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Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code

Nonresidential HVAC Controls

2022-NR-HVAC4-D **|** Nonresidential HVAC **|** September 2020 FINAL CASE REPORT

Prepared by Energy Solutions and Red Car Analytics

Please send comments to info@title24stakeholders.com.

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Executive Summary

This document presents recommended code changes that the California Energy Commission will be considering for adoption in 2021. If you have comments or suggestions prior to the adoption, please email info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared.

Introduction

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The overall goal of this Final CASE Report is to present a code change proposal for nonresidential HVAC Controls. The report contains pertinent information supporting the code change.

Measure Description

Background Information

VAV Deadband Airflow

The proposed code changes would modify existing prescriptive requirements that specify airflow rates when variable air volume (VAV) zones are in deadband operation.

Deadband operation is defined as a temperature range where the heating, ventilation, and air conditioning (HVAC) system is neither calling for cooling or heating.[1] In California, the maximum allowable zone airflow during deadband operation is the larger of 20 percent of peak primary airflow or the design minimum outdoor airflow rate as determined in accordance with Section 120.1(c)3. This proposed change would reduce complexity by eliminating the requirement to consider 20 percent of peak primary airflow. The maximum airflow rate during deadband operation would simply be equal to the design minimum outdoor airflow rate. Depending on occupancy types, this would result in a decrease in airflow during deadband operation for most of the prototype buildings and climate zones as 20 percent of peak primary airflow is typically greater than design minimum outdoor airflow rates. The revisions would apply to all buildings that use VAV systems for new construction, additions, and alterations. Because of the lower airflow rate and less fan heat during deadband operation, fan and cooling energy consumptions will decrease but heating energy consumption will increase.

Expand Economizer Requirements

This measure would modify the existing prescriptive requirements for economizers by including economizers on smaller capacity units with corresponding requirements for fault detection diagnostics (FDD). Economizers are a proven measure in California and save energy by taking advantage of the mild California climate to increasing the amount of free cooling. The proposed code changes would modify existing prescriptive requirements in Section 140.4 applicable to nonresidential HVAC equipment.

Dedicated Outdoor Air Systems (DOAS)

Dedicated outdoor air systems (DOAS) have high potential to reduce HVAC energy usage in nonresidential buildings and are also a key solution for all-electric buildings. They are used in a majority of California nonresidential net zero energy projects. Also, DOAS are become increasingly popular in California and nationwide because they offer more flexibility for designers and building owners. Title 24, Part 6 does not currently have a clear definition or prescriptive requirements for DOAS. The proposed code changes would generate cost-effective energy savings, help protect consumers, and support state goals to move towards carbon neutral buildings. The proposed code changes would add a prescriptive section to Section 140.4 specifically for all nonresidential DOAS.

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[1] Section 100.1(b) of Title 24, Part 6 includes the following definition of deadband, “DEADBAND is the temperature range within which the HVAC system is neither calling for heating or cooling.”

Exhaust Air Heat Recovery

This measure would implement new requirements for exhaust air heat recovery for systems that meet criteria of outdoor air fraction, climate zone, design flow rate, and hours of operation. The requirements are designed based on similar requirements from Section 6.5.6 of ASHRAE Standard 90.1 (2019) which has included requirements for Exhaust Air Heat Recovery since 2004. The requirements partially align with standard 90.1 but have been updated to be applicable for California's climates and the state of the market.

Proposed Code Change

VAV Deadband Airflow

This measure would amend the existing prescriptive requirement for zone airflow rates in Section 140.4(d) by specifying that the primary airflow in the deadband to be the design ventilation airflow, which would align with recent changes to ASHRAE Standard 90.1 (2019). This measure would impact both new and existing buildings which utilize variable air volume HVAC systems.

