6
Nonresidential plumbing and HVAC contractors	2,394	52,977	$4.5
Other Nonresidential equipment contractors	506	8,884	$0.9

Source: (State of California, Employment Development Department n.d.)

3.3.2 Impact on Building Designers and Energy Consultants

Building designer and energy consultants continuously adjust design practices to comply with changing building codes practices. Building codes (including the California Energy Code) are typically updated on a three-year revision cycle and building designers and energy consultants engage in continuing education and training in order to remain up-to-date with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are in the Architectural Services sector (North American Industry Classification System 541310). The following table from the CASE 2020 report shows the number of businesses, employment, and total annual payroll for Building Architectural Services. The proposed code changes could potentially impact all firms within this sector. The CASE 2020 report provided estimates of the impact nonresidential HVAC controls have on businesses that focus on nonresidential new construction.

The North American Industry Classification System (NAICS) does not provide specific market estimates for energy consultants.[21] Instead, businesses that focus on consulting related to building energy efficiency are in the Building Inspection Services sector

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[21] NAICS is used by Federal statistical agencies to classify businesses for collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was development jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and the Mexico Instituto Nacional de Estadistica y Geografia, to compare business statistics among North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

(NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[22] It is not possible to determine which businesses within the building inspection sector (i.e., building designer and consultant sectors) offering energy efficiency services. The following table provides an upper estimate of the size of this sector in California.

Table 9: California building designer and energy consultant sectors (CASE 2020)

Sector	Businesses	Employment	Annual Payroll (billions $)
Architectural Services[a]	3,704	29,611	$2.9
Building Inspection Services[b]	824	3,145	$0.2

Source: (State of California, Employment Development Department n.d.)

a. Architectural Services (NAICS 541310) comprises private-sector businesses primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;

b. Building Inspection Services (NAICS 541350) comprises private-sector businesses primarily engaged in providing building (residential & nonresidential) inspection services encompassing all aspects of the building structure and component systems, including energy efficiency inspection services.

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 Department of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

3.3.4 Impact on Building Owners and Occupants

The nonresidential building sector includes a number of building types, but this report only had time and resources available to evaluate small office, medium retail, and small school building types. Energy use by occupants of nonresidential buildings varies with electricity used primarily for lighting, HVAC, and refrigeration. Natural gas is primarily used for space and water heating. According to information published in the 2019 California Energy Efficiency Action Plan, there are more than 7.5 billion square feet of commercial floor space in California using

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[22] Businesses primarily engaged in evaluating building structure and component systems including energy efficiency inspection services and home inspection services. This sector does not include businesses engaged in providing inspections for pests, hazardous wastes or other environmental contaminates, nor does it include state and local government entities that focus on building or energy code compliance/enforcement of building codes and regulations.

19 percent of California's total annual energy use (Kenney 2019).[23] The diversity of building and business types within this sector creates a challenge for disseminating information on energy and water efficiency solutions, as does the variability in sophistication of building owners and the relationships between building owners and occupants.

According to the CASE 2020 report, building owners and occupants would benefit from lower energy bills. As discussed in Section 3.2.4.1, when building occupants save on energy bills, they tend to spend it elsewhere in the economy thereby creating jobs and economic growth for the California economy. The CASE 2020 Report did not expect the proposed code change to impact building owners or occupants adversely.

3.3.5 Impact on Building Component Retailers (including manufacturers and distributors)

The CASE 2020 Report did not expect any significant impacts on manufacturers and distributors of the economizer, economizer perimeter gap sealing, and FDD fan-on correction measures.

3.3.6 Impact on Building Inspectors

The following table provides employment and payroll information for state and local government agencies in which many inspectors of noncommercial buildings are employed. Building inspectors participate in continuing training to stay current on energy efficiency standards and building regulations. The CASE 2020 report determined the proposed code changes would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

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[23] Kenney, Michael, Heather Bird, and Heriberto Rosales. 2019. 2019 California Energy Efficiency Action Plan. Publication Number: CEC-400-2019-010-CMF, California Energy Commission.

Table 10: California employment in state and government agencies with building inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs	State	17	283	$29.0
Local	36	2,882	$205.7	
Urban and Rural Development Admin[b]	State	35	552	$48.2
Local	52	2,446	$186.6	

a. Administration of Housing Programs (NAICS 925110) comprises government primarily engaged in the administration and planning of housing programs, including building codes and standards, housing authorities, and housing programs, planning, and development.
b. Urban and Rural Development Administration (NAICS 925120) comprises government primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are zoning boards and commissions.

3.3.7 Impact on Statewide Employment

The CASE 2020 Report did not provide any significant employment or financial impacts to any particular sector of the California economy. Nevertheless, the proposed change might have modest impacts on employment in California. In Section 3.2.4, the CASE 2020 report estimated the proposed change in economizer requirements would affect statewide employment and economic output directly and indirectly through its impact on builders, designers and energy consultants, and building inspectors. In addition, the CASE 2020 report estimated how energy savings associated with the proposed change in economizer requirements would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities

3.4 Economic Impacts

Adoption of the code change proposal is based on the CASE 2020 report for economizers.[24] The CASE 2020 report provided the following tables regarding economic impacts due to additional direct spending in the commercial building industry by architects, energy consultants, and building inspectors. According to the CASE 2020 report, money saved by commercial building owners or other organizations affected by the 2022 code cycle proposal would not result in additional economic impacts by those businesses. However, utility bill energy savings would likely have a multiplier effect in economy. Table 11 shows the

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[24] Minezaki, T., S. Wang, E. Martin, N. Bulger. 2020. Nonresidential HVAC Controls. California Statewide Codes and Standards Enhancement (CASE) Program. https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-Final-CASE-Report-HVAC-Controls.pdf. See pages 83-87

proposed measures would have an estimated California life-cycle net present value energy savings impact of $16.67 million. Table 12 shows the proposed measures would have an estimated impact of $12.7 million on the California nonresidential construction sector based on the CASE 2020 report. Table 13 shows the proposed measures would have an estimated impact of $6.95 million on the California building designers and energy consultants based on the CASE 2020 report. Table 14 shows the proposed measures would have an estimated impact of $0.71 million on the California building inspectors based on the CASE 2020 report.

Table 11: California estimated life-cycle net present value of energy savings from the proposed measures

Proposed Measure	Annual Electricity Savings (GWh)	Power Demand Savings (MW)	Annual Natural Gas Savings (MMtherms)	Lifecycle Present Valued Energy Cost Savings (PV$ million)
Economizer Calibration and Perimeter Gap Seal	0.3	(0.1)	0.3	$1.16
FDD Fan-on Correction	22.3	0.1	0.1	$11.50
Expand Economizer Requirements to 18 kBtuh	8.9	0.6	(0.1)	$4.01
Total Energy Impacts	**31.4**	**0.6**	**0.3**	**$16.67**

Table 12: Estimated impact proposed measure would have on the California nonresidential construction sector (CASE 2020)

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Commercial Builders)	46	$3.01	$3.99	$6.60
Indirect Effect (Additional spending by firms supporting Commercial Builders)	10	$0.72	$1.15	$2.21
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	20	$1.12	$2.00	$3.26
Total Economic Impacts	**76**	**$4.85**	**$7.13**	**$12.07**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

Table 13: Estimated impact proposed measure would have on the California building designers and energy consultants sectors (CASE 2020)

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Building Designers & Energy Consultants)	17	$1.79	$1.77	$3.15
Indirect Effect (Additional spending by firms supporting Bldg. Designers & Energy Consult.)	11	$0.74	$1.00	$1.59
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	14	$0.76	$1.35	$2.21
Total Economic Impacts	**42**	**$3.29**	**$4.13**	**$6.95**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

Table 14: Estimated impact that adoption of the proposed measure would have on California building inspectors (CASE 2020)

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Building Inspectors)	3	$0.28	$0.33	$0.39
Indirect Effect (Additional spending by firms supporting Building Inspectors)	0	$0.02	$0.04	$0.06
Induced Effect (Spending by employees of Building Inspection Bureaus and Departments)	2	$0.09	$0.16	$0.26
Total Economic Impacts	**5**	**$0.38**	**$0.52**	**$0.71**

Source: Analysis by Evergreen Economics of data from the IMPLAN V3.1 modeling software.

3.4.1 Creation or Elimination of Jobs

This report and the CASE 2020 report does not anticipate that the measures proposed for the 2022 code cycle regulation would lead to the creation of new types of jobs or the elimination of existing types of jobs. The proposed change would not result in economic disruption to any sector of the California economy. The estimates of economic impacts discussed above would lead to little or no changes in employment of existing jobs.

3.4.2 Creation or Elimination of Businesses within California

As stated above, the proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a small change to HVAC fan controls, economizers, and occupant controlled smart thermostats which would not excessively burden or competitively disadvantage California businesses.

3.4.3 Competitive Advantages or Disadvantages for Businesses within California

The proposed changes might lead to competitive advantages for California businesses insofar as building designers, consultants, and contractors would be able to build more efficient nonresidential buildings in other states and across the globe based on more efficient practices adopted in California.[25]

3.4.4 Increase or Decrease of Investments in the State of California

The CASE 2020 report analyzed national data on corporate profits and capital investment by businesses that expand capital stock (referred to as net private domestic investment or NPDI).[26] Table 15 shows an average NDPI of 31% from 2015 to 2019 as a percentage of corporate profits ranging from 26 to 35 percent. The macroeconomic data show no net impacts on increasing or decreasing investments in California based on previous building code cycle changes from 2015 to 2019.

Table 15: Net domestic private investment and corporate profits, U.S. (CASE 2020)

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
2015	609.3	1,740.3	35%
2016	456.0	1,739.8	26%
2017	509.3	1,813.6	28%
2018	618.3	1,843.7	34%
2019	580.9	1,827.0	32%
		5-Year Average	**31%**

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

3.4.5 Effects on Innovation in Products, Materials, or Processes

The code change proposal improves emerging trends in building technologies by identifying and encouraging inventors to develop new innovative building technologies to improve energy efficiency and reduce carbon dioxide emissions. The code change proposal will drive, lead to, and/or incentivize innovation in building materials, components, or processes, and avoid stifling innovation based on the following energy efficiency measures: 1) expand economizer requirements on HVAC systems with mechanical cooling capacities greater than 18 kBtuh, 2) patented economizer perimeter gap sealing, and 3) patented FDD fan-on correction.

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

[26] Net private domestic investment is the total amount of investment in capital by the business sector used to expand capital stock, rather than maintain or replace due to depreciation. Corporate profit is the money left after a corporation pays its expenses (CASE 2020).

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

According to the CASE 2020 report, the proposed code changes will not have any measurable impact on California's General Fund, special funds, or local government funds.

California General Funds or Special Funds

California has budget for building energy efficiency code development, education, compliance, and enforcement. California allocates 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 included in existing state budgets. The costs to state government are small compared to overall energy savings benefits associated with the code change proposals. All submeasures are cost effective. Therefore, the proposed code changes will not have any negative impact on the California general fund or special funds.

Local Government Cost

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2022 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). The CASE 2020 report provides an Appendix E, describing how the proposed code change might impact various market actors involved in the compliance and enforcement process to minimize negative impacts on local governments. The proposed code changes in this report are similar to changes in the CASE 2020 report.

3.4.6.1 Cost of Enforcement

Cost to the State

According to the CASE 2020 report, state governments budget for code development, education, and compliance enforcement. State governments allocate 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. Since all submeasures have been shown to be cost effective, the report does not expect any significant economic costs to the State of California.

Cost to Local Governments

According to the CASE 2020 report all proposed code changes to Title 24, Part 6 would result in changes to compliance. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2022 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 Appendix E, 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.

3.4.6.2 Impacts on Specific Persons

Previous code proposals with similar measures indicate that the proposed code changes will not impact any specific group or groups of persons including persons of a specific protected class, persons eligible to participate in affordable housing programs, renters, commuters, etc.

4. ENERGY SAVINGS

4.1 Key Assumptions for Energy Savings Analysis

The energy savings for the basecase and proposed code change measures are modeled using the EnergyPlus California Building Energy Code Compliance (CBECC-Com) software.[27] EnergyPlus building energy simulation models were modified by Big Ladder Software to include the proposed changes to the energy standards. EnergyPlus input assumptions for the economizer perimeter gap sealing measure are based on laboratory test measurements performed by Intertek®, an ISO-certified laboratory used by manufacturers and the United States (US) Department of Energy (DOE) to test HVAC equipment for compliance with Federal energy efficiency standards.

The proposed code changes include two patented measures: 1) economizer calibration and perimeter gap sealing, and 2) FDD fan-on correction. The proposed code change measures are available on the market and will be widely available through wholesale distributors and manufacturers by 2022. The proposed code changes also include a third measure: 3) expand economizer requirements to 18,000 Btuh which is widely available on the market and offered by all manufacturers and wholesale distributors. The EnergyPlus input assumptions for the base and proposed code change are provided in Table **5** (above). The EnergyPlus base economizer unoccupied closed damper position outdoor airflow (OA) is 21.3%, the occupied minimum OA is 26.5 to 32.5% (depending on building occupancy), and the maximum OA is 70.9%. The EnergyPlus economizer perimeter gap sealing measure unoccupied minimum closed damper OA is 12.9%, the occupied minimum damper position OA is between 19.5 and 34.6% (depending on the building occupancy), and fully open damper position OA is 70.2%. The economizer damper position OA values are based on laboratory tests of multiple packaged HVAC systems at Intertek® (see below).[28] The FDD fan-on correction measure is modeled in EnergyPlus by assuming continuous fan operation in the base models and automatically turning off the ventilation fan during unoccupied periods in the code change models. The EnergyPlus base

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[27] NORESCO, LLC. 2020. CBECC-Com Nonresidential Compliance Software. http://bees.archenergy.com/index.html

Crawley, D., L. Lawrie, C. Pedersen, F. Winkelmann 2000. EnergyPlus: Energy Simulation Program. ASHRAE Journal 42(4):49-56. Atlanta, GA. https://www.researchgate.net/publication/230606369_EnergyPlus_Energy_Simulation_Program

[28] Mowris, R. P. Jacobs, 2020. Smart Economizer™ for Commercial HVAC Systems. Proceedings of the 2020 ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: ACEEE.

Mowris, R., E. Jones, R. Eshom, K. Carlson, J. Hill, P. Jacobs, J. Stoops. 2016. Laboratory Test Results of Commercial Packaged HVAC Maintenance Faults. Prepared for the California Public Utilities Commission. Prepared by Robert Mowris & Associates, Inc. (RMA). http://www.calmac.org/publications/RMA_Laboratory_Test_Report_2012-15_v3.pdf small school and small office prototypes have no economizer and the expand economizer requirements measure is modeled in EnergyPlus using a fixed drybulb or differential dry bulb economizer control method.

The FDD fan-on correction measure would expand on existing CEC FDD requirements for HVAC systems for two fan control options: 1) an Efficient Fan Controller® (EFC®) or 2) a smart thermostat where the two fan control options have provide the patented (or licensed) FDD fan-on correction algorithms (which can be uploaded wirelessly and used to verify proper operation of the FDD fan-on correction measure). The FDD fan-on correction measure automatically detects and turns off a continuous fan operation when a building is unoccupied or provides a continuous fan-on fault alarm for a building operator or maintenance personnel to turn off a continuous fan-on operation during unoccupied periods. FDD Fan-on correction code change proposal is applicable to 13 to 78% of buildings per previously published evaluation studies (DNVGL 2016; Jacobs & Higgins 2003). Savings for the FDD fan-on correction are weighted assuming 13% of buildings have this fault.

The measures have an effective useful life and persistence of at least 15 years. The expand economizer requirements measures includes additional net present maintenance costs which occur at the 7.5-year time frame and are the net present maintenance costs are included within the economizer Incremental Measure Cost.

Time Dependent Valuation (TDV) factors are based on the CEC March 27, 2020 compliance metrics workshop (CEC 2020).[29] Electricity TDV factors include a 15-percent retail adder and the natural gas TDV factors include the impact of methane leakage. The electricity TDV factors used in the energy savings analyses were obtained from Energy and Environmental Economics, Inc (E3 2016).[30] Final TDV factors released by the CEC in June 2020 use 20-year global warming potential (GWP) values instead of 100-year GWP values used to derive current TDV factors. The 20-year GWP values increased TDV factors slightly. TDV energy savings presented in this report are lower than values based on 20-year GWP values used in the analysis. The proposed code changes will be more cost effective using revised TDV factors. Energy savings presented in kWh (or GWh) and therms (or MMtherms) are not affected by TDV or demand factors.