Expand Economizer Requirements

This measure would incorporate two changes to the existing prescriptive requirements for economizers in Section 140.4 (e). This would impact new construction as well as major alterations and additions when a new HVAC unit is installed. These requirements would include the following:

1. Reduce economizing threshold from current level of 54,000 Btu/h to 33,000 Btu/h
2. Modify wording within Table 140.4-D to align with proposed changes in ASHRAE 90.1
3. Incorporate an exception to exempt systems from economizer requirements if an area meets the new dedicated outside air system prescriptive requirements.

Dedicated Outdoor Air Systems (DOAS)

This measure would add prescriptive requirements to DOAS when used as the primary source of ventilation in nonresidential buildings to include a minimum level of efficiency criteria and control capabilities and an exception to economizing. This would impact primarily new construction though would also cover all major alterations and additions when a new HVAC system was installed of this type in existing buildings.

A DOAS in this context is defined as a HVAC system which delivers 100 percent ventilation air separately from any heating and cooling system.

This would apply to all DOAS being used as a buildings primary means of ventilation of any size in a nonresidential application. The efficiency criteria include:

1. Providing each space with either:
    1. A separate cooling system with an economizer or
    2. A DOAS unit with minimum level of sensible energy recovery ratio, demand control ventilation when above 1,000 cfm, and with bypass capabilities for ventilation economizing.
2. DOAS unit fan systems shall have the ability to modulate fan speed, primarily for balancing and reducing operation fan power.
3. Zone terminal fans for cooling or heating must cycle to off if no call for conditioning.
4. Ventilation supply air shall be delivered directly to a space or downstream of a terminal unit cooling or heating coil.
5. DX-DOAS or DOAS with active cooling must have a maximum reheat limit of 60F when in cooling mode.
6. A total system fan power in line with prescriptive fan power tables in 140.4 (c).

Exhaust Air Heat Recovery

This measure would add new prescriptive requirements for exhaust air heat recovery requirements in California. The requirements are based on similar requirements from ASHRAE Standard 90.1 which take into account climate zone, design airflow rate, percent of outdoor air, and hours of operation but are modified for California's 16 climate zones and utilize a sensible recovery ratio rather than an enthalpy recovery ratio as the performance metric needed for devices. The proposal also adopts several related exemptions from the ASHRAE Standard 90.1 on exhaust air energy recovery, Section 6.5.6.1.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents that would be modified as a result of the proposed change(s).

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)
VAV Deadband Airflow	Prescriptive	140.4(d)	No changes	Yes	NRCC-MCH-E NRCC-PRF-E
Expand Economizer Requirements	Mandatory/ Prescriptive	120.2(i): FDD 140.4(e)1	JA6.3	Yes	NRCC-MCH-E NRCC-PRF-E
Dedicated Outdoor Air Systems (DOAS)	Prescriptive	140.4 (p) (new section)	No changes	Yes	NR MECH Acceptance Test modifications
Exhaust Air Heat Recovery	Prescriptive	140.4 (p) (new section)	NA7.5.4	Yes	NRCC-MCH-E NRCC-PRF-E

Market Analysis and Regulatory Assessment

This proposal updates Title 24, Part 6 prescriptive requirements for HVAC controls in four separate proposals as outlined above. The measures utilize recent industry research and incorporate proven energy savings measures. The proposal requires the use of building technologies which are widely available on the market and offered by several manufacturers. Implementation of these measures will lean on the pre-existing stakeholder groups to implement and known approaches.

The VAV deadband airflow measure incorporates recent changes adopted by the latest version of ASHRAE Standard 90.1. Expand economizer requirements measure builds upon previous economizer requirements and natural growth in the market to extend to lower capacity units. DOAS measure develops prescriptive requirements for systems that have already been installed for many years using the performance pathway. Exhaust air heat recovery measure developed climate-specific requirements to utilize heat recovery in air handlers which have been utilized in other climates under ASHRAE Standard 90.1.

Cost Effectiveness

The proposed code changes were found to be cost effective for all climate zones where it is proposed to be required. The benefit-to-cost (B/C) ratio compares the benefits or cost savings to the costs over a 15-year period of analysis. Proposed code changes that have a B/C ratio of 1.0 or greater are cost effective. The larger the B/C ratio, the faster the measure pays for itself from energy cost savings. The B/C ratio for these measures vary significantly across the climate zones. See Section 3.4/4.4/5.4 for the methodology, assumptions, and results of the cost-effectiveness analysis.

Statewide Energy Impacts: Energy, Water, and Greenhouse Gas (GHG) Emissions Impacts

Table 2 presents the estimated energy and demand impacts of the proposed code change that will be realized statewide during the first 12 months that the 2022 Title 24, Part 6 requirements are in effect. First-year statewide energy impacts are represented by the following metrics: electricity savings in gigawatt-hours per year (GWh/yr), peak electrical demand reduction in megawatts (MW), natural gas savings in million therms per year (MMTherms/yr), and time dependent valuation (TDV) energy savings in kilo British thermal units per year (TDV kBtu/yr). See Section 2.5/3.5/4.5/5.5 for more details on the first-year statewide impacts calculated by the Statewide CASE Team. Sections 2.3/3.3/4.3/5.3 contains details on the per-unit energy savings calculated by the Statewide CASE Team.

Table 2: First-Year Statewide Energy and Impacts

Measure	Electricity Savings (GWh/yr)	Peak Electrical Demand Reduction (MW)	Natural Gas Savings (MMTherms /yr)	TDV Energy Savings (TDV kBtu/yr)
VAV Deadband Airflow	4.2	0.4	0.3	184.5
New Construction	1.2	0.1	0.1	54.8
Additions and Alterations	3.0	0.3	0.2	129.6
Expand Economizer Requirements	21.7	1.1	(0.2)	476.8
New Construction	6.7	0.3	(0.1)	147.0
Additions and Alterations	15.0	0.7	(0.1)	329.8
Dedicated Outdoor Air Systems (DOAS)	39.5	4.3	0.0	1,126.1
New Construction	24.8	2.7	(0.01)	703.3
Additions and Alterations	14.7	1.6	0.0	422.8
Exhaust Air Heat Recovery	(0.3)	0.0	0.4	145.3
New Construction	(0.1)	0.0	0.1	39.8
Additions and Alterations	(0.2)	0.0	0.3	105.4

Table 3 presents the estimated avoided GHG emissions associated with the proposed code change for the first year the standards are in effect. Avoided GHG emissions are measured in metric tons of carbon dioxide equivalent (metric tons CO2e). Assumptions used in developing the GHG savings are provided in Appendix C of this report. The monetary value of avoided GHG emissions is included in TDV cost factors and is thus included in the cost-effectiveness analysis. The first-year impacts of these measures are expected to reduce GHG emissions by 18,580 Metric Tons of CO2 equivalent accounting for a monetary value of $1.97 Million as shown in the table below.

Table 3: First-Year Statewide GHG Emissions Impacts

Measure	Avoided GHG Emissions (Metric Tons CO2e/yr)	Monetary Value of Avoided GHG Emissions ($2023)
VAV Deadband Airflow	2,629	$279,218
Expand Economizer Requirements	4,159	$441,683
Dedicated Outdoor Air Systems (DOAS)	9,533	$1,012,639
Exhaust Air Heat Recovery	2,259	$239,952
Total	**18,580**	**$1,973,492**

Water and Water Quality Impacts

Table 4 presents the estimated first year water savings resulting from the Exhaust Air Heat Recovery. The savings result from reduced cooling load at the cooling tower for systems that utilize on water-cooled chilled water systems. There are not expected to be significant water impacts from any other measures.