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[29] CEC. 2020. Nonresidential Construction Forecasts. https://www.energy.ca.gov/title24/participation.html

[30] Energy + Environmental Economics. 2020. Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2022 Time Dependent Valuation (TDV) and Source Energy Metric Data Sources and Inputs. https://www.ethree.com/wp-content/uploads/2017/01/TN212524_20160801T120224_2019_TDV_Methodology_Report_7222016.pdf. Electric TDV factors are from "Electric TDVs 2022 - 15 pct Retail Adj Scaled by Avoided Costs.xlsx." Natural gas TDV factors are from "2022_TDV_Policy_Compliant_CH4Leak_FlatRtlAdd_20191210.xlsx". Electricity demand factors are from "2022 TDV Demand Factors.xlsx".

4.1.1 HVAC Equipment and Economizers Tested at Intertek®

Intertek® tested four new economizers on three packaged HVAC Roof Top Units (RTUs) with DX Air Conditioning (AC) compressors and economizers and Gas Furnace (GF) heating. Intertek® tested the following four (4) packaged RTUs: 1) 7.5-ton two-compressor TXV packaged DX AC GF with Economizer #1, 2) 3-ton non-TXV packaged DX AC GF with Economizer #5, 3) 3-ton TXV packaged DX AC GF with Economizer #6, and 4) 7.5-ton two-compressor TXV packaged DX AC GF with Economizer #2. Duct leakage for all tests was 6% at 25 Pascal (Pa). Each packaged RTU was tested with an economizer designed and manufactured for each specific RTU.

Table 16 provides a description of each unit. Equipment was setup in two chambers at the laboratory to emulate indoor and outdoor conditions per Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 340/360 (AHRI 2019).[31] Test conditions differ from those used to rate cooling and heating systems to match typical installations in California.[32]

Table 16: Description of HVAC RTUs tested at Intertek® laboratory

Description	RTU #2: 7.5-ton DX AC GF Econo #1	RTU #3: 3-ton DX AC GF Econo #5	RTU #3: 3-ton DX AC GF Econo #6	RTU #5: 7.5-ton DX AC GF Econo #2
Model	THC092A4RKA1RA0C1A1	48HJM004-351	LGA036H2BS	THC092A4RKA1RA0C1A1
Rated SEER/EER	11 EER 11.8 IPLV	13 SEER/11.0 EER	13 SEER/11.2 EER	11 EER 11.8 IPLV
Rated heat efficiency	80% Efficiency	80.5% Efficiency	80% Efficiency	80% Efficiency
Rated cooling capacity, airflow, static pressure	90000 Btuh total 66509 Btuh sensible, 3000 scfm at 0.5 IWC	36000 Btuh total. 25009 Btuh sensible, 1050 scfm at 0.5 IWC	36000 Btuh total, 25920 Btuh sensible, 1200 scfm at 0.5 IWC	90000 Btuh total 66509 Btuh sensible, 3000 scfm at 0.5 IWC
Refrigerant charge	R22 102/99 oz. TXV	R22 89 oz. non-TXV	R22 112 oz. TXV	R22 102/99 oz. TXV
Rated heat capacity, airflow, static pressure	120000/150000 Btuh 3,000 scfm at 0.5 IWC	48300/60000 Btu/hr, 1,050 scfm @ 0.4 IWC	62400/78000 Btu/hr, 1,050 scfm @ 0.4 IWC	120000/150000 Btuh 3,000 scfm at 0.5 IWC
Fan-off delay	60 seconds heating	Fixed 30 sec. heating	60 sec. heating	60 seconds heating

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[31] ANSI/AHRI. 2019. 340/360 Standard for Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment. Arlington, VA: AHRI.

[32] Cooling tests were performed at 95F dry bulb (DB) OAT and 75F DB indoor air temperature (IAT) and 62F wet bulb (WB). Gas heating tests were performed at 47F DB OAT and 72F DB IAT and 53F WB (AHRI 2019).

4.1.2 Intertek® Laboratory Test Setup

The Intertek® laboratory is used by manufacturers to certify air conditioners and heat pumps for AHRI equipment efficiency testing for the U.S. Department of Energy (DOE) compliance and enforcement program to meet energy conservation standards required by the Energy Policy and Conservation Act of 1975 as amended (GAO 1975).[33] The test facility consists of climate-controlled indoor and outdoor chambers where ducts, evaporator, condenser, furnace or hydronic heating equipment and forced air units are located. HVAC systems and test equipment were assembled and installed in the test chambers by laboratory technicians. Cooling verification tests were performed according to the AHRI Standard 340/360 2019 (AHRI 2019). Economizer airflow tests were performed according to ANSI/ASHRAE 41.2-1987 Standard Methods for Laboratory Airflow Measurement (ANSI/ASHRAE 1987).[34] Thermal efficiency tests were performed according to ANSI Z21.47-5th Edition 2006/CSA 2.3-5th Edition 2006 (ANSI/CSA 2006).[35] Laboratory test equipment was calibrated per ISO 17025 by an accredited provider per the International Laboratory Accreditation Cooperation (ILAC) (ISO 2017).[36]

4.1.3 Methods for Establishing Minimum Damper Position

Technicians use the "finger method" to establish minimum damper positions by placing their fingers between damper blades. One finger is assumed to be 10% open, 2-fingers are assumed to be 20% open, and 3-fingers are assumed to be 30% open. Using fingers to set damper positions causes variations depending on finger size and placement with respect to the damper and frame. Laboratory tests were performed with wooden dowels to set damper positions as shown in Figure 5.

Figure 5: Economizer damper positions using 1, 2, and 3-finger dowels

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[33] GAO (Government Accountability Office) 1975. S. 622 – 94th Congress: Energy Policy and Conservation Act. Public Law 94–163, 89 Stat. 871. Washington DC: GAO https://www.govtrack.us/congress/bills/94/s622

[34] ANSI/ASHRAE 1987. ASHRAE 41.2-1987 Standard Methods for Laboratory Airflow Measurement. NY, NY: ANSI.

[35] ANSI 2006. ANSI Z21.47-5th Edition 2006/CSA 2.3 2006– Standard for Gas-Fired Central Furnaces. NY, NY: ANSI.

[36] ISO (International Standards Organization). 2017. ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories. Geneva, Switzerland: ISO.

Finger diameters are as follows: 1-finger = 0.7 inch (1.8 cm), 2-fingers = 1.3 inches (3.3 cm), and 3-fingers = 2 inches (5.1 cm). These dimensions were used to establish voltages for each position using digital economizer controllers.

Digital economizer controllers establish minimum damper positions based on default settings or field entered voltage signals (Honeywell 2014) or minimum ventilation percentages (Belimo 2013; Pelican 2016). The closed damper position is generally 2 Volts (V), and the fully open damper position is generally 10V. Each 0.8V increment above 2V rotates the actuator shaft open by 10%. Intertek® performed tests at the following damper positions: closed (2V), 10% (2.8 V), 20% (3.6 V), 30% (4.4 V), 38.8% (5.1V or 1-finger), 50% (5.1V or 2-fingers), 61.3% (6V or 3-fingers), and fully open (10V).

Digital economizer controllers have a user interface for technicians to set minimum positions more accurately than analog controllers. However, digital economizers provide a rotational position of the damper which does not correspond to the OAF. Furthermore, when economizers are being installed, technicians often set the minimum damper position visually. If the minimum damper position appears to be insufficient, then technicians might use the finger method to increase the damper position. Whatever method is used to establish the minimum damper position can cause insufficient or excess outdoor airflow which will impact indoor air quality and energy efficiency (Jacobs & Higgins 2003; Cowan 2004; Heinemeier 2018; DNVGL 2018).

This code change proposal recommends an automated FDD method to calibrate the minimum damper position within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow depending on building occupancy and report calibration results on an ongoing basis to reduce or eliminate insufficient or excess outdoor airflow which impacts indoor air quality and energy efficiency.

4.1.4 Intertek® Laboratory Test Method

Intertek® laboratory tests were performed under steady-state conditions to measure the base and the proposed code design economizer cooling capacity, efficiency, and Outdoor Air Fraction (OAF) for a range of economizer actuator control voltages and damper positions (RMA 2016). The OAF is defined as the percentage of outdoor airflow divided by the total evaporator airflow.[37] Accurate outdoor and total evaporator airflow measurements are difficult to make in the field especially outdoor airflow which mixes with return airflow prior to entering the evaporator. A simple equation to measure the OAF using air temperature measurements in degrees Fahrenheit (F) is provided in Equation 1.

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[37] ASHRAE 62.1 defines OAF as the fraction of outdoor air intake flow in the system primary airflow.

Equation 1 $OAF_m = \frac{T_r - T_m}{T_r - T_o}$

Where,

OAF_m = outdoor air fraction based on the measured Dry Bulb (DB) Mixed Air Temperature or MAT as a fraction of total airflow (dimensionless or percentage)

T_r = drybulb Return Air Temperature or RAT (F)

T_o = drybulb Outdoor Air Temperature or OAT (F)

T_m = Mixed Air Temperature or MAT (F)

The outdoor air and return airflows are well mixed and the OAT and RAT can be accurately measured. The MAT is difficult to measure due to turbulence as outdoor and return air enter the mixed air chamber. In order to use Equation 1 to calculate OAF, the DB temperature difference between OAT and RAT must be at least 10F to 20F. The OAF measurement will be more accurate if the OAT and RAT difference is greater than 20F.

Intertek® performed tests at 55F DB OAT and 51F Wet Bulb (WB) OAT conditions, and 75F DB and 62F WB indoor RAT conditions. Tests were performed with the blower fan operating and the economizer perimeter gap between economizer frame and the system cabinet unsealed and sealed. Each test was performed for 15 minutes to achieve steady-state conditions with 30 minutes of data recorded at 5-second intervals including: DB and WB OAT, RAT, MAT entering the evaporator or mixed air leaving the fan, air pressure (p), airflow (scfm), and fan power. These measurements were used to calculate outdoor airflow as a fraction of the total airflow across the evaporator coil. Air temperatures were measured using resistance temperature detector (RTD) sensors in the outdoor, return, and supply air samplers. The OAT entering the economizer was also measured using an array of 6 thermocouple sensors installed in the economizer inlet. The average return air drybulb temperature was also measured using an array of 6 thermocouple sensors installed in the return duct. The volumetric flow rate of air was measured using a Code Tester.[38] Intertek® also measured outdoor air, return air, and mixed air enthalpy, humidity, and sensible and latent heat.

To distinguish between compressible and incompressible flow in ideal gases, the Mach number (ratio of speed of flow to speed of sound) must be greater than 0.3 before significant compressibility occurs. The Mach number of the tested HVAC equipment is less than 0.03 (10 times lower). Therefore, the standard Bernoulli energy equation is used to calculate the mechanical heat loss of the fan as shown in Equation 2.

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[38] The "code tester" is the airflow measuring apparatus described in Section 5.3 Test Chambers (Code Testers), ANSI/ASHRAE 41.2-1987 (RA92). Standard Methods for Laboratory Airflow Measurement.

Equation 2 $$\dot{W}_{fan} + \dot{m}\frac{v_1^2}{2} + gz_1 + \dot{m}\frac{p_1}{\rho} = \dot{m}\frac{v_2^2}{2} + gz_2 + \dot{m}\frac{p_2}{\rho} + \dot{E}_{loss\ fan}$$

Where,

Subscript 1 refers to entering return conditions and **subscript 2** refers to leaving supply conditions

$\dot{W}_{fan}$ = measured electric power used by fan (W)

$\dot{m}$ = mass flow of air (kg/s)

ρ = density of air (kg/m^3)

V = velocity of air (m/s)

g = acceleration of gravity 9.81 (m/s^2)

z = elevation above reference plane (m)

p = pressure of air (1) entering or (2) leaving the fan (Pa)

$\dot{E}_{loss\ fan}$ = mechanical heat loss of fan excluding mechanical work causing air movement (W)

The air velocity and elevation above the reference plane are the same at the inlet and outlet positions. Therefore, the Bernoulli equation can be simplified to calculate the heat loss of the fan as shown in Equation 3.

Equation 3 $$\dot{E}_{loss\ fan} = \dot{W}_{fan} - \dot{m}\frac{(p_2 - p_1)}{\rho}$$

The fan power is measured and the fan mechanical heat loss is calculated for each test performed at 55F outdoor conditions with compressors off. Fan heat is added to the airstream as it passes across the fan motor which increases the mixed air temperature leaving the fan. The fan-heat temperature increase is calculated using Equation 4.

Equation 4 $$\Delta T_{fan} = \frac{\dot{E}_{loss\ fan}}{c_p \rho \dot{V}}$$

Where,

ΔT_{fan} = temperature increase of air due to fan heat (C)

c_p = specific heat of air at constant pressure (J/kg-C)

$\dot{V}$ = volumetric flow rate of air (m^3/s)

The temperature in degrees Fahrenheit from Celsius is calculated in Equation 5.

Equation 5 $$\Delta T_{fan} = T(C)\frac{9}{5} + 32 = T(F)$$

The fan adds heat but not moisture to the airstream. Therefore the average mixed air humidity ratio (leaving the fan) is equal to the supply air humidity ratio measured for each test using RTD sensors in the supply air sampler. Additionally, the temperature of the mixed air before the fan equals that measured for the supply air minus temperature increase due to fan heat as provided by Equation 4. The enthalpy of the mixed air is determined from the mixed air temperature and the supply air humidity ratio. The average RAT, MAT, and OAT are measured for each test. Enthalpy measurements are used to calculate the outdoor air fraction (OAF) using Equation 6.

Equation 6 $$OAF_e = \frac{h_r - h_m}{h_r - h_o}$$

Where,

OAF_e = outdoor air fraction of air based on enthalpy (dimensionless)
h_r = enthalpy of return air from conditioned space (Btu/lbm or J/kg)
h_m = enthalpy of mixed air leaving fan based on supply air humidity ratio and temperature minus temperature increase due to fan, ΔTfan (Btu/lbm or J/kg)
h_o = enthalpy of outdoor air (Btu/lbm or J/kg)

Enthalpy is calculated using Equation 7 from ASHRAE 2009.[39]

Equation 7 $$h = 0.24t + \left[\frac{\frac{(1093 - 0.556w)0.62198p_{ws}}{p_a - p_{ws}} - 0.24(t - w)}{1093 + 0.444t - w} \right] [1061 + 0.444t]$$

Where,

h = specific enthalpy of moist air (Btu/lbm)
t = dry bulb temperature (F)
w = wet bulb temperature (F)
p_a = atmospheric pressure for tests (psia)
p_{ws} = saturation pressure for wet bulb temperature from Equation 8 (psia)

Equation 8 $$p_{ws} = EXP(C1 + C2 + C3)$$

Where,

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[39] ASHRAE 2009. ASHRAE Handbook-Fundamentals. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc. Hyland, R.W. and A. Wexler. 1983b. Formulations for the Thermodynamic Properties of the Saturated Phases of Water from 173.15 K to 473.15 K. ASHRAE Transactions 89(2A):500-519.

$$C1 = -10440.397(w+459.67)^{-1} - 23.71601592 - 0.027022355(w+459.67)$$

$$C2 = 0.00001289036(w+459.67)^{2} - 2.4780681\times10^{-9}(w+459.67)^{3}$$

$$C3 = 6.5459673\ln(w+459.67)$$

Equation 9 provides another method to calculate the OAF using the RAT, OAT, Supply Air Temperature (SAT), and the fan-heat temperature increase measured during the initial calibration setup.

Equation 9 $$OAF_S = \frac{T_r - (T_S - \Delta T_{fan})}{T_r - T_o}$$

Where,

OAF_S = outdoor air fraction based on measured SAT, RAT, and OAT (dimensionless)

ΔT_{fan} = fan-heat temperature increase measured during the initial calibration as the difference between SAT_α and OAT_α where the subscript "α" refers to an initial calibration setup measurement with the HVAC fan operating and without cooling or heating system operating when OAT_α is within +/-0.5F of RAT_α (F) or assume ΔT_{fan} is 1.2 ± 0.5F depending on fan motor Watts or hp.

The fan-heat temperature increase is included in Equation 6 and Equation 9. The fan-heat temperature increase is not included in Equation 1 since the MAT is measured upstream of the fan.