Table 4: First-Year Water and Embedded Electricity Impacts

Impact	On-Site Indoor Water Savings (gallons/yr)	On-site Outdoor Water Savings (gallons/yr)	Embedded Electricity Savings[a] (kWh/yr)
Exhaust Air Heat Recovery	0	938,672	3,346

a. Assumes embedded energy factor of 3,565 kWh per million gallons of water for outdoor use (CPUC 2015).

Compliance and Enforcement

Overview of Compliance Process

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process would have on various market actors. The compliance process is described in the respective submeasure sections for each measure. Impacts that the proposed measure would have on market actors is described in Section 2.2/3.2/4.2/5.2 and Appendix E.

Field Verification and Acceptance Testing

For expand economizer requirements, DOAS, and exhaust air heat recovery measures, there would be modifications to existing acceptance testing. For economizers, this would simply add smaller capacity units to the existing test for HVAC systems. For DOAS units, this would add a new set of criteria for DOAS units into the scope of acceptance testing. For exhaust air heat recovery, new criteria for climate zone and design airflow will need to be added to indicate when an air handler will require this device and the economizer functional testing will need to be modified to test the bypass functions.

1. Introduction

This document presents recommended code changes that the California Energy Commission will be considering for adoption in 2021. If you have comments or suggestions prior to the adoption, please email info@title24stakeholders.com. Comments will not be released for public review or will be anonymized if shared.

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

This Final CASE Report presents four unique code change proposal for nonresidential heating, ventilation, and air conditioning (HVAC) controls. The submeasures names and the sections of the report in which they are presented are provided below:

- Section 2 – VAV Deadband Airflow
- Section 3 – Expand Economizer Requirements
- Section 4 – Dedicated Outdoor Air Systems (DOAS)
- Section 5 – Exhaust Air Heat Recovery

The following is a brief summary of the contents of subsections within Section 2 through 4 of the report:

- Measure Descriptions of this Final CASE Report provide a description of the measure and its background. This section also presents a detailed description of how this code change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.

- In addition to the Market Analysis, this section includes a review of the current market structure. Subsection 2.2/3.2/4.2/5.2 describe the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards, such as fire, seismic, and other safety standards, and whether technical, compliance, or enforceability challenges exist.
- Energy Savings presents the per-unit energy, demand reduction, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate per-unit energy, demand reduction, and energy cost savings.
- Cost and Cost Effectiveness presents the materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs, i.e., equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.
- First-Year Statewide Impacts present the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2022 code takes effect. This includes the amount of energy that would be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic in the state of California. Statewide water consumption impacts are also reported in this section.
- Proposed Revisions to Code Language conclude the report sections with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, Compliance Manual, and compliance documents.

The following appendices provide additional information and supplementary analyses:

- Appendix A: presents the methodology and assumptions used to calculate statewide energy impacts.
- Appendix B: Embedded Electricity in Water Methodology: presents the methodology and assumptions used to calculate the electricity embedded in water use (e.g., electricity used to draw, move, or treat water) and the energy savings resulting from reduced water use.
- Appendix C: presents the methodologies and assumptions used to calculate impacts on GHG emissions and water use and quality.
- Appendix D: presents detailed information on updates to the California Building

Energy Code Compliance (CBECC) Software.

- Appendix E: presents how the recommended compliance process could impact identified market actors.
- Appendix F: documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: presents a summary of the complete results of the DOAS energy impact per building.
- Appendix H: presents a summary of DOAS manufacturer technical capabilities.
- Appendix I: presents DOAS incremental cost references.
- Appendix J: provides a summary of DOAS heat recovery ventilation data.
- Appendix K: provides a summary of the DOAS modeling analysis.
- Appendix L: provides a summary on DOAS energy equivalence with air side economizers in mixed air systems.
- Appendix M: provides individual surface plots showing cost effectiveness for each climate zone.
- Appendix N: provides additional prototype model results in nominal TDV savings.

2. Variable Air Volume Deadband Airflow

2.1 Measure Description

2.1.1 Measure Overview

The proposed code changes would modify existing prescriptive requirements that specify airflow rates when variable air volume (VAV) zones are in deadband operation. Deadband operation is defined as a temperature range where the heating, ventilation, and air conditioning (HVAC) system is neither calling for cooling or heating.[2] In California, the maximum allowable zone airflow during deadband operation is the larger of 20 percent of peak primary airflow or the design minimum outdoor airflow rate as determined in accordance with Section 120.1(c)3. This proposed change would reduce complexity by eliminating the requirement to consider 20 percent of peak primary airflow. The maximum airflow rate during deadband operation would simply be equal to the design minimum outdoor airflow rate. Depending on occupancy types, this would result in a decrease in airflow during deadband operation for most of the prototype buildings and climate zones most situations as 20 percent of peak primary airflow is typically greater than design minimum outdoor airflow rates. The revisions would apply to all buildings that use VAV systems for new construction, additions, and alterations. Because of the lower airflow rate and less fan heat during deadband operation, fan and cooling energy consumptions will decrease but heating energy consumption will increase. The revisions to the compliance software would be minimal and it would be of negligible cost to implement. Energy savings would result from reduced reheat and reduced fan energy. This proposed code change would align Title 24, Part 6 with American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 90.1-2019 (ASHRAE, Standard 90.1 2019).

2.1.2 Measure History

Requirements for VAV zone controls have been subject to code changes in both 2008 and 2013 (CASE: Reduce Reheat 2011) and are well known in the industry. The proposed code changes have already been adopted into ASHRAE 90.1 and utilize the existing controls infrastructure adopted in 2008 and 2013 to implement this measure at no cost.

Title 24, Part 6 includes two prescriptive options for airflow during deadband operation. The required ventilation airflow calculated in Section 120.1(c)3 for indoor air quality or

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[2] Section 100.1(b) of Title 24, Part 6 includes the following definition of deadband, “DEADBAND is the temperature range within which the HVAC system is neither calling for heating or cooling.”

20 percent of the peak primary airflow. This measure would remove the 20 percent of peak primary airflow option so that deadband airflow will be dictated by indoor air quality requirements alone. This recommendation is based on technical research conducted for ASHRAE's research project, RP-1515 Thermal and Air Quality Acceptability in Buildings that Reduce Energy by Reducing Minimum Airflow from Overhead Diffusers (ASHRAE, RP-1515 2015), which was co-funded by the California Energy Commission (Energy Commission) PIER program. The research project evaluated occupants' thermal comfort and air quality satisfaction of reduced airflows using lab and field studies. It also investigated energy savings resulting from setting deadband airflow setpoints to about 10 percent of design cooling airflow and found that lower flow rates resulted in improved occupant thermal comfort and improved air quality satisfaction. Subsequent studies found similar results (ASHRAE Journal 2019). Findings from RP-1515 resulted in the approval of Addendum AU to ASHRAE 90.1-2016, which reduced the deadband airflow requirements. As a result, this measure proposes to align Title 24, Part 6 with ASHRAE Standard 90.1-2019 and simplify the existing code requirements.

2.1.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents would be modified by the proposed change. See Section 2.6 of this report for detailed proposed revisions to code language.

For the potential inclusion for healthcare facilities, the Statewide CASE Team believes this measure should be considered for all non-essential VAV-type HVAC systems.

2.1.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of the California Energy Code as shown below. See Section 2.6.2 of this report for marked-up code language.

SECTION 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

Section 140.4(d) Space-conditioning Zone Controls: The purpose of this change is to amend existing language to simplify calculations of maximum allowable deadband airflow for terminal VAV boxes for DDC systems by eliminating the need to consider 20 percent of peak primary airflow. This code change removes complexity and aligns with ASHRAE Standard 90.1 (ASHRAE, Standard 90.1 2019) while maintaining minimum outdoor airflow requirements (Title 24, Part 6 2019)(Section 120.1).