4.1.5 Intertek® Laboratory Test Results of Economizer OAF

Table 17 provides the Intertek® laboratory test results of the measured OAF versus economizer damper position for four economizers tested on three packaged RTUs with unsealed and sealed economizer perimeter gap. For the closed damper position (2V) tests the average OAF is 21.3% with the unsealed perimeter gap and the average OAF is 12.9% with the sealed perimeter gap. The default EnergyPlus prototypical base models assume 0% OAF at the closed damper position and 100% OAF at the fully open damper position. For 10V tests with fully open damper position the average OAF is 70.9% with the unsealed perimeter gap and the average OAF is 70.2% with the sealed perimeter gap. Sealing the perimeter gap reduces unintended excess outdoor airflow at the closed or minimum damper positions, but only reduces the OAF by -0.4 to +3% when the damper is fully open.

Table 17: Economizer damper position versus OAF for unsealed and sealed economizer perimeter gap (Intertek® test data see Mowris 2016)

Economizer Damper Position	Economizer Actuator Volts (V)	Base Unsealed Perimeter Gap (OAF %)	Code Change Sealed Perimeter Gap (OAF %)
7.5-ton RTU #2 Econo #1		Table 55 (RMA 2016)	Table 55 (RMA 2016)
Closed	2	12.1%	8.2%
10% open	2.8	13.5%	10.0%
20% open	3.6	15.5%	11.7%
30% open	4.4	19.4%	16.6%
38.8% open (1-finger)	5.1	23.5%	20.1%
50% open (2-fingers)	6	31.1%	28.3%
55% open (2.5-fingers)*	6.4	34.2%	31.5%
61.3% open (3-fingers)	6.9	39.7%	35.5%
Fully open	10	72.7%	69.7%
3-ton RTU #3 Econo #6		Table 96 (RMA 2016)	Table 96 (RMA 2016)
Closed	2	19.9%	12.3%
10% open	2.8	20.7%	14.2%
20% open	3.6	22.4%	16.9%
30% open	4.4	24.9%	20.4%
38.8% open (1-finger)	5.1	27.8%	23.9%
50% open (2-fingers)	6	32.5%	29.6%
61.3% open (3-fingers)	6.9	38.2%	35.7%
Fully open	10	66.4%	66.0%
3-ton RTU #4 Econo #5		Table 78 (RMA 2016)	Table 78 (RMA 2016)
Closed	2	23.5%	14.0%
10% open	2.8	26.0%	17.4%
20% open	3.6	28.9%	21.2%
30% open	4.4	32.2%	25.4%
38.8% open (1-finger)	5.1	32.6%	26.6%
50% open (2-fingers)	6	40.0%	35.0%
61.3% open (3-fingers)	6.9	52.4%	50.6%
Fully open	10	66.3%	65.8%
7.5-ton RTU #5 Econo #2		Table 56 (RMA 2016)	Table 56 (RMA 2016)
Closed	2	29.7%	17.1%
10% open	2.8	31.5%	18.4%
20% open	3.6	34.9%	22.2%
30% open	4.4	46.1%	32.1%
38.8% open (1-finger)	5.1	43.5%	34.6%
50% open (2-fingers)	6	56.1%	43.8%
55% open (2.5-fingers)*	6.4	58.5%	47.0%
61.3% open (3-fingers)	6.9	61.5%	51.1%
Fully open	10	78.1%	79.3%
Average Intertek® tests			
Closed	2	**21.3%**	**12.9%**
10% open	2.8	**22.9%**	**15.0%**
20% open	3.6	**25.4%**	**18.0%**
30% open	4.4	**32.3%**	**25.7%**
38.8% open (1-finger)	5.1	**31.9%**	**26.3%**
50% open (2-fingers)	6	**39.9%**	**34.2%**
55% open (2.5-fingers)*	6.4	**42.5%**	**37.1%**
61.3% open (3-fingers)	6.9	**47.9%**	**43.2%**
Fully open	10	**70.9%**	**70.2%**

* OAF values for 2.5-fingers are interpolated based on measurements for 2-fingers and 3-fingers.

Figure 1 shows the average measured damper position OAF (y) versus economizer actuator control voltage (x) for the unsealed and the sealed perimeter gap based on average measurements for the four economizers tested by Intertek®. The diagonal dashed line from lower left to upper right illustrates the current CEC title 24 standards which assume the OAF is proportional to the economizer actuator voltage (x) where the closed position provides 0% OAF and the fully open position provides 100% OAF. The upper light black solid curve shows the OAF for the uncalibrated and unsealed economizer perimeter gap defined by Equation 10.

Equation 10 $OAF_{unsealed} = y = 0.0037x^2 + 0.0189x + 0.1509$

Where,

x = actuator voltage (V)

The lower dark black solid curve shows the OAF for the calibrated and sealed economizer perimeter gap defined by Equation 11.

Equation 11 $OAF_{sealed} = y = 0.0043x^2 + 0.0214x + 0.0607$

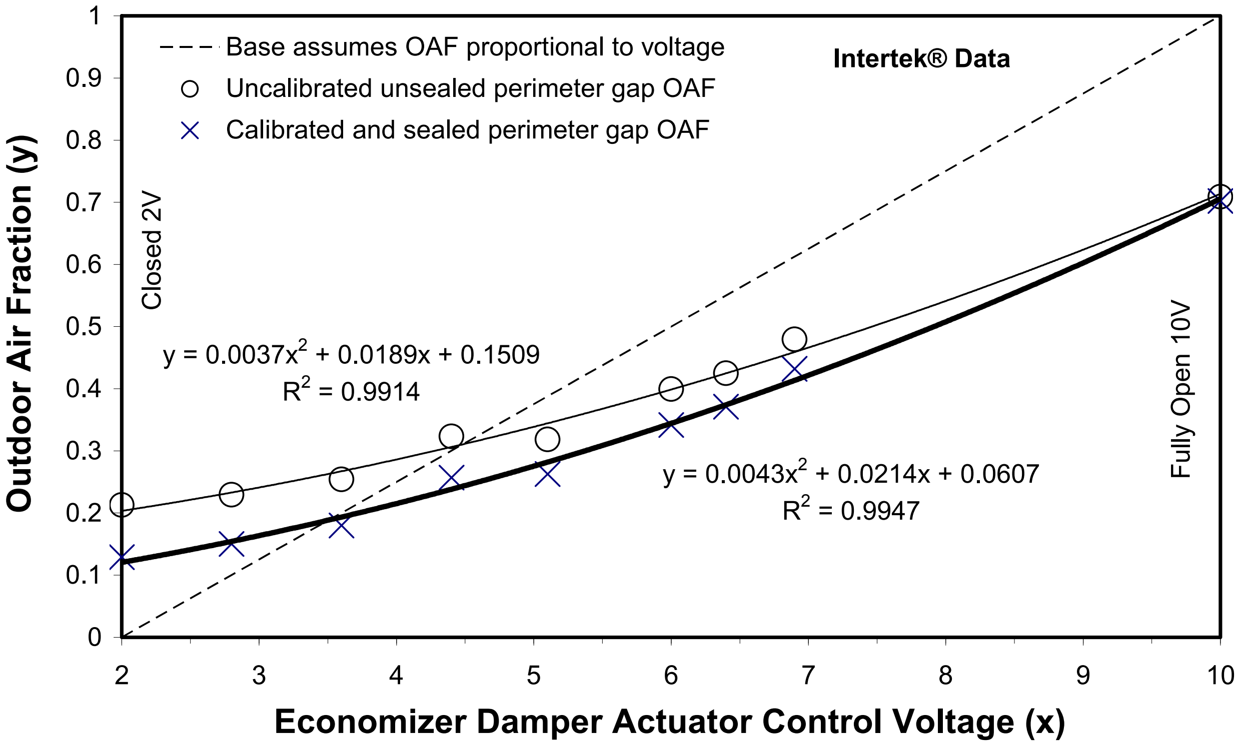

Figure 6: Laboratory tests of the average OAF (y) versus actuator voltage (x) for unsealed and sealed economizer perimeter gap

4.1.6 Key Modeling Assumptions for Economizer Calibration and Perimeter Gap Sealing

Table 18 provides the Outdoor Air Fraction (OAF) modeling assumptions for the standard and proposed design for the small office, medium retail, and small school prototypes.

Table 18: Standard and proposed design OAF based on Intertek® test data

EnergyPlus Prototype	Damper Position	Standard Design actuator Volts (V)	Standard Design uncalibrated economizer unsealed perimeter gap OAF (%)	Proposed Design calibrated sealed economizer Volts (V)	Proposed Design calibrated economizer sealed perimeter gap OAF (%)
SmallOffice	Closed	2	21.3%	2	13.9%
SmallOffice	Minimum	3.6	26.5%	3.6	19.5%
SmallOffice	Full open	10	70.9%	10	70.2%
MediumRetail	Closed	2	21.3%	2	13.9%
MediumRetail	Minimum	4.0	28.4%	4.5	24.5%
MediumRetail	Full open	10	70.9%	10	70.2%
SmallSchool	Closed	2	21.3%	2	13.9%
SmallSchool	Minimum	4.8	32.5%*	6.0	34.6%
SmallSchool	Fully open	10	70.9%	10	70.2%

Note: * Standard design SmallSchool EnergyPlus prototype does not provide sufficient outdoor airflow to meet ASHARE 62.1 minimum outdoor airflow requirements for classrooms.

The standard design assumes: 1) 0% OAF at the closed position when the building is unoccupied, 2) minimum OAF of: 19.5% (small office), 24.5% (medium retail), and 34.6% (small school) (or other OAF depending on building occupancy), and 3) 100% OAF when economizing. The standard design uncalibrated economizer unsealed perimeter gap minimum OAF values are: 26.5% (small office), 28.4% (medium retail), and 32.5% (small school) based on actuator voltages of 3.6V, 4V, and 4.8V and Equation 10.[40] The proposed design calibrated economizer sealed perimeter gap minimum OAF values are: 19.5% (small office), 24.5% (medium retail), and 34.5% (small school) based on the calibrated actuator voltages of 3.6V, 4.5V, and 6V and Equation 11. The current CEC Title 24 standards provide insufficient outdoor airflow for schools which impacts indoor air quality, health, safety and academic performance. The current CEC Title 24 standards provide excess outdoor airflow for small office and medium retail buildings. Appendix D provides the EnergyPlus Input Data File (IDF) AvailabilityManagerAssignmentList object and the Minimum Fraction of Outdoor Air Schedule Name to model the expand economizer requirements to 18 kBtuh measure.

4.1.7 Key EnergyPlus Modeling Assumptions for FDD Fan-on Correction

The current EnergyPlus models specify continuous fan-on operation when the

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[40] Small office EnergyPlus OAF is 19.5% or 3.6V corresponding to 26.5% OAF based on Eq. 10, medium retail is 24.5% or 4V corresponding to 28.4% OAF based on Eq. 10, and small school is 34.5% or 4.8V corresponding to 32.5% OAF based on Eq. 10.

building is occupied or unoccupied or the fan is turned off when the building is unoccupied. Research findings from evaluation studies indicate that the ventilation fan operates continuously for 13 to 78% of buildings (DNVGL 2016; Jacobs & Higgins 2003). The proposed design FDD fan-on correction provides continuous fan-on operation during occupied periods and turns off the fans during unoccupied periods using the fan schedule. Appendix D provides the EnergyPlus IDF information for the AvailabilityManagerAssignmentList object to model the expand economizer requirements to 18 kBtuh measure.

4.1.8 Key EnergyPlus Assumptions for Expand Economizer Requirements to 18 kBtuh

The current EnergyPlus simulation models do not include an economizer for HVAC systems with mechanical cooling capacities less than 54,000 Btu/h. The proposed design reduces the threshold to 18,000 Btu/hr. Appendix D provides the EnergyPlus IDF information for the BasaeSys7 OACtrl object to model the expand economizer requirements to 18 kBtuh measure.

4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, Verified® Inc., and Big Ladder Software compared current design practices to design practices that would comply with the proposed requirements. There is an existing Title 24 standard that covers the building systems in question, so the existing conditions assume a building minimally complies with the 2019 Title 24 Standards. Verified® Inc. And Big Ladder Software used current design practices as the existing conditions. All energy savings are calculated based on the mixed fuel baseline (i.e., electric space cooling and ventilation fans, and natural gas space heating).

The energy impacts were modeled using specific EnergyPlus prototypical building models that represent typical building geometries for different types of buildings. A brief description of the prototype buildings used in the analysis are presented in Table 19. Energy modeling was performed using prototypical nonresidential EnergyPlus building models that had direct expansion (DX) mechanical cooling capacities ranging from 18,000 Btuh to less than 54,000 Btuh. After investigating all air handlers on CBECC-Com prototype models, Big Ladder Software found three building types that would be impacted.[41]

As described above, the CASE 2020 report provides market data from a manufacturing survey through AHRI. Based the AHRI survey data, the CASE 2020 report provided an estimate of 5,000 economizers installed on HVAC systems with mechanical cooling capacities greater than 33,000 and less than 54,000 Btuh in

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[41] The Retail/MixedUse and RestaurantFastFood prototypes models were excluded from the analysis due to larger units serving common areas, corridors or kitchens which might be served by DOAS units in the future and were not likely to be representative of unit performance based on cooling loads and high outdoor air fractions.

the California market. Analysis of AHRI sales data provided an estimate of 16,320 additional economizers installed on HVAC systems with mechanical cooling capacities greater than 18,000 Btuh and less than 33,000 Btu in California.[42]

The California Energy Commission provided guidance on the type of prototype buildings that must be modeled. Nonresidential energy saving estimates are calculated using ASHRAE 90.1 prototypes for nonresidential buildings available in CBECC-Com EnergyPlus software. The Small Office, Medium Retail, and Small School CBECC-Com prototypes were used to calculate energy savings. Table 19 provides the details of each building prototype used in the analysis.

Table 19: Prototype buildings used for energy, demand, cost, and environmental impacts analysis

Prototype Name	Number of Stories	Floor Area (ft²)	Number of Stories	Statewide Area (million ft²)
Small Office	1	5,503	Office with 1 story, 5 zones with pitched roof and unconditioned attic. One RTU per zone with packaged cooling and no economizers.	8.4
Medium Retail	1	24,566	Retail building with 1 story, 4 zones, one RTU per zone with packaged cooling and economizers.	25.8
Small School	1	24,415	Small school building with 1 story, 11 zone primary school serving classrooms, offices, corridors, and cafeteria. One RTU per zone with packaged cooling and 9 of 11 zones have no economizers	10.0
TOTAL				**44.2**

The energy impacts of the proposed measures are climate specific and evaluated in each of the 16 climate zones. Energy savings, energy cost savings and peak demand savings were calculated on an hourly basis using a Time Dependent Valuation methodology.

The estimated energy and peak electricity demand savings are based on simulating the proposed code changes using the 2022 Research Version of the CBECC-Com. CBECC-Com generates two models based on user inputs: the standard design and the proposed design. The standard design represents the geometry of the design a builder would like to build and inserts a defined set of features that result in an energy budget that is minimally compliant with 2019 Title 24, Part 6 code requirements. Features used in the standard design are described in the 2019 Nonresidential ACM Reference Manual.

The proposed design represents the same geometry as the standard design, but assumes more energy efficient inputs based on the proposed code changes. Savings estimates for each prototypical building are based on the difference in energy and peak demand use between the standard design and specific inputs

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[42] Air-Conditioning, Heating, & Refrigeration Institute (AHRI). 2020. U.S. Manufacturers' Shipments of Central Air Conditioners and Air-Source Heat Pumps by BTUH http://www.ahrinet.org/resources/statistics/historical-data/central-air-conditioners-and-air-source-heat-pumps

for the proposed design. There is an existing Title 24, Part 6 requirement that covers the building system in question and applies to both new construction and alterations, so the standard design is minimally compliant with the 2019 Title 24 requirements. As indicated in Section 140.4(e) Economizers, each cooling air handler with a cooling capacity over 54,000 Btu/h shall include an air economizer capable of modulating outside air and return air dampers to supply 100 percent of the design supply air quantity as outside-air. However, providing 100 percent of the design supply airflow as outdoor airflow is not possible based on Intertek® tests of multiple HVAC economizers. Therefore, the maximum outdoor airflow for the standard design is reduced to 70.9% and the maximum outdoor airflow for the proposed design with economizer perimeter gap sealing is 70.2%.

The proposed design was identical to the standard design in all ways except for the revisions that represent the proposed changes to the code. Table 20 presents which parameters were modified and what values were used in the standard design and proposed design. Specifically, the proposed conditions assume a differential dry bulb economizer.