2.1.3.2 Summary of Changes to the Reference Appendices

The proposed code change would not modify the Reference Appendices.

2.1.3.3 Summary of Changes to the Nonresidential ACM Reference Manual

This proposal would modify Section 5.6.6.1 VAV Air Flow of the Nonresidential ACM Reference Manual. The option of using 20 percent of the peak supply air volume to the zone will be removed from standard for Dual Maximum control sequence in the deadband. See Section 2.6.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

2.1.3.4 Summary of Changes to the Nonresidential Compliance Manual

Chapter 4: Mechanical Systems of the Nonresidential Compliance Manual would need to be revised to incorporate changes to Section 4.5.2 Prescriptive Requirements

See Section 2.1.3.4 of this report for the detailed proposed revisions to the text of the Compliance Manuals.

2.1.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 2.6.6.

- 2019-NRCC-MCH-E - Section K: Terminal Box Controls would need to be amended to indicate that there would no longer be 20 percent zonal airflow requirement.

2.1.4 Regulatory Context

2.1.4.1 Existing Requirements in the California Energy Code

Currently VAV airflow requirements for nonresidential buildings are subject to two distinct sections of the California Energy Code (Title 24, Part 6 2019): Section 120.1(c) and Section 140.4 (d). Section 120.1(c) provides mandatory requirements for minimum ventilation. For example, breakrooms, lobby, and office space all have specific ventilation corrections based on square footage (see Table 120.1-A – Minimum Ventilation Rates in Title 24, Part 6 for more details). Section 140.4(d) provides prescriptive requirements for terminal box controls stating that deadband airflow shall not exceed the greater of the mandatory requirements or 20 percent peak primary airflow.

2.1.4.2 Relationship to Requirements in Other Parts of the California Building Code

VAV minimum airflow requirements are separately listed under the California Mechanical Code (Title 24, Part 4 2019) under Chapter 4: Ventilation Air, Section 403.2 and subsequent subsections which reference ASHRAE 62.1 ventilation requirements. However, as noted in Section 402.1, these regulations are superseded by the California Energy Code.

2.1.4.3 Relationship to Local, State, or Federal Laws

There are no relevant local, state, or federal laws.

2.1.4.4 Relationship to Industry Standards

Both ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC) contain sections on zone controls. This code change proposal would align with the 2019 version of ASHRAE Standard 90.1 (ASHRAE, Standard 90.1 2019)

For IECC, the 2018 version created a new section to incorporate specifications for VAV zone airflow but did not incorporate the guidance from the ASHRAE AU addendum which removed the 20 percent minimum flowrate approach[3] (IECC 2018). There were no proposals for IECC 2021 that recommending aligning with ASHRAE and eliminating the 20 percent minimum flowrate approach (Energy Efficient Codes Coalition 2020).

2.1.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** During the design phase, the mechanical engineers would need to make small modifications to their existing VAV box schedule templates for the mechanical drawings. This would simplify the code by basing minimum airflow for the deadband operation on one value instead of two. This would make it incrementally easier for designers and associated subcontractors. In order to accommodate the change, designers should also call out this change in the sequence of operations and other supporting design documents to ensure controls subcontractors are aware of the new requirements and plan checkers can note clarity for future compliance.
- **Permit Application Phase:** At this phase, plan-checkers with the authority having jurisdiction would need to ensure that the new flow rate minimums and flow setpoint is called out in the mechanical schedule and sequence of operations to ensure this is implemented properly. This code change should be incrementally easier for code officials. Under this phase, NRCC-MCH-E

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[3] See Section C403.6.1: Variable air volume and multiple-zone systems

Certificate of Compliance would verify that the zonal control strategy specified for each zone is meeting the requirements.