Comparing the difference between energy and peak demand impacts of the standard design versus the proposed design provides the energy impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

Table 20: Modifications made to standard design in each prototype to simulate proposed code change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
Small office	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 26.5%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 19.51%/70,2%
Small office	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small office	All	Economizer ≥ 18 kBtuh	No economizer operation	Fixed dry bulb economizer control
Medium retail	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 28.4%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 24.54%/70.2%
Medium retail	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small school	All	Economizer calibration perimeter gap seal	Unoccupied min OA: 21.3%; Occupied min/max OA: 32.5%/70.9%	Unoccupied min OA: 12.9%; occupied min/max OA: 34.5%/70.2%
Small school	All	FDD fan-on correction	24x7 fan operation	Occupancy-based fan control
Small school	All	Economizer ≥ 18 kBtuh	No economizer operation for 9 of 11 RTUs	Differential dry bulb economizer control 9 of 11

4.3 Per Unit Energy Impacts and Energy Savings Results

The proposed measure electricity and natural gas energy savings, peak demand savings, source energy, and TDV energy savings per square foot are presented in Table 21. Per unit savings for the first year are expected to be 1.10 to 1.24 kilowatt-hours per year (kWh/ft²-yr) and -0.004 to 0.10.028 therms/ ft²-year depending upon climate zone. Demand savings are expected to be 0.000001 to 0.000184 kilowatts (kW/ft²) depending upon climate zone. Savings increase for cooling-dominated climates as the economizer offsets mechanical cooling with outdoor air cooling during mild conditions. In all simulated prototypes and climate zones, the total TDV energy savings are positive ranging from 81.6 to 114.2 TDV kBtuh/ft²-yr. The proposed measure savings are positive in every climate zone.

Table 21: First year energy impacts per square foot (ft²)

Climate Zone	Electricity Savings (kWh/ ft²-yr)	Peak Electricity Demand Savings (kW/ft²)	Natural Gas Savings (therms/ft²-yr)	Source Energy Savings (kBtu/ft²-yr)	TDV Energy Savings (TDV kBtu/ ft²-yr)
1	1.24	0.000128	-0.004	12.91	81.6
2	1.17	0.000173	-0.002	12.39	82.9
3	1.24	0.000128	-0.004	12.91	81.6
4	1.17	0.000173	-0.002	12.39	82.9
5	1.24	0.000128	-0.004	12.91	81.6
6	1.20	0.000001	-0.002	12.80	82.1
7	1.20	0.000001	-0.002	12.80	82.1
8	1.20	0.000001	-0.002	12.80	82.1
9	1.20	0.000001	-0.002	12.80	82.1
10	1.10	0.000043	0.005	12.44	89.4
11	1.10	0.000043	0.005	12.44	89.4
12	1.10	0.000043	0.005	12.44	89.4
13	1.10	0.000043	0.005	12.44	89.4
14	1.14	0.000184	0.000	12.26	88.7
15	1.14	0.000184	0.000	12.26	88.7
16	1.10	0.000100	0.028	14.94	114.2

4.3.1 Percent Annual Energy Savings per Measure

The proposed package of code change measures saves energy on every HVAC End Use Intensity (EUI). Table 22 provides the percent annual energy savings summary per EUI for all the code change proposal measures. The statewide average savings are 6% for fan, 12% for space cooling, and 3% for space heating. Table 23 provides the percent energy savings per EUI for the economizer calibration and perimeter gap sealing measure with average savings of 0% for fan, -1% for space cooling, and 5% for space heating. Table 24 provides the percent energy savings per EUI for the FDD fan-on correction with average savings of 6% for fan, 0% for space cooling, and 2% for space heating. Table 25 provides the percent energy savings per EUI for the expand economizer requirements to 18 kBtuh measure with average savings of 0% for fan, 15% for space cooling, and -5% for space heating.

Economizer calibration and perimeter gap sealing cooling savings are -1% because the small school prototype OAF for the standard design is assumed to be 32.5% which is insufficient based on EnergyPlus OAF of 34.5% translated into 4.8V (0.345*8V+2V=4.8V) and entered into Equation 10.

Equation 10 $OAF_{sd} = 0.0037*(4.8)^2 + 0.0189*(4.8) + 0.1509 = 0.325$

The proposed design OAF is increased to 34.5% OAF based on Equation 11 using 6V actuator voltage to meet the ASHRAE 62.1 minimum design 34.5% OAF in the EnergyPlus small school prototype model.

Equation 11 $OAF_{pd} = 0.0043*(6)^2 + 0.0214*(6) + 0.0607 = 0.345$

Research studies indicate excess outdoor airflow is a common economizer fault (Jacobs 2003; Cowan 2004; Hart 2006; Mowris 2016; Heinemeier 2018). Excess outdoor airflow is caused by failed actuators or gears causing dampers to be stuck open or excess outdoor airflow caused by technicians using their fingers to set minimum damper positions too far open.

Table 26 provides sensitivity analysis of the percentage energy savings for economizer calibration and perimeter gap sealing assuming 40 to 50% more excess outdoor airflow for the standard design compared to Table 23. In Table 23 and Table 26, the proposed design minimum damper position OAF is 19.51% for small office, 24.54% for medium retail, and 34.5% for small school.[43] In Table 23, the standard design minimum damper position OAF is 26.5% (3.6V) for the small office, 28.4% OAF (4V) for the medium retail, and 32.5% (4.8V) for the small school. In Table 26 the standard design minimum damper position excess OAF is 39.8% (2-fingers or 6V) for the small office, 42.3% (2.5-fingers or 6.4V) for the medium retail, and 45.7% (3-fingers or 6.9V) for the small school. With 40 to 50% more excess outdoor airflow, the percentage energy savings for economizer calibration and perimeter gap sealing are -1% for fan, 2% for space cooling and 33% for space heating as shown in Table 26. The sensitivity analysis indicates that economizer calibration and perimeter gap sealing save space heating energy which will otherwise increase by 5% or more with the expand economizer requirements to 18 kBtuh measure. Table 23 shows that increasing OAF with calibration and perimeter gap sealing provides 1% cooling savings in climate zones 14 and 15. Table 26 shows that reducing excess OAF with calibration and perimeter gap sealing provides 2% cooling savings in climate zones 6 though 9 and 5% to 7% cooling energy savings in climate zones 10 through 15. Current CEC Standards, FDD requirements, and EnergyPlus models provide no information regarding how to properly install an economizer with calibration and perimeter gap sealing to verify proper minimum outdoor airflow and indoor air quality per ASHRAE 62.1.

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[43] Small office standard design OAF of 26.3% is reduced to proposed design OAF of 19.51%, medium retail standard design OAF of 28.4% is reduced to proposed design OAF of 24.54%, and small school standard design OAF of 32.5% is increased to proposed design OAF of 34.5%.

Table 22: Percentage energy savings for all code change proposal measures

Climate Zone	Fan End Use Intensity (EUI) annual savings (%)	Cooling End Use Intensity (EUI) annual savings (%)	Heating End Use Intensity (EUI) annual savings (%)
1	6%	37%	1%
2	6%	14%	2%
3	6%	37%	1%
4	6%	14%	2%
5	6%	37%	1%
6	6%	10%	1%
7	6%	10%	1%
8	6%	10%	1%
9	6%	10%	1%
10	6%	5%	5%
11	6%	5%	5%
12	6%	5%	5%
13	6%	5%	5%
14	5%	4%	3%
15	5%	4%	3%
16	6%	17%	7%
Average	**6%**	**12%**	**3%**

Table 23: Percentage energy savings for economizer calibration and perimeter gap sealing

Climate Zone	Fan End Use Intensity (EUI) annual savings (%)	Cooling End Use Intensity (EUI) annual savings (%)	Heating End Use Intensity (EUI) annual savings (%)
1	0%	-3%	4%
2	0%	-1%	4%
3	0%	-3%	4%
4	0%	-1%	4%
5	0%	-3%	4%
6	0%	-1%	5%
7	0%	-1%	5%
8	0%	-1%	5%
9	0%	-1%	5%
10	0%	0%	6%
11	0%	0%	6%
12	0%	0%	6%
13	0%	0%	6%
14	0%	1%	6%
15	0%	1%	6%
16	1%	-1%	7%
Average	**0%**	**-1%**	**5%**

Table 24: Percentage energy savings for FDD fan-on correction

Climate Zone	Fan End Use Intensity (EUI) annual savings (%)	Cooling End Use Intensity (EUI) annual savings (%)	Heating End Use Intensity (EUI) annual savings (%)
1	6%	0%	1%
2	6%	0%	2%
3	6%	0%	1%
4	6%	0%	2%
5	6%	0%	1%
6	6%	0%	2%
7	6%	0%	2%
8	6%	0%	2%
9	6%	0%	2%
10	6%	0%	2%
11	6%	0%	2%
12	6%	0%	2%
13	6%	0%	2%
14	5%	1%	3%
15	5%	1%	3%
16	5%	1%	1%
Average	**6%**	**0%**	**2%**

Table 25: Percentage energy savings for expand economizer requirements to 18 kBtuh

Climate Zone	Fan End Use Intensity (EUI) annual savings (%)	Cooling End Use Intensity (EUI) annual savings (%)	Heating End Use Intensity (EUI) annual savings (%)
1	0%	45%	-5%
2	0%	18%	-5%
3	0%	45%	-5%
4	0%	18%	-5%
5	0%	45%	-5%
6	0%	13%	-7%
7	0%	13%	-7%
8	0%	13%	-7%
9	0%	13%	-7%
10	0%	6%	-2%
11	0%	6%	-2%
12	0%	6%	-2%
13	0%	6%	-2%
14	0%	3%	-7%
15	0%	3%	-7%
16	0%	23%	-1%
Average	**0%**	**15%**	**-5%**

Table 26: Sensitivity analysis of percentage energy savings for economizer calibration and perimeter gap sealing where the standard design has 40 to 50% more excess outdoor airflow than the Table 23 standard design[44]

Climate Zone	Fan End Use Intensity (EUI) annual savings (%)	Cooling End Use Intensity (EUI) annual savings (%)	Heating End Use Intensity (EUI) annual savings (%)
1	0%	-4%	34%
2	-1%	1%	33%
3	0%	-4%	34%
4	-1%	1%	33%
5	0%	-4%	34%
6	-1%	2%	35%
7	-1%	2%	35%
8	-1%	2%	35%
9	-1%	2%	35%
10	-1%	5%	30%
11	-1%	5%	30%
12	-1%	5%	30%
13	-1%	5%	30%
14	-1%	7%	37%
15	-1%	7%	37%
16	0%	0%	27%
Average	**-1%**	**2%**	**33%**

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[44] Small office standard design excess OAF of 39.8% is reduced to proposed design OAF of 19.51%, medium retail standard design excess OAF of 42.3% is reduced to proposed design OAF of 24.54%, and small school standard design excess OAF of 45.7% is increased to proposed design OAF of 34.5%.

5. LIFE CYCLE COST AND COST-EFFECTIVENESS

5.1 Energy Cost Savings Methodology

Time Dependent Value (TDV) energy is a normalized format for comparing electricity and natural gas 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 and 15 year Effective Useful Life (EUL) for nonresidential measures. The TDV cost impacts are presented in 2023 present valued dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDVkBtus". Peak demand savings are presented in peak power reductions (kW). The Energy Commission provided the 2023 TDV values that were used in the analyses for this report (Energy Commission 2019).

The energy savings and peak electricity demand reductions resulting from the proposed measures are based on EnergyPlus building simulations using the CEC prototypes. Inputs for the economizer perimeter gap sealing are based on Intertek® laboratory tests. These benefits can be quantified using the Standards reference methods (e.g., CBECC-Com). No enhancements are required to perform the simulations.

5.2 Energy Cost Savings Results

The average estimated first year TDV energy cost savings are 2.7 $\$/ft^2$. The estimated 15-year TDV energy cost savings are 8.8 $\$/ft^2$. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 27: Annual TDV energy cost savings over 15 year period of analysis - per square foot (ft2)

Climate Zone	Annual 15 Year TDV Electricity Cost Savings (Nominal $/ft^2)	Annual 15 Year TDV Natural Gas Cost Savings (Nominal $/ft^2)	Total Annual 15 Year TDV Energy Cost Savings (Nominal $/ft^2)
1	$2.7	-$0.1	$2.6
2	$2.7	-$0.1	$2.7
3	$2.7	-$0.1	$2.6
4	$2.7	-$0.1	$2.7
5	$2.7	-$0.1	$2.6
6	$2.7	-$0.1	$2.7
7	$2.7	-$0.1	$2.7
8	$2.7	-$0.1	$2.7
9	$2.7	-$0.1	$2.7
10	$2.5	$0.2	$2.7
11	$2.5	$0.2	$2.7
12	$2.5	$0.2	$2.7
13	$2.5	$0.2	$2.7
14	$2.6	$0.0	$2.6
15	$2.6	$0.0	$2.6
16	$2.6	$0.8	$3.4
Average	**$2.7**	**$0.0**	**$2.7**

Table 28: TDV energy cost savings over 15 year period of analysis - per square foot (ft2)

Climate Zone	15 Year TDV Electricity Cost Savings (2023 PV $/ft²)	15 Year TDV Natural Gas Cost Savings (2023 PV $/ft²)	Total 15 Year TDV Energy Cost Savings (2023 PV $/ft²)
1	$8.8	($0.4)	$8.4
2	$8.9	($0.2)	$8.7
3	$8.8	($0.4)	$8.4
4	$8.9	($0.2)	$8.7
5	$8.8	($0.4)	$8.4
6	$8.9	($0.2)	$8.7
7	$8.9	($0.2)	$8.7
8	$8.9	($0.2)	$8.7
9	$8.9	($0.2)	$8.7
10	$8.3	$0.5	$8.8
11	$8.3	$0.5	$8.8
12	$8.3	$0.5	$8.8
13	$8.3	$0.5	$8.8
14	$8.7	($0.1)	$8.6
15	$8.7	($0.1)	$8.6
16	$8.5	$2.6	$11.1
Average	**$8.7**	**$0.1**	**$8.8**

5.3 Incremental First Cost

Verified® Inc. and Big Ladder Software estimated the Current Incremental Construction Costs and Post-adoption Incremental Construction Costs based on the CASE 2020 report, a CASE 2011 report, and actual costs of installing the proposed code change measures on nonresidential HVAC units.[45] The Current Incremental Construction Cost represents the incremental cost of the measure if a building meeting the proposed standard were built today. The Post-adoption Incremental Construction Cost represents the anticipated cost assuming full market penetration of the measure as a result of the new Standards, resulting in possible reduction in unit costs as manufacturing practices improve over time and

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[45] Verified® Inc. is a licensed C-20 HVAC contractor installing economizers, economizer calibration and perimeter gap sealing, and eFAN® economizer and fan controllers with FDD fan-on correction in California at nonresidential customer sites.

PECI and Taylor Engineering. 2011. CASE: Light Commercial Unitary, Codes and Standards Enhancement (CASE) Initiative. "Light Commercial Unitary." (CASE 2011) http://title24stakeholders.com/wp-content/uploads/2017/10/2013_CASE-Report_Light-Commercial-Unitary-HVAC.pdf.

with increased production volume of qualifying products the year the Standard becomes effective.

Per Energy Commission’s guidance, design costs are not included in the incremental first cost.

5.4 Lifetime Incremental Maintenance Costs

Incremental Maintenance Cost (IMC) is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the period of analysis. The present value of equipment and maintenance costs (savings) is calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2019 TDV. The present value of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate of 3 percent).

$$\textbf{Present Value of Maintenance Cost} = \textbf{Maintenance Cost x} \left[\frac{1}{1+d}\right]^{n}$$

The economizer IMC and Replacement Costs are based on a CASE 2011 report on Light Commercial Unitary HVAC authored by Portland Energy Conservation Inc. (PECI) and Taylor Engineering. The CASE 2011 report used data from PG&E’s AirCare Plus maintenance program to determine a 48% failure rate of economizers over a 15-year useful life of the equipment.[46] Maintenance or equipment replacement costs assume 48 percent of the IMC cost at the halfway point (7.5 years) of the useful life of 15 years, which provides a present value maintenance cost of $232 based on an economizer IMC of $760 per unit installed from the CASE 2020 report.[47]

$$\textbf{Economizer Replacement Cost} = \$292 = 0.48\ \text{x}\$760 \left[\frac{1}{1+0.03}\right]^{7.5}$$

The Statewide CASE Team worked with members of the Air-Conditioning Refrigeration & Heating Institute (AHRI) in July 2020 and August 2020 to develop a survey and obtain IMC information from AHRI members. Nine out of 34 manufacturers responded to the survey with cost information. The CASE 2020 report provides an economizer IMC of $760 and maintenance cost of $292 for total IMC of $1052. The IMC for the economizer perimeter gap sealing measure is

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[46] PECI and Traylor Engineering. 2011. CASE: Light Commercial Unitary, Codes and Standards Enhancement (CASE) Initiative. "Light Commercial Unitary." (CASE 2011) http://title24stakeholders.com/wp-content/uploads/2017/10/2013_CASE-Report_Light-Commercial-Unitary-HVAC.pdf.

[47] CASE 2011 report provides a maximum economizer IMC of $786 installed based on survey data from four manufacturers (see Figure 58, page 89).

$300 including installation with an assumed Effective Useful Life (EUL) of 15 years. The IMC for the FDD fan-on correction measure is $300 including installation with an assumed Effective Useful Life (EUL) of 15 years.[48] The incremental costs for the proposed code change measures are provided in the following table.

Table 29: Incremental cost for proposed code change measures

Measure	Measure Cost Including Installation	Maintenance Net Present Cost	Incremental Cost
Economizer calibration and perimeter gap sealing	$300		$300
FDD fan-on correction	$300		$300
Expand economizer requirements to 18 kBtuh	$760	$292	$1052

5.5 Lifecycle Cost-Effectiveness

This measure proposes a mandatory or prescriptive requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 15 year period of analysis.

Energy Commission's procedures for calculating lifecycle cost-effectiveness are documented in LCC Methodology. Big Ladder Software followed these guidelines when developing the cost-effectiveness analysis for this measure. Energy Commission's guidance dictated which costs were included in the analysis. 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 considered. The design cost was not included nor was the incremental cost of the code compliance verification.

According to 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 per unit lifecycle Cost-effectiveness Analyses are presented in the following tables. Table 30 provides the life-cycle cost-effectiveness summary for all code change proposal measures including: economizer perimeter gap sealing, FDD fan-on correction, and expand economizer requirements to 18 kBtuh. The weighted average benefit-cost ratio is 5.8.

Table 31 provides the life-cycle cost-effectiveness summary for the economizer calibration and perimeter gap sealing measure with a weighted average benefit-cost ratio of 2.7.

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[48] Walsh, J. 2020. Personal communication. IMC and EUL for patented economizer calibration and perimeter gap sealing measure and FDD fan-on correction measure include materials and labor for HVAC contractors to install the measures. August 5.

Table 32 provides the life-cycle cost-effectiveness summary for the FDD fan-on correction measure with a weighted average benefit-cost ratio of 20.7. Table 33 provides the life-cycle cost-effectiveness summary for the expand economizer requirements to 18,000 Btuh measure with a weighted average benefit-cost ratio of 1.8.

Verified® Inc. and Big Ladder Software found all of the proposed measures are cost-effective in every climate zone and all measures save money over the 15 year period of analysis relative to the existing conditions. As noted above, the proposed code changes are cost- effective in every climate zone with a weighted average benefit-cost ratio of 5.8.

Table 30: Life cycle cost-effectiveness summary per square foot (ft^2) for all code change proposal measures

Climate Zone	Benefit: TDV Energy Cost Savings[1] (2023 PV$/ft²)	Cost: Total Incremental First Cost and Maintenance Cost[2] (2023 PV$/ft²)	Planned Benefit to Cost (B/C) Ratio
1	$12.6	$2.3	5.6
2	$12.8	$2.3	5.7
3	$12.6	$2.3	5.6
4	$12.8	$2.3	5.7
5	$12.6	$2.3	5.6
6	$12.6	$2.3	5.6
7	$12.6	$2.3	5.6
8	$12.6	$2.3	5.6
9	$12.6	$2.3	5.6
10	$13.8	$2.3	6.1
11	$13.8	$2.3	6.1
12	$13.8	$2.3	6.1
13	$13.8	$2.3	6.1
14	$13.7	$2.3	6.1
15	$13.7	$2.3	6.1
16	$17.6	$2.3	7.8
Average	**$13.1**	**$2.3**	**5.8**

Table 31: Life cycle cost-effectiveness summary per square foot (ft2) for economizer calibration and perimeter gap sealing

Climate Zone	Benefit: TDV Energy Cost Savings[1] (2023 PV$/ft^2)	Cost: Total Incremental First Cost and Maintenance Cost[2] (2023 PV$/ft^2)	Planned Benefit to Cost (B/C) Ratio
1	$0.8	$0.5	1.7
2	$1.0	$0.5	2.1
3	$0.8	$0.5	1.7
4	$1.0	$0.5	2.1
5	$0.8	$0.5	1.7
6	$0.1	$0.5	0.1
7	$0.1	$0.5	0.1
8	$0.1	$0.5	0.1
9	$0.1	$0.5	0.1
10	$2.7	$0.5	5.8
11	$2.7	$0.5	5.8
12	$2.7	$0.5	5.8
13	$2.7	$0.5	5.8
14	$2.3	$0.5	5.1
15	$2.3	$0.5	5.1
16	$6.3	$0.5	13.8
Average	**$1.2**	**$0.5**	**2.7**

Table 32: Life cycle cost-effectiveness summary per square foot (ft2) for FDD fan-on correction

Climate Zone	Benefit: TDV Energy Cost Savings[1] (2023 PV$/ft^2)	Cost: Total Incremental First Cost and Maintenance Cost[2] (2023 PV$/ft^2)	Planned Benefit to Cost (B/C) Ratio
1	$8.6	$0.5	18.8
2	$9.3	$0.5	20.3
3	$8.6	$0.5	18.8
4	$9.3	$0.5	20.3
5	$8.6	$0.5	18.8
6	$9.3	$0.5	20.4
7	$9.3	$0.5	20.4
8	$9.3	$0.5	20.4
9	$9.3	$0.5	20.4
10	$9.9	$0.5	21.6
11	$9.9	$0.5	21.6
12	$9.9	$0.5	21.6
13	$9.9	$0.5	21.6
14	$9.7	$0.5	21.2
15	$9.7	$0.5	21.2
16	$9.7	$0.5	21.2
Average	**$9.4**	**$0.5**	**20.7**

Table 33: Life cycle cost-effectiveness summary per square foot (ft2) for expand economizer requirements to 18,000 Btuh

Climate Zone	Benefit: TDV Energy Cost Savings[1] (2023 PV$/ft²)	Cost: Total Incremental First Cost and Maintenance Cost[2] (2023 PV$/ft²)	Planned Benefit to Cost (B/C) Ratio
1	$3.2	$1.3	2.4
2	$2.5	$1.3	1.9
3	$3.2	$1.3	2.4
4	$2.5	$1.3	1.9
5	$3.2	$1.3	2.4
6	$3.3	$1.3	2.4
7	$3.3	$1.3	2.4
8	$3.3	$1.3	2.4
9	$3.3	$1.3	2.4
10	$1.2	$1.3	0.9
11	$1.2	$1.3	0.9
12	$1.2	$1.3	0.9
13	$1.2	$1.3	0.9
14	$1.7	$1.3	1.2
15	$1.7	$1.3	1.2
16	$1.6	$1.3	1.2
Average	**$2.4**	**$1.3**	**1.8**

1. **TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (see http://docketpublic.energy.ca.gov/PublicDocuments/16-BSTD-06/TN212524_20160801T120224_2019_TDV_Methodology_Report_7222016.pdf, Chapter 5 pages 51-53). Other savings are discounted at a real 3% rate. Includes incremental first cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.
2. **Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Present value cost = Current cost x (1/(1.03)^n). Costs are discounted by 3% real 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 Benefit/Cost Ratio is Infinite.

6. FIRST YEAR STATEWIDE IMPACTS

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

Big Ladder Software calculated the first year statewide savings by multiplying the per unit savings, which are presented in Section 4.3 Per Unit Energy Impacts and Energy Savings Results, by the statewide new construction forecast for 2023, which is presented in more detail in Appendix A: Statewide Savings Methodology. The first year energy impacts represent the first year annual savings from all buildings that were completed in 2023. The lifecycle energy cost savings represents the energy cost savings over the entire 30-year period of analysis. Results are presented in Table 34.

Given data regarding the new construction forecast for 2023, Big Ladder Software estimates that the proposed code change will reduce annual statewide electricity use by 31.4 GWh with an associated demand reduction of 0.42 MW. Natural gas use is expected to be reduced by 0.29 million therms. The energy savings for buildings constructed in 2023 are associated with a Present Valued (PV) energy cost savings of approximately PV $16.35 million in (discounted) energy costs over the 15-year period of analysis.

Table 34: Statewide energy and energy cost impacts

Climate Zone	Statewide Construction in 2023 (million sq ft)	First Year[1] Electricity Savings (GWh)	First Year[1] Peak Electrical Demand Reduction (MW)	First Year[1] Natural Gas Savings (million therms)	First Year[1] Source Energy Savings (kBtu/sq ft)	Lifecycle[2] Present Valued Energy Cost Savings (PV$ million)
1	0.2	0.2	0.01	0.00	9	$0.08
2	1.1	0.9	0.05	0.00	9	$0.44
3	4.8	3.7	0.17	0.02	9	$1.88
4	2.4	1.8	0.10	0.01	8	$0.90
5	0.5	0.4	0.02	0.00	9	$0.20
6	3.3	2.2	-0.01	0.01	7	$1.09
7	3.0	2.4	0.00	0.01	9	$1.19
8	4.7	3.0	-0.02	0.01	7	$1.49
9	7.1	4.2	-0.01	0.02	7	$2.11
10	5.1	3.7	0.00	0.07	9	$2.02
11	1.2	1.0	0.00	0.02	10	$0.52
12	6.0	4.3	0.03	0.08	9	$2.38
13	2.5	2.1	0.00	0.03	10	$1.12
14	1.1	0.9	0.02	0.00	9	$0.43
15	0.8	0.6	0.02	0.00	9	$0.31
16	0.4	0.3	0.03	0.01	12	$0.19
TOTAL	**44.1**	**31.4**	**0.42**	**0.29**	**142.2**	**$16.35**

1. First year savings from all buildings completed statewide in 2023.
2. Energy cost savings from all buildings completed statewide in 2023 accrued during 30-year period of analysis.

6.2 Statewide Greenhouse Gas Emissions Reductions

Big Ladder Software calculated avoided greenhouse gas (GHG) emissions assuming the emissions factors specified in the USEPA Emissions & Generation Resource Integrated Database (eGRID) for the WECC California (CAMX) subregion. The electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020.[49] Avoided GHG emissions from natural gas savings

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[49] When evaluating the impact of increasing the Renewable Portfolio Standard (RPS) from 20 percent renewables by 2020 to 33 percent renewables by 2020, California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The incremental emissions

attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in the USEPA Compilation of Air Pollutant Emissions Factors (AP-42).

Table 35 presents an estimated first year statewide avoided greenhouse gas emissions (GHG) emissions due to the proposed code change of 9,132 million metric tons of carbon dioxide equivalents (MMTCO$_2$e).

Table 35: First year statewide greenhouse gas emissions impacts

Measure	Electricity Savings (GWh/yr)	Reduced GHG Emissions from Electricity Savings (MMT CO$_2$e)	Natural Gas Savings (Million Therm/yr)	Reduced GHG Emissions form Natural Gas Savings (MMT CO$_2$e)	Total Reduced CO2e Emissions[2] (MMT CO$_2$e)
Economizer calibration and perimeter gap sealing	0.3	71	0.3	1,655	1,726
FDD fan-on correction	22.3	5,352	0.1	604	5,956
Expand economizer Requirement to 18 kBtuh	8.9	2,131	(0.1)	(680)	1,451
TOTAL	**31.4**	**7,554**	**0.3**	**1,578**	**9,132**

1. First year savings from all buildings completed statewide in 2023.
2. Assumes the following emission factors: 240.36 MTCO2e/GWh and 5454.4 MTCO2e/Million Therms.

6.3 Statewide Water Use Impacts

The proposed code change will not result in water savings,

6.4 Statewide Material Impacts

Table 36 provides the statewide impacts of material use for the proposed code change. The expand economizer requirements to 18,000 Btu/hr measure would increase the amount of steel required for economizers by 1,060,605 pounds per year based on approximately 16,317 units/year for each prototype and climate zone combination that would require economizers (that previously did not). The average weight of an economizer is 65 pounds based on a range of 50 to 85 pounds per economizer depending on the mechanical cooling capacity and manufacturer data.[50] The economizer perimeter gap sealing measure would increase the amount of UL-181 aluminum metal tape required to seal the economizer perimeter gap by 2,350 pounds based on 0.144 pounds per

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were calculated by dividing the difference between California emissions in the CARB high and low generation forecasts by the difference between total electricity generated in those two scenarios.

[50] Trane. 2006. Trane Product Catalog. Page 145 of 439. Weight is for economizer model BAYECON. See https://api.ferguson.com/dar-step-service/Query?ASSET_ID=4551620&USE_TYPE=PARTS&PRODUCT_ID=2838000

economizer and 1.8 pounds per 2.5" x 1800" roll and average length of tape per economizer of 144 inches.[51]

Table 36: Impacts of material use

	Impact on Material Use Material Increase (I), Decrease (D), or No Change (NC) Compared to Base Case (lbs/year)					
	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others (Aluminum Metal Tape)**
Impact (I, D, or NC)	NC	NC	NC	I	NC	I
Per Unit Impacts (lbs/sq ft)				0.02405		0.000053
First Year[1] Statewide Impacts (lbs)				1,060,605		2,350

1. First year savings from all buildings completed statewide in 2023.

6.5 Other Non-Energy Impacts

The proposed code change would improve Indoor air quality specifically improving control and quantity of outdoor airflow during occupied hours to help reduce the impact of pandemics such as COVID-19. ASHRAE recommends increasing outdoor ventilation by opening outdoor air dampers to 100% during the COVID-19 pandemic.[52] Increasing outdoor airflow and improving indoor air quality is important for schools and classrooms and business with mechanical cooling capacities less than 54,000 Btu/hr and greater than 18,000 Btu/hr. Improved indoor air quality will provide health and safety benefits, productivity, and/or increased property valuation.

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 2019 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

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[51] Duck Brand 675590 HVAC UL 181A-P Listed Foil Tape for Rigid Ducts, 2.5-Inch by 50 Yards, Single Roll, Silver. 1.8 pounds per roll. See https://www.amazon.com/Duck-675590-181A-P-Listed-2-5-Inch/dp/B0025KUSUU.

[52] ASHRAE. 2020. ASHRAE EPIDEMIC TASK FORCE. Page 13 of 55. https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-healthcare-c19-guidance.pdf. Schoen, L., 2020. Guidance for Building Operations During the COVID-19 Pandemic. https://www.ashrae.org/file%20library/technical%20resources/ashrae%20journal/2020journaldocuments/72-74_ieq_schoen.pdf.

7.1 Standards

SECTION 110.2 – MANDATORY REQUIREMENTS FOR SPACE-CONDITIONING EQUIPMENT

(sections omitted)

(c) Thermostats. All heating or cooling systems not controlled by a central energy management control system (EMCS) shall have a setback thermostat and a Fault Detection Diagnostic (FDD) fan-on correction control capability to detect, report a fan-on alarm message, and override a continuous fan-on duration setting when the space is unoccupied.

1. Setback Capabilities. All thermostats shall have a clock mechanism that allows the building occupant to program the temperature setpoints for at least four periods within 24 hours. Thermostats for heat pumps shall meet the requirements of Section 110.2(b).

2. FDD fan-on correction control capabilities. All thermostats shall have a FDD fan-on correction control capability to detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user and automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied.

SECTION 120.2 – REQUIRE CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Subsection 120.2(e) Shut-off and Reset Controls for Space-conditioning Systems. Each space-conditioning system shall be installed with controls that comply with the following:

1. The control shall be capable of automatically shutting off the system and/or the ventilation fan when the building is unoccupied or during periods of nonuse and shall have:

A. An automatic time switch control device complying with Section 110.9, with an accessible manual override that allows operation of the system for up to 4 hours; or

B. An occupancy sensor; or

C. A 4-hour timer that can be manually operated with a Fault Detection Diagnostic (FDD) fan-on correction control to detect and override a continuous fan-on duration setting when the space is unoccupied; or

D. A FDD fan-on correction control to detect and override a continuous fan-on duration setting when the space is unoccupied.