- **Construction Phase:** Under this phase, the controls subcontractor would implement the flowrate setpoint for the deadband flowrate which the controls subcontractor is already doing.
- **Inspection Phase:** Under this phase, the mechanical systems are tested as part of acceptance testing. The minor change being that under NRCA-MCH-13-A, step 7, inspectors would need to verify that the deadband flow rate is adheres to the proposed flowrates. There are no necessary changes to the compliance document, and the proposed change will simplify the inspection process because the inspector would not need to determine if the flowrate was determined based on 20 percent of peak primary airflow or the design minimum outdoor airflow rate as the option to use 20 percent of peak primary airflow option would be removed.

As outlined above, this measure would have limited changes to the existing design and construction process. The Statewide CASE Team does not expect implementation of this measure to add substantive changes to the existing code compliance process.

2.2 Market Analysis

2.2.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team then considered how the proposed standard may impact the market in general as well as individual market actors. Information was gathered about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during three public stakeholder meetings that the Statewide CASE Team held on October 15, 2019 (Statewide CASE Team: HVAC Part 1 2019) and April 14, 2020 (Statewide CASE Team: HVAC Controls 2020). Presentation slides, meeting notes, and summary of the code change language can be found in the resources section of this report.

Primary market actors for this measure include VAV box manufacturers, HVAC designers, controls contractors, and commissioning agents. Manufacturers build VAV boxes compiling the various components such as valves, dampers, coils, and actuators, and HVAC designers determine the ductwork layout that connect an individual VAV box to the air handler and specify the equipment sizes. Controls contractors program the

VAV boxes to adhere to the requirements of the zone and to connect those actions to the building automation system. Commissioning agents verify that the system is implemented properly adhering to the owner’s project requirements.

The Statewide CASE Team does not anticipate significant changes or difficulties in complying with this measure. The minimal changes would occur with HVAC designers which would have to adjust their mechanical drawings and schedules to reflect the new deadband airflow requirements – all other market actors would operate in the same way.

2.2.2 Technical Feasibility, Market Availability, and Current Practices

As noted in the Measure Description section, VAV box controls have been subject to code changes in both 2008 and 2013 Title 24, Part 6 and are well known in the industry. The proposed code change has already been adopted into ASHRAE Standard 90.1 and this measure would simplify compliance by requiring airflow minimums in the deadband to be subject only to the airflow minimums required as part of Table 120.1-A of the California Energy Code. There are no known technical feasibility or market availability barriers.

Currently, the maximum allowable zone airflow during deadband operation is the larger of 20 percent of peak primary airflow or the design minimum outdoor airflow rate. In most cases 20 percent of peak primary airflow is larger than the design minimum outdoor airflow rate. It is common practice to set the airflow at 20 percent of peak airflow even though this provides more outside air than is required.

2.2.3 Market Impacts and Economic Assessments

2.2.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California’s construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 5).[4] In 2018, total payroll was $80 billion. Nearly 17,000 establishments and 344,000 employees focus on the commercial sector.

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

Table 5: California Construction Industry, Establishments, Employment, and Payroll

Construction Sectors	Establishments	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 change to nonresidential HVAC controls would likely affect commercial builders and nonresidential electrical, HVAC, and plumbing contractors but would not significantly impact other building trades. The effects on the commercial building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 6 shows the commercial building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report as they are related directly related to the purchase and installation of HVAC equipment.

Table 6: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code

Construction Subsector	Establishments	Employment	Annual Payroll (billions $)
Commercial Building Construction	4,508	75,558	$6.7
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.)

2.2.3.2 *Impact on Building Designers and Energy Consultants*

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. 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 compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 7: California Building Designer and Energy Consultant Sectors shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for Nonresidential HVAC Controls to affect firms that focus on nonresidential construction.

There is not a North American Industry Classification System (NAICS)[5] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[6] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 7 provides an upper bound indication of the size of this sector in California.

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[5] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of 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 Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

[6] Establishments in this sector include businesses primarily engaged in evaluating a building’s structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily 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.