(sections omitted)

(i)Economizer Fault Detection and Diagnostics (FDD). All newly installed air handlers with a mechanical cooling capacity greater than ~~54,000~~ or equal to 18.000 Btu/hr and an installed air economizer shall include: 1) a stand-alone or integrated Fault Detection and Diagnostics (FDD) system in accordance with Subsections 120.2(i)1 through 120.2(i)8, 2) the economizer perimeter gap shall be sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number.

Revise Section 102.2(i) section (i) (i) Economizer Fault Detection and Diagnostics (FDD) (page 144) subsection 7 (page 145).

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[[,]];

F. Economizer perimeter gap has not sealed; and

G. Economizer minimum damper position has not been calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

SECTION 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

A building complies with this section by being designed with and having constructed and installed a space-conditioning system that meets the applicable requirements of Subsections (a) through (o).

(sections omitted)

(c) Fan Systems. Each fan system having a total fan system motor nameplate horsepower exceeding 5 hp used for space conditioning shall meet the requirements of Items 1, 2, and 3 below. Total fan system power demand equals the sum of the power demand of all fans in the system that are required to operate at design conditions in order to supply air from the heating or cooling source to the conditioned space, and to return it back to the source or to exhaust it to the outdoors. All fan systems shall be controlled by a thermostat that has a FDD fan-on correction control capability to detect and override a continuous fan-on duration setting when the conditioned space is unoccupied.

(sections omitted)

(e) Economizers.

1. Each cooling air handler that has a design total mechanical cooling capacity ~~over 54,000~~ greater than or equal to 18.000 Btu/hr, or chilled-water cooling

systems without a fan or that use induced airflow that has a cooling capacity greater than the systems listed in Table 140.4-C, shall include either:

A. An air economizer capable of modulating outside-air and return-air dampers to supply ~~100 percent~~ as much as possible of the design supply air quantity as outside-air when the dampers are fully open, and the economizer perimeter gap between the economizer frame and the cabinet shall be sealed with a UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and the economizer minimum damper position must be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy; or

B. A water economizer capable of providing ~~100 percent~~ as much as possible of the expected system cooling load when the dampers are fully open, at outside air temperatures of 50°F dry-bulb and 45°F wet-bulb and below and the economizer minimum damper position must be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy when the building is occupied and the outside air temperatures are greater than 50°F dry-bulb and 45°F wet-bulb.

EXCEPTION 1 to Section 140.4(e)1: Where special outside air filtration and treatment, for the reduction and treatment of unusual outdoor contaminants, makes compliance infeasible.

EXCEPTION 2 to Section 140.4(e)1: Where the use of outdoor air for cooling will affect other systems, such as humidification, dehumidification, or supermarket refrigeration systems, so as to increase overall building TDV energy use.

EXCEPTION 3 to Section 140.4(e)1: Systems serving high-rise residential living quarters and hotel/motel guest rooms.

EXCEPTION 4 to Section 140.4(e)1: Where comfort cooling systems have the cooling efficiency that meets or exceeds the cooling efficiency improvement requirements in TABLE 140.4-D.

EXCEPTION 5 to Section 140.4(e)1: Fan systems primarily serving computer rooms. See Section 140.9(a) for computer room economizer requirements.

7.2 Reference Appendices

Appendix JA5 – Technical Specifications For Occupant Controlled Smart Thermostats

(sections omitted)

JA5.2 Required Functional Specifications

JA5.2.1 Setback Capabilities

An OCST shall meet the requirements of Section 110.2(c) including a FDD fan-on correction control capability to detect and override a continuous fan-on duration setting when the conditioned space is unoccupied. Thermostats for heat pumps shall also meet the requirements of Section 110.2(b).

(sections omitted)

JA5.2.6 Required Functional Behavior

(sections omitted)

(c) FDD fan-on correction control capabilities. All thermostats shall have a FDD fan-on correction control capability to detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied.

Appendix JA6 – HVAC System Fault Detection and Diagnostic Technology

(sections omitted)

JA6.1.6.1.3 Parameters Measured

The following parameters shall be measured:

(sections omitted)

(i) fan-on duration (minutes).

(j) building occupancy (minutes).

(sections omitted)

JA6.1.6.3 System Fault Indication

(sections omitted)

JA6.1.6.2.4 Continuous Fan-On Duration Fault

The FDD fan-on duration fault shall detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a continuous fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied.

JA6.3 Economizer Fault Detection and Diagnostics Certification Submittal Requirements

Title 24, Part 6, Section 120.2(i) requires that economizer FDD functions be installed on air-cooled unitary air conditioning systems with an air handler mechanical cooling capacity ~~over 54,000~~ greater than or equal to 18.000 Btu/hr cooling capacity, with the ability to detect the faults specified in Section 120.2(i). The FDD functions shall include: 1) verification that the economizer perimeter gap is sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, 2) verification that the economizer minimum damper position is calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy, and 3) FDD fan-on correction capabilities to detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a continuous fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied. 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.

JA6.3.1 Information that shall be included with the Declaration

(sections omitted)

(c) The controller is capable of providing system status by indicating the following:

(sections omitted)

vii. Supply fan is operating continuously when the conditioned space is unoccupied.

viii. Economizer perimeter gap has been sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and the economizer minimum damper position is calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

(sections omitted)

Evidence: Laboratory test: describe how the mode is simulated and the wording used to indicate the status.

(sections omitted)

(d) The unit controller is capable of manually initiating each operating mode so that the operation of compressors, economizers, fans, and heating system, if applicable, can be independently tested and verified. Evidence: Photocopy of controller manual showing instructions for manually initiating each operating mode and instructions for the installation technician to seal the economizer perimeter gap with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and instructions for the installation technician or an automatic method to verify that the economizer minimum damper position is calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

(sections omitted)

(f) The unit control is capable of detecting the following faults:

i. Air temperature sensor failure/fault.

ii. Not economizing when it should.

iii. Economizing when it should not.

iv. Damper not modulating.

v. Excess outdoor air.

vi. Economizer perimeter gap has not been verified or reported as sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number.

vii. Economizer minimum damper position has not been calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

viii. Supply fan is operating continuously when the conditioned space is unoccupied.

Nonresidential Appendices

Appendix NA7 – Installation and Acceptance Requirements for Nonresidential Buildings and Covered Processes

(sections omitted)

NA7.5 Mechanical Systems Acceptance Tests

(sections omitted)

NA7.5.1.1.2 Functional Testing

Step 0: If the system has an outdoor air economizer, verify the economizer perimeter gap is sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and verify the economizer minimum damper position is calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

(sections omitted)

NA7.5.1.1.2 Functional Testing

(sections omitted)

Step 4: With the supply fan control setting operating the fan continuously and no thermostat call for heating or thermostat call for cooling, disconnect the occupancy sensor signal from the HVAC system terminal block or economizer and verify the supply fan turns off, and then reconnect the occupancy sensor signal and verify the supply fan turns on continuously again.

~~Step 4~~ Step 5: Restore system to "as-found" operating conditions

7.3 ACM Reference Manual

5.7.2.2 Schedules

(tables with no changes are omitted)

Air Handler Fan Cycling	
Applicability	All fan systems
Definition	This building descriptor indicates whether the system supply fan operates continuously or cycles with building loads when the HVAC schedule indicates the building is occupied. (See night cycle control input for fan operation during unoccupied hours.) The fan systems in most commercial buildings operate continuously, and the FDD fan-on correction capability detects a continuous fan-on duration setting when the space is unoccupied and reports a fan-on alarm message to a user including a message to cancel or confirm a continuous fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied.
Units	List continuous or cycles with loads
Input Restrictions	As designed if the HVAC system serves zones with a dedicated outside air source for ventilation; otherwise, continuous.
Standard Design	For healthcare facilities, same as the proposed design. For all others, Cycles with loads for FPFC and SZAC systems; continuous for all other standard design system types.
Standard Design: Existing Buildings	

(tables with no changes are omitted)

5.7.4 Outdoor Air Controls and Economizers

5.7.4.1 Outside Air Controls

Maximum and Minimum Outside Air Ratio	
Applicability	All systems with modulating outside air dampers
Definition	The descriptor is used to limit the maximum amount of outside air that a system can provide as a percentage of the design supply air. It is used where the installation has a restricted intake capacity.
Units	Ratio
Input Restrictions	Maximum ~~1.0~~ 0.69 for all systems ~~above 54,000~~ greater than or equal to 18,000 Btu/h cooling capacity; 0.9 for other systems. Unoccupied minimum outside air ratio closed position 0.13 for all systems
Standard Design	Maximum ~~1.0~~ 0.69 for all systems ~~above 54,000~~ greater than or equal to 18,000 Btu/h cooling capacity; ~~0.9~~ 0.69 for other systems Unoccupied minimum outside air ratio closed position not greater than 0.13 for all systems and economizer perimeter gap between the economizer frame and the cabinet shall be sealed with a UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number.
Standard Design: Existing Buildings	Maximum ~~1.0~~ 0.70 for all systems ~~above 54,000~~ greater than or equal to 18,000 Btu/h cooling capacity; ~~0.9~~ 0.70 for other systems Unoccupied minimum outside air ratio closed position not greater than 0.218 for all systems

(tables with no changes are omitted)

5.7.4.2 Air Side Economizers

Economizer Control Type	
Applicability	All systems with an air-side economizer
Definition	An air-side economizer increases outside air ventilation during periods when system cooling loads can be reduced from increased outside air flow. The control types include: • No economizer. • Fixed dry-bulb. The economizer is enabled when the temperature of the outside air is equal to or lower than temperature fixed setpoint (e.g., 75°F). • Differential dry-bulb. The economizer is enabled when the temperature of the outside air is lower than the return air temperature. • Differential enthalpy. The economizer is enabled when the enthalpy of the outside air is lower than the return

Economizer Control Type	
	air enthalpy. • Differential dry-bulb and enthalpy. The system shifts to ~~100~~ at least 70 percent outside air or the maximum outside air position needed to maintain the cooling SAT setpoint, when the outside air dry-bulb is less than the return air dry-bulb AND the outside air enthalpy is less than the return air enthalpy. This control option requires additional sensors. • Economizer minimum damper position when the building is occupied must be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.
Units	List (see above)
Input Restrictions	As designed
Standard Design	For healthcare facilities, same as the proposed design. For all others, The control should be no economizer when the standard design total cooling capacity < ~~54,000~~ 18,000 Btu/h and when the standard design cooling system is not a computer room air handling unit (CRAH). Otherwise, the standard design shall assume an integrated differential dry-bulb economizer. An exception is that economizers shall not be modeled for systems serving high-rise residential or hotel/motel guestroom occupancies.
Standard Design: Existing Buildings	

Economizer Integration Level	
Applicability	Airside economizers
Definition	This input specifies whether or not the economizer is integrated with mechanical cooling. It is up to the modeling software to translate this into software-specific inputs to model this feature. The input could take the following values: • Non-integrated - The system runs the economizer as the first stage of cooling. When the economizer is unable to meet the load, the economizer returns the outside air damper to the minimum position and the compressor turns on as the second stage of cooling. • Integrated - The system can operate with the economizer fully open to outside air and mechanical cooling active (compressor running) simultaneously, even on the lowest cooling stage.
Units	List (see above)

Economizer Integration Level	
Input Restrictions	List non-integrated or integrated
Standard Design	For healthcare facilities, same as the proposed design. For all others, integrated for systems above capacity ~~54,000~~ 18,000 Btu/h at Air-Conditioning, Heating, and Refrigeration Institute (AHRI) conditions
Standard Design: Existing Buildings	

7.4 Compliance Manuals

Chapter 4 – Mechanical of the 2019 Nonresidential Compliance Manual would need to be revised.

Section 4.5.2.2 Economizers would need to be updated in three locations. First, to describe the change in the economizer requirement threshold from 54,000 Btu/h to 18,000 Btu/h. Second, to require economizer perimeter gap sealing between the system cabinet and the economizer frame and the economizer minimum damper position must be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy and the economizer must be calibrated to within plus or minus 5% of the ASHRAE 62.1 standard for the building occupancy. Third, to require the Occupant Controlled Smart Thermostats (OCST) include FDD fan-on correction capability to detect a continuous fan-on duration setting when the space is unoccupied and report a fan-on alarm message to a user including a message to cancel or confirm a fan-on duration control and capability to automatically override the continuous fan-on duration setting to turn off the fan when the space is unoccupied and enable the fan-on duration control setting to turn on the supply fan when the space is occupied, alarm message, and reporting.

7.5 Compliance Forms

Chapter 4 – Mechanical of the 2019 Nonresidential Compliance Manual would need to be revised.

Section 4.5.1.1.1.13 Economizer Fault Detection Diagnostics

Change Economizer Fault Detection and Diagnostics (FDD) is a mandatory requirement for all newly installed air handlers with a mechanical cooling capacity greater than ~~54,000~~ 18,000 Btu/hr and an air economizer.

e. Excess outdoor air. This failure occurs when the economizer provides an excessive level of ventilation, usually much higher than is needed for design minimum ventilation due to excess outdoor airflow due to an improper damper position or economizer perimeter gap leakage. It causes an energy penalty during periods when the economizer should not be enabled (during cooling mode when outdoor conditions are higher than the economizer high limit set point). During heating mode, excess outdoor air will increase heating energy.

f. FDD system must have an entry indicating the economizer perimeter gap is sealed and when economizer is shipped the manufacturer must provide UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and the FDD system must be able to verify the economizer minimum damper position is calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

Section 4.5.1.1.1.18

§140.4(e).

An economizer must be fully integrated and must be provided for each individual cooling air handler system. It must have a total mechanical cooling capacity over ~~54,000~~ 18,000 Btu/h, a chilled water-cooling system without a fan, or a chilled water-cooling system that uses induced airflow. It must also have a cooling capacity greater than the systems listed in Table 4-17. The economizer may be either:

1. An air economizer capable of modulating outside air and return air dampers to supply ~~all~~ as much as possible of the design supply air quantity as outside air and the economizer perimeter gap must be sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number, and the economizer controller must be capable of verifying that the economizer minimum damper position can be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy;

D. Air Economizer Construction

§140.4(e)2D

3. Economizer outside air and return air dampers shall have a maximum leakage rate of 10 cfm/sq ft at 250 Pascals (1.0 in. w.g) when tested in accordance with AMCA Standard 500-D. The leakage rates for the outside and return dampers shall be certified to the Energy Commission in accordance with §110.0. The economizer perimeter gap must be sealed with UL-181 metal tape or other UL-listed material manufactured, licensed and/or approved by GreenFan Inc. where the UL-181 metal tape or UL-listed material are marked with a US patent number 9,671,125 or other pending US patent number licensed by GreenFan Inc., and the economizer controller must be capable of verifying that the economizer minimum damper position can be calibrated to within plus or minus 5% of the ASHRAE 62.1 minimum outdoor airflow for the building occupancy.

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APPENDICES

Appendix A: Statewide Savings Methodology

First-year statewide energy and peak savings are calculated by multiplying the EnergyPlus prototypical building level energy and peak demand savings based on the difference between the standard design and the proposed code change design times the statewide construction estimates for the first year the proposed standards would be effective in year 2023. The projected floorspace of new construction and altered nonresidential buildings that would be impacted by each proposed code change in 2023 is presented in Table **38**.

The CEC Demand Analysis Office provided the nonresidential new construction forecast for 2023, which is available on the CEC website at: https://www.energy.ca.gov/title24/participation.html.

Table 37: provides a complete description of space types used in the nonresidential new construction forecast (not types are used in this report). Table 38 provides the percent of impacted floorspace by building type for each of the code change proposal measures including: 1) economizer perimeter gap sealing, 2) FDD fan-on correction, and 3) expand economizer requirements to 18 kBtuh. Due to time and budget constraints, the analysis provided in this CASE report is limited to three prototypes (small school, medium retail, and small office). Therefore, the statewide energy and peak demand savings provided in this CASE report are conservative. The economizer perimeter gap sealing measure and the FDD fan-on correction measure are applicable to all building types which would increase the statewide savings of the code change proposal.

Table 38 Translation from Forecast Climate Zone (FCZ) to Building Climate Zone (BCZ) with FCZ along the X-axis and BCZ along the Y-axis. Table 40 provides CEC data of the total estimated nonresidential new construction floor space in 2023 by Climate Zone (CZ) and building type (million square feet).

Table 37: Description of space types used in the nonresidential new construction forecast

Building Prototype	**Description**
OFF-SMALL	Offices less than 30,000 ft^2
OFF-LRG	Offices larger than 30,000 ft^2
REST	Any facility that serves food
RETAIL	Retail stores and shopping centers
FOOD	Any service facility that sells food and or liquor
NWHSE	Nonrefrigerated warehouses
RWHSE	Refrigerated Warehouses
SCHOOL	Schools K-12, not including colleges
COLLEGE	Colleges, universities, community colleges
HOSP	Hospitals and other health-related facilities
HOTEL	Hotels and motels
MISC	All other space types that do not fit another category

Table 38: Percent of impacted floorspace by building type (new construction)

Building Type **Building sub-type**	**Prototype** **Model**	**Economizer Perimeter Gap Sealing**	**FDD Fan-on Correction**	**Expand Economizer to 18 kBtuh**
Small Office	OfficeSmall	100%	100%	100%
Large Offices	N/A			
Large Office	OfficeMedium	0%	0%	0%
Large Office	OfficeLarge	0%	0%	0%
Restaurant	RestaurantFastFood	0%	0%	0%
Retail	RETAIL			
Retail	*RetailStandAlone*	100%	100%	100%
Retail	*RetailLarge*	100%	100%	0%
Retail	*RetailMedium*	100%	100%	0%
Retail	*RetailStripMall*	100%	100%	100%
Retail	*RetailMixedUse*	100%	100%	100%
Grocery	FOOD	0%	0%	0%
Non-Refrig Warehouse	NWHSE	0%	0%	0%
Refrig Warehouse	RWHSE	0%	0%	0%
Schools	SCHOOL			
School	*SchoolPrimary*	100%	100%	100%
School	*SchoolSecondary*	100%	100%	100%
College	COLLEGE	0%	0%	0%
College	*OfficeSmall*	0%	0%	0%
College	*OfficeMedium*	0%	0%	0%
College	*OfficeMediumLab*	0%	0%	0%
College	*PublicAssembly*	0%	0%	0%
College	*SchoolSecondary*	0%	0%	0%
College	*ApartmentHighRise*	0%	0%	0%
Hospital	HOSP	0%	0%	0%
Hotel/motel	HotelSmall	0%	0%	0%

Table 39: Translation from FCZ to BCZ

Forecast zones along X-axis, climate zones along Y-axis

	0	1	2	3	4	5	6
1	17.90%	0.00%	13.51%	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	80.20%	0.00%	0.00%	0.00%	0.00%
3	0.00%	52.43%	6.28%	0.00%	3.64%	0.00%	52.26%
4	0.00%	30.39%	0.00%	0.00%	0.00%	0.00%	15.39%
5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	32.33%
6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
9	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
11	0.42%	0.00%	0.00%	84.77%	22.07%	0.00%	0.00%
12	0.00%	17.18%	0.00%	0.00%	72.61%	4.55%	0.00%
13	0.00%	0.00%	0.00%	0.00%	0.00%	94.81%	0.00%
14	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
15	3.18%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
16	78.50%	0.00%	0.01%	15.23%	1.68%	0.64%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 39: Translation from FCZ to BCZ (cont.)

Forecast zones along X-axis, climate zones along Y-axis

	7	8	9	10	11	12	13
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
5	0.00%	0.18%	0.00%	0.00%	0.00%	0.00%	0.00%
6	18.89%	61.19%	0.00%	0.00%	0.00%	6.60%	0.00%
7	0.00%	0.00%	0.00%	0.00%	0.00%	62.81%	0.00%
8	43.99%	0.00%	0.00%	0.00%	0.00%	1.94%	0.00%
9	32.29%	37.22%	0.00%	0.00%	0.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	71.19%	86.11%	27.88%	0.00%
11	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.42%
12	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	99.58%
13	0.00%	0.00%	78.49%	0.00%	0.00%	0.00%	0.00%
14	4.51%	0.00%	12.10%	24.17%	0.00%	0.66%	0.00%
15	0.00%	0.00%	0.00%	0.10%	13.33%	0.12%	0.00%
16	0.33%	1.41%	9.41%	4.55%	0.56%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 39: Translation from FCZ to BCZ (cont.)

Forecast zones along X-axis, climate zones along Y-axis

	14	15	16	17	18	19	20
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	17.18%	0.00%	0.00%	0.00%	0.00%
7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	27.90%	0.00%	0.00%	0.00%	0.00%
9	0.00%	0.00%	54.92%	99.35%	100.00%	0.00%	0.00%
10	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
11	0.00%	44.55%	0.00%	0.00%	0.00%	0.00%	0.00%
12	100.00%	52.65%	0.00%	0.00%	0.00%	0.00%	0.00%
13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
14	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%
15	0.00%	0.00%	0.00%	0.00%	0.00%	99.98%	0.00%
16	0.00%	2.61%	0.00%	0.65%	0.00%	0.00%	100.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 40: Estimated new nonresidential construction in 2023 by Climate Zone (CZ) and building type (Million square feet)

Climate Zone	Small Office	Large Office	Restaurant	Retail	Grocery	Non-Refrig. Warehouse
CZ 1	0.035175679	0.114797092	0.015379671	0.105887256	0.028460539	0.077259841
CZ 2	0.209022613	0.681621566	0.091362485	0.628999777	0.169099564	0.459149381
CZ 3	0.744038483	3.84212879	0.375165837	2.874726862	0.707800043	2.381855334
CZ 4	0.371969234	2.016253088	0.191394041	1.473399101	0.35899845	1.223486071
CZ 5	0.081298635	0.352725792	0.039001705	0.298227991	0.075593021	0.227281805
CZ 6	0.558138383	2.756426756	0.3800881	2.101335062	0.530878465	1.879997722
CZ 7	0.772988876	1.550141896	0.24806473	1.482067296	0.445073286	1.1082226
CZ 8	0.732204995	4.126620956	0.548342207	3.016191618	0.749164113	2.70201865
CZ 9	1.177502719	7.6788254	0.922433768	4.715759812	1.152329445	4.322036636
CZ 10	0.985711895	1.508027947	0.650791893	2.823354783	0.779888816	3.441195004
CZ 11	0.269042391	0.322487964	0.087931169	0.582022642	0.192766995	0.636824843
CZ 12	1.409103395	3.215716027	0.412343265	3.170179704	0.824079044	3.186690674
CZ 13	0.574557079	0.494845784	0.190763258	1.218458015	0.409627114	1.087092988
CZ 14	0.192726772	0.519041463	0.143149606	0.668169197	0.176125064	0.739574393
CZ 15	0.188980329	0.157913275	0.071415598	0.384238626	0.129441391	0.540421347
CZ 16	0.078110511	0.133203774	0.041232214	0.211890727	0.061880138	0.224714437
Total	8.380571988	29.47077757	4.408859548	25.75490847	6.79120549	24.23782173

Source: Energy Commission Demand Analysis Office

Table 40: Estimated new nonresidential construction in 2023 by Climate Zone and building type (Million square feet) (Continued)

Climate Zone	Refrigerated Warehouse	Schools	Colleges	Hospitals	Hotel/Motels	Miscellaneous
CZ 1	0.006231054	0.04870007	0.026546969	0.036211927	0.041751313	0.141552663
CZ 2	0.037054174	0.289356793	0.157689232	0.21513154	0.247947981	0.840814991
CZ 3	0.188952222	1.18067699	0.686909604	0.926748956	1.137828895	3.902283704
CZ 4	0.095815086	0.599111674	0.352071955	0.472184558	0.58754426	2.005538066
CZ 5	0.01927542	0.123822888	0.070626718	0.098480811	0.114362194	0.397779333
CZ 6	0.066772083	0.664616851	0.372107159	0.493892702	0.696703576	2.274822727
CZ 7	0.012656057	0.712507276	0.327665594	0.540321717	0.749614881	1.71981507
CZ 8	0.096477602	0.912297864	0.525479391	0.7235149	0.965376588	3.29775223
CZ 9	0.14203058	1.229060799	1.002011619	1.316951125	1.488419716	5.294852785
CZ 10	0.085550445	1.24915386	0.494491624	0.701735466	0.815201147	3.534685651
CZ 11	0.072258626	0.332905257	0.138454675	0.220068516	0.164340971	0.731782204
CZ 12	0.24290583	1.399892443	0.640806471	1.035311599	0.971757296	3.756807791
CZ 13	0.187033625	0.7254288	0.27364938	0.457269252	0.307314035	1.518142169
CZ 14	0.029889473	0.258330693	0.107431586	0.152382005	0.17852401	0.804140631
CZ 15	0.017321534	0.180968942	0.047201487	0.087358084	0.134416492	0.466390385
CZ 16	0.019073779	0.099407927	0.03977503	0.059863326	0.054606776	0.262363905
Total	1.319297591	10.00623913	5.262918496	7.537426482	8.655710133	30.94952431

Source: Energy Commission Demand Analysis Office

Appendix B: Embedded Electricity in Water Methodology

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

Appendix C: Environmental Impacts Methodology

Greenhouse Gas Emissions Impacts Methodology

Avoided GHG emissions are calculated assuming the emissions factors specified in the USEPA Emissions & Generation Resource Integrated Database (eGRID) for the WECC California (CAMX) subregion[53]. This ensures consistency between state and federal estimations of potential environmental impacts.

To be conservative, the emissions factors are calculated based on the incremental cost factors of electricity between the low and high load scenarios. These emission factors are intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario. The incremental emissions were calculated by dividing the difference between California emissions in the high and low generation forecasts by the difference between total electricity generated in those two scenarios.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in the USEPA Compilation of Air Pollutant Emissions Factors (AP-42).[54]

Greenhouse Gas Emissions Monetization Methodology

The 2022 TDV cost values used in the LCC Methodology includes the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs) and the Cost-effectiveness Analysis presented in Section 5 of this report does include the cost savings from avoided GHG emissions. To demonstrate the cost savings of avoided GHG emissions, the authors disaggregated value of avoided GHG emissions from the other economic impacts. The authors used the same monetary values that are used in the TDV factors – \$106.2/MTCO_2e.

Water Use and Water Quality Impacts Methodology

There are no impacts to water quality or water use.

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

Technical Basis for Software Change: Economizer Calibration and Perimeter Gap Sealing

The current standard design specifies: 1) 0% Outdoor Air Fraction (OAF) at the closed position when the building is unoccupied, 2) 15% to 38% OAF at the

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[53] https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

[54] https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors

ASHRAE 62.1 minimum damper position depending on building occupancy, and 3) 100% OAF when economizing. The proposed design under the code change proposal for economizer calibration and economizer perimeter gap sealing established in Section 3.3 reduces the following OAF values based on Intertek® test data. The standard design closed damper position (2V) provides 21.3% OAF with an unsealed perimeter gap, compared to 12.9% OAF with sealed perimeter gap. Intertek® test data shows the minimum damper position varies from 26.5% to 32.5% depending on building occupancy with unsealed perimeter gap compared to 19.54% to 34.5% OAF for the sealed perimeter gap. The fully open damper position (10V) provides 70.9% OAF with unsealed perimeter gap compared to 70.2% OAF for the sealed perimeter gap. Sealing the perimeter gap significantly reduces unintended excess outdoor airflow at the closed or minimum damper positions, but only reduces the OAF by -0.4 to +3% when the damper is fully open. The average Intertek® test data are used in the EnergyPlus simulations for calculating energy and peak demand impacts for the economizer perimeter gap sealing code change proposal. The EnergyPlus input variable adjusts the Minimum Fraction of Outdoor schedule to simulate the performance of these systems.

Description of Software Change: Economizer Calibration and Perimeter Gap Sealing

Background Information for Software Change

This report describes how the economizer calibration and perimeter gap sealing measure can be implemented in CBECC-Com for an airside economizer.

Existing CBECC-Com Modeling Capabilities

CBECC-Com currently models the standard design for each air-side economizer with a design OAF as follows: 1) 0% Outdoor Air Fraction (OAF) at the closed position when the building is unoccupied, 2) assumed minimum OAF of: 19.5% (small office), 24.5% (medium retail), and 34.6% (small school) (or other OAF depending on building occupancy), and 3) 100% OAF when economizing. Section 4 provides Intertek® tests of four economizers tested on three packaged RTUs indicating that these OAF assumptions are incorrect. Based on Intertek® tests, the actual minimum OAF values are: 26.5% (small office), 28.4% (medium retail), and 32.5% (small school) due to uncalibrated and unsealed economizer perimeter gap.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 3.3 including primary building types, space types, climate zones, or systems that are predominantly affected by the measure. CBECC-Com would need to be modified to adjust the standard design to higher OAF values per the OAF schedule and the proposed design would adjust to lower OAF values per the OAF schedule. Based on Intertek® tests the proposed revisions to the CBECC-Com EnergyPlus prototypes will be achievable based on the following ASHRAE 62.1 minimum OAF values based on occupancy: 19.5% (small office), 24.5% (medium retail), and 34.6% (small school) for calibrated economizer with sealed perimeter gap (or other OAF depending on building occupancy).

User Inputs to CBECC-Com: Economizer Calibration and Perimeter Gap Sealing

Changes noted above to the OAF schedule for the standard design and the proposed design would be required.

Simulation Engine Inputs: Economizer Calibration and Perimeter Gap Sealing

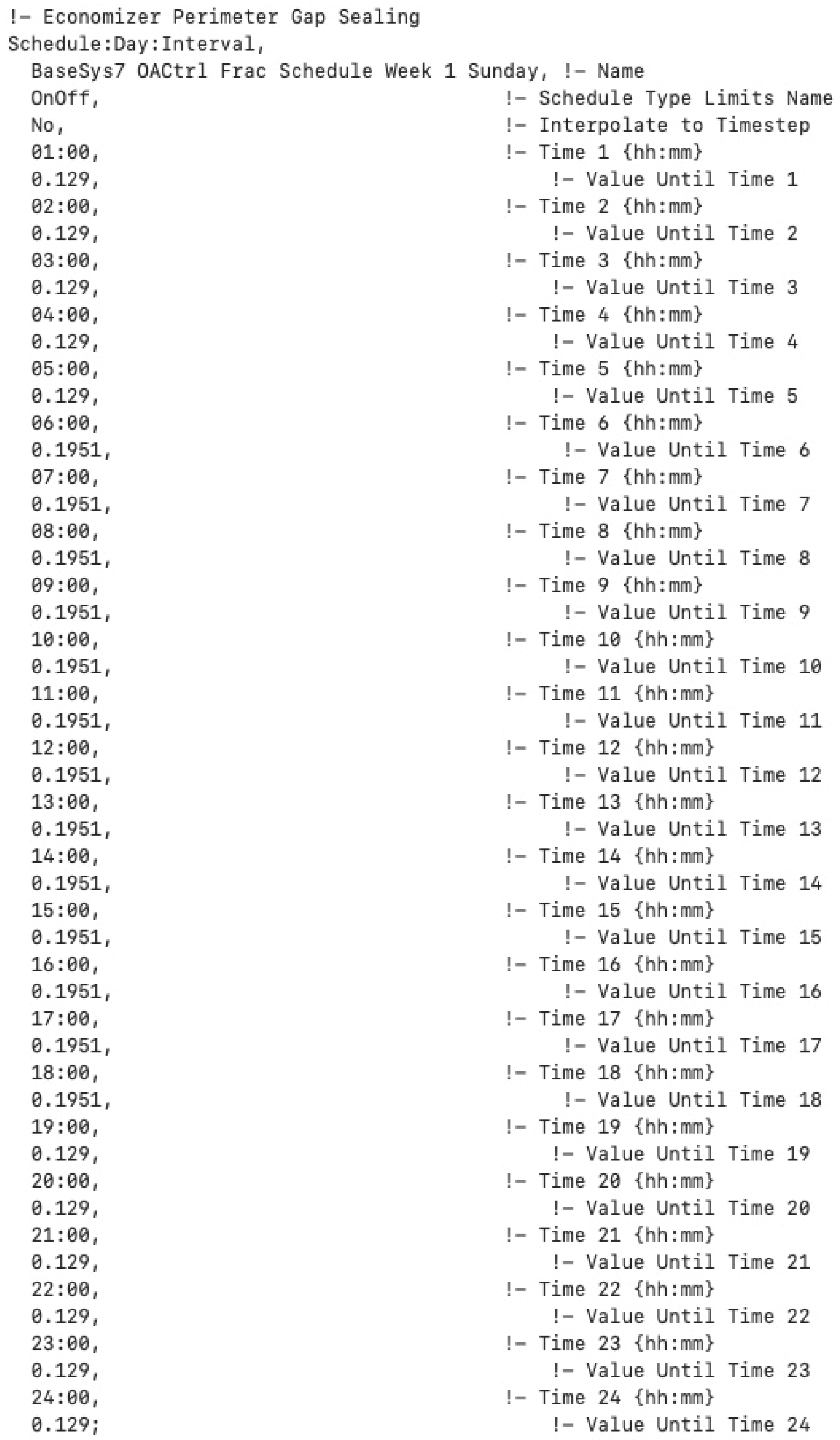
EnergyPlus/California Simulation Engine Inputs

Table **41** summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the BaseSys7 OACtrl object (see Figure 7).

Table 41: EnergyPlus input variables for economizer calibration and perimeter gap sealing

EnergyPlus Class = Controller:OutdoorAir (Minimum Fraction OA Schedule)			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Minimum Fraction of Outdoor Air Schedule Name		None	Update schedule values to reflect sealing

Figure 7 provides the EnergyPlus Input Data File (IDF) information used to model the economizer calibration and perimeter gap sealing measure for the proposed design for the small office prototype.



```
!- Economizer Perimeter Gap Sealing
Schedule:Day:Interval,
  BaseSys7 OACtrl Frac Schedule Week 1 Sunday, !- Name
  OnOff,                                  !- Schedule Type Limits Name
  No,                                     !- Interpolate to Timestep
  01:00,                                  !- Time 1 {hh:mm}
  0.129,                                      !- Value Until Time 1
  02:00,                                  !- Time 2 {hh:mm}
  0.129,                                      !- Value Until Time 2
  03:00,                                  !- Time 3 {hh:mm}
  0.129,                                      !- Value Until Time 3
  04:00,                                  !- Time 4 {hh:mm}
  0.129,                                      !- Value Until Time 4
  05:00,                                  !- Time 5 {hh:mm}
  0.129,                                      !- Value Until Time 5
  06:00,                                  !- Time 6 {hh:mm}
  0.1951,                                      !- Value Until Time 6
  07:00,                                  !- Time 7 {hh:mm}
  0.1951,                                      !- Value Until Time 7
  08:00,                                  !- Time 8 {hh:mm}
  0.1951,                                      !- Value Until Time 8
  09:00,                                  !- Time 9 {hh:mm}
  0.1951,                                      !- Value Until Time 9
  10:00,                                  !- Time 10 {hh:mm}
  0.1951,                                      !- Value Until Time 10
  11:00,                                  !- Time 11 {hh:mm}
  0.1951,                                      !- Value Until Time 11
  12:00,                                  !- Time 12 {hh:mm}
  0.1951,                                      !- Value Until Time 12
  13:00,                                  !- Time 13 {hh:mm}
  0.1951,                                      !- Value Until Time 13
  14:00,                                  !- Time 14 {hh:mm}
  0.1951,                                      !- Value Until Time 14
  15:00,                                  !- Time 15 {hh:mm}
  0.1951,                                      !- Value Until Time 15
  16:00,                                  !- Time 16 {hh:mm}
  0.1951,                                      !- Value Until Time 16
  17:00,                                  !- Time 17 {hh:mm}
  0.1951,                                      !- Value Until Time 17
  18:00,                                  !- Time 18 {hh:mm}
  0.1951,                                      !- Value Until Time 18
  19:00,                                  !- Time 19 {hh:mm}
  0.129,                                      !- Value Until Time 19
  20:00,                                  !- Time 20 {hh:mm}
  0.129,                                      !- Value Until Time 20
  21:00,                                  !- Time 21 {hh:mm}
  0.129,                                      !- Value Until Time 21
  22:00,                                  !- Time 22 {hh:mm}
  0.129,                                      !- Value Until Time 22
  23:00,                                  !- Time 23 {hh:mm}
  0.129,                                      !- Value Until Time 23
  24:00,                                  !- Time 24 {hh:mm}
  0.129;                                      !- Value Until Time 24
```

Figure 7: Minimum fraction OA schedule referenced by Controller:OutdoorAir for economizer calibration and perimeter gap sealing (e.g., SmallOffice)

Technical Basis for Software Change: FDD Fan-on Correction

The current standard design specifies continuous fan-on duration when the building is occupied or unoccupied periods or assumes the fan is turned off when the building is unoccupied. Section 4 provides research findings from evaluation studies indicating that assumptions regarding fans being turned off during unoccupied periods are incorrect (DNVGL 2016; Jacobs & Higgins 2003). The new proposed design under the code change proposal for FDD fan-on correction provides continuous fan-on operation during occupied periods and turns off the fans during unoccupied periods using the fan schedule. The EnergyPlus software inputs properly models the Smart Efficient Fan Controller® with FDD fan-on correction algorithms or smart thermostats licensed to upload or include the patented FDD fan-on correction software algorithms.

Description of Software Change: FDD Fan-on Correction

Background Information for Software Change

This report describes how the FDD fan-on correction measure can be implemented in CBECC-Com for a HVAC system with an airside economizer.

Existing CBECC-Com Modeling Capabilities

CBECC-Com currently models the standard design with the fan schedule being on fan-on continuously when the building is occupied or unoccupied or assumes the fan is turned off when the building is unoccupied (which isn't correct for 13 to 78% of nonresidential buildings). The proposed design under the code change proposal for FDD fan-on correction provides a schedule of continuous fan-on operation during occupied periods and turns off the fans during unoccupied periods using the fan schedule.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 3.3 including primary building types, space types, climate zones, or systems that are predominantly affected by the measure. CBECC-Com would need to be modified to adjust the standard design to continuous fan-on operation per the fan schedule and the proposed design would adjust the fan schedule to turn off the fan when the building is unoccupied. The proposed design allows the thermostat schedules to operate the fan for a call for cooling or heating.

User Inputs to CBECC-Com: FDD Fan-on Correction

Changes noted above to the OAF schedule for the standard design and the proposed design would be required.

Simulation Engine Inputs: FDD Fan-on Correction

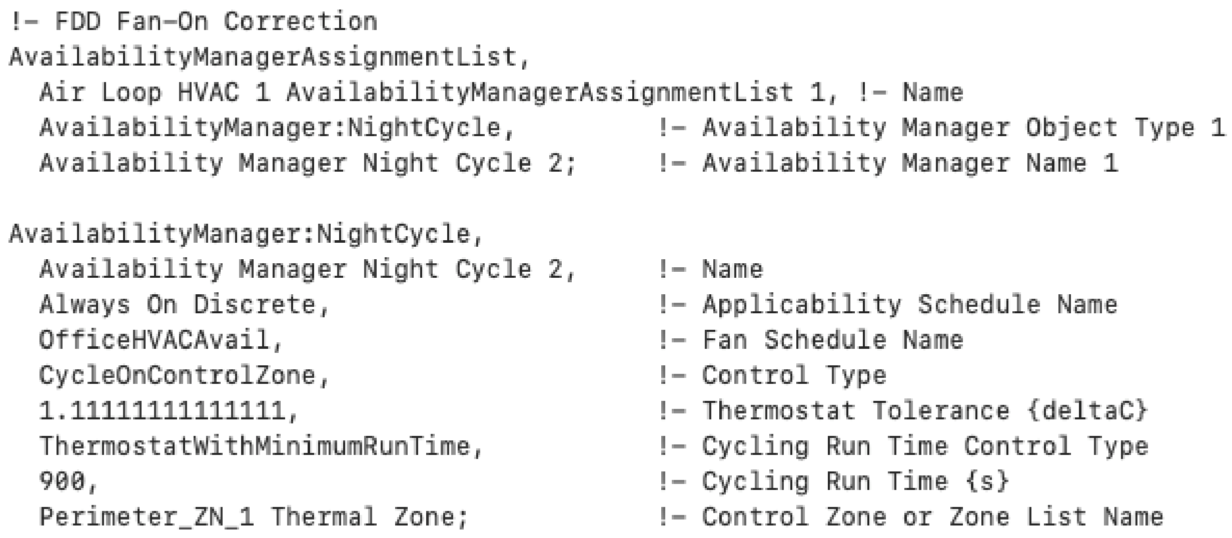
EnergyPlus/California Simulation Engine Inputs

Table 41 summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the AvailabilityManagerAssignmentList object (see Figure 8).

Table 42: EnergyPlus input variables for FDD fan-on correction

EnergyPlus Class = AvailabilityManagerAssignmentList			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Availability Manager Object Type		None	Switch from Scheduled (24x7) to NightCycle
Availability Manager Name		None	
EnergyPlus Class = AvailabilityManager:NightCycle			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Fan Schedule Name		None	Follow HVAC operation schedule

Figure 8 provides the EnergyPlus Input Data File (IDF) information used to model the FDD fan-on correction measure for the proposed design for the small office prototype.



```
!- FDD Fan-On Correction
AvailabilityManagerAssignmentList,
  Air Loop HVAC 1 AvailabilityManagerAssignmentList 1, !- Name
  AvailabilityManager:NightCycle,         !- Availability Manager Object Type 1
  Availability Manager Night Cycle 2;     !- Availability Manager Name 1

AvailabilityManager:NightCycle,
  Availability Manager Night Cycle 2,     !- Name
  Always On Discrete,                     !- Applicability Schedule Name
  OfficeHVACAvail,                        !- Fan Schedule Name
  CycleOnControlZone,                     !- Control Type
  1.11111111111111,                       !- Thermostat Tolerance {deltaC}
  ThermostatWithMinimumRunTime,           !- Cycling Run Time Control Type
  900,                                    !- Cycling Run Time {s}
  Perimeter_ZN_1 Thermal Zone;            !- Control Zone or Zone List Name
```

Figure 8: AvailabilityManagerAssignmentList for FDD fan-on correction

Technical Basis for Software Change: Expand Economizer Requirements to 18 kBtuh

An air-side economizer is a mature technology in commercial settings as described in Section 3.2. The current standard design specifies the threshold of 54,000 Btu/h to require an air-side economizer for each cooling air handler. The new prescriptive criteria for air-side economizer established in Section 3.3 reduces the threshold from 54,000 Btu/h to 18,000 Btu/hr, and outlines other key variables needed to simulate the performance of these systems in energy modeling software.

Description of Software Change: Expand Economizer Requirements to 18 kBtuh

Background Information for Software Change

This report describes how the lower cooling capacity can be implemented in CBECC-Com for an airside economizer.

Existing CBECC-Com Modeling Capabilities

CBECC-Com currently models the standard design air-side economizer with a design total mechanical cooling capacity over 54,000 Btu/h for each cooling air handler.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 3.3 including primary building types, space types, climate zones, or systems that are predominantly affected by the measure. CBECC-Com would need to be modified to adjust the standard design air-side economizer threshold to be 18,000 Btu/h.

User Inputs to CBECC-Com: Expand Economizer Requirements to 18 kBtuh

No changes to user inputs are needed to support this measure.

Simulation Engine Inputs: Expand Economizer Requirements to 18 kBtuh

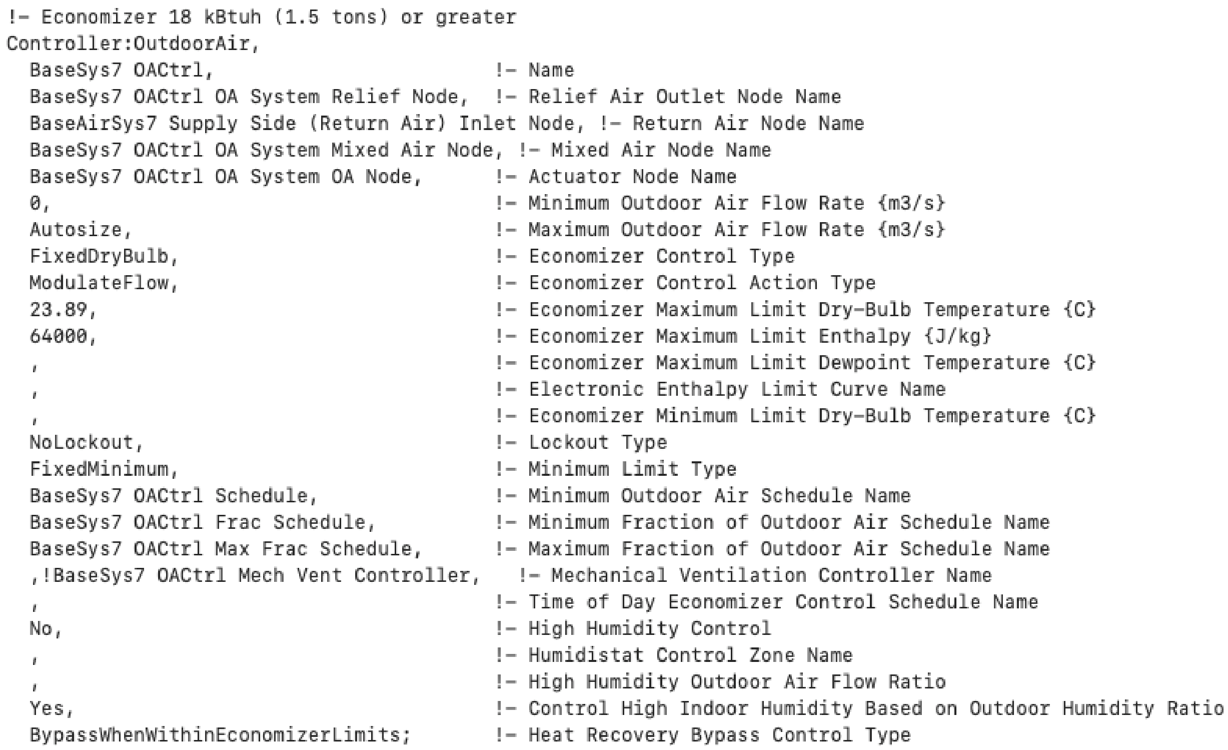
EnergyPlus/California Simulation Engine Inputs

Table **41** summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the BaseSys7 OACtrl object (Figure 9).

Table 43: EnergyPlus input variables for expand economizer requirements to 18 kBtuh

EnergyPlus Class = Controller:OutdoorAir			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Economizer Controller Type	Control Method	None	

Figure 9 provides the EnergyPlus Input Data File (IDF) information used to model the expand economizer requirements to 18 kBtuh measure for the proposed design for the small office prototype.



```
!- Economizer 18 kBtuh (1.5 tons) or greater
Controller:OutdoorAir,
  BaseSys7 OACtrl,                          !- Name
  BaseSys7 OACtrl OA System Relief Node,  !- Relief Air Outlet Node Name
  BaseAirSys7 Supply Side (Return Air) Inlet Node, !- Return Air Node Name
  BaseSys7 OACtrl OA System Mixed Air Node, !- Mixed Air Node Name
  BaseSys7 OACtrl OA System OA Node,      !- Actuator Node Name
  0,                                        !- Minimum Outdoor Air Flow Rate {m3/s}
  Autosize,                                 !- Maximum Outdoor Air Flow Rate {m3/s}
  FixedDryBulb,                             !- Economizer Control Type
  ModulateFlow,                             !- Economizer Control Action Type
  23.89,                                    !- Economizer Maximum Limit Dry-Bulb Temperature {C}
  64000,                                    !- Economizer Maximum Limit Enthalpy {J/kg}
  ,                                         !- Economizer Maximum Limit Dewpoint Temperature {C}
  ,                                         !- Electronic Enthalpy Limit Curve Name
  ,                                         !- Economizer Minimum Limit Dry-Bulb Temperature {C}
  NoLockout,                                !- Lockout Type
  FixedMinimum,                             !- Minimum Limit Type
  BaseSys7 OACtrl Schedule,                 !- Minimum Outdoor Air Schedule Name
  BaseSys7 OACtrl Frac Schedule,            !- Minimum Fraction of Outdoor Air Schedule Name
  BaseSys7 OACtrl Max Frac Schedule,        !- Maximum Fraction of Outdoor Air Schedule Name
  ,!BaseSys7 OACtrl Mech Vent Controller,     !- Mechanical Ventilation Controller Name
  ,                                         !- Time of Day Economizer Control Schedule Name
  No,                                       !- High Humidity Control
  ,                                         !- Humidistat Control Zone Name
  ,                                         !- High Humidity Outdoor Air Flow Ratio
  Yes,                                      !- Control High Indoor Humidity Based on Outdoor Humidity Ratio
  BypassWhenWithinEconomizerLimits;         !- Heat Recovery Bypass Control Type
```

Figure 9: Controller:OutdoorAir input for expand economizer requirements to 18,000 Btuh