Table 7: California Building Designer and Energy Consultant Sectors

Sector	Establishments	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 establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;

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

2.2.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

2.2.3.4 Impact on Building Owners and Occupants

Commercial Buildings

The commercial building sector includes a wide array of building types, including offices, restaurants and lodging, retail, and mixed-use establishments, and warehouses (including refrigerated) (Kenney 2019). Energy use by occupants of commercial buildings also varies considerably with electricity used primarily for lighting, space cooling and conditioning, and refrigeration. Natural gas consumed primarily for heating water and for space heating. According to information published in the 2019 California Energy Efficiency Action Plan, there is more than 7.5 billion square feet of commercial floor space in California and consumes 19 percent of California’s total annual energy use (Kenney 2019). 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.

Estimating Impacts

Building owners and occupants would benefit from lower energy bills. As discussed in Section 2.2.4.1, 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 Statewide CASE Team does not expect the proposed code change for the 2022 code cycle to impact building owners or occupants adversely.

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

The Statewide CASE Team does not expect any significant impacts on manufacturers and distributors of these products.

2.2.3.6 Impact on Building Inspectors

Table 8 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 8: Employment in California State and Government Agencies with Building Inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs[a]	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

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

a. Administration of Housing Programs (NAICS 925110) comprises government establishments 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 establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

2.2.3.7 Impact on Statewide Employment

As described in Sections 2.2.3.1 through 2.2.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 2.2.4, the Statewide CASE Team estimated how the proposed change in VAV Controls 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 Statewide

CASE Team estimated how energy savings associated with the proposed change in Nonresidential HVAC Controls would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities.

2.2.4 Economic Impacts

For the 2022 code cycle, the Statewide CASE Team used the IMPLAN model software, along with economic information from published sources, and professional judgement to developed estimates of the economic impacts associated with each proposed code changes.[7] While this is the first code cycle in which the Statewide CASE Team develops estimates of economic impacts using IMPLAN, it is important to note that the economic impacts developed for this report are only estimates and are based on limited and to some extent speculative information. In addition, the IMPLAN model provides a relatively simple representation of the California economy and, though the Statewide CASE Team is confident that direction and approximate magnitude of the estimated economic impacts are reasonable, it is important to understand that the IMPLAN model is a simplification of extremely complex actions and interactions of individual, businesses, and other organizations as they respond to changes in energy efficiency codes. In all aspect of this economic analysis, the CASE Authors rely on conservative assumptions regarding the likely economic benefits associated with the proposed code change.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial building industry, architects, energy consultants, and building inspectors. The Statewide CASE Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2022 code cycle regulations would result in additional spending by those businesses.

As noted in Section 2.4.3, the Statewide CASE Team does not expect any incremental equipment, maintenance, or labor costs for this submeasure. Additionally, the Statewide CASE Team does not expect the VAV deadband airflow proposal to add any time-consuming tasks to the existing responsibilities of building inspectors or designers. Thus, there would be no economic impacts experienced by the construction sector. The following three submeasures would experience economic impacts.

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[7] IMPLAN (Impact Analysis for Planning) software is an input-output model used to estimate the economic effects of proposed policies and projects. IMPLAN is the most commonly used economic impact model due to its ease of use and extensive detailed information on output, employment, and wage information.

2.2.4.1 Creation or Elimination of Jobs

The Statewide CASE Team 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. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 2.2.4 would lead to modest changes in employment of existing jobs.

2.2.4.2 Creation or Elimination of Businesses in California

As stated above, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to HVAC Controls which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes.

2.2.4.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is incorporated inside or outside of the state.[8] Therefore, the Statewide CASE Team does not anticipate that these proposed measures would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

2.2.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[9] As Table 9 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, with an average of 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable

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[8] 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.

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

estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 9: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
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.)

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in investment in any directly or indirectly affected sectors of California's economy.

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

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

2.2.4.5.1 Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government would be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs 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 Statewide CASE Team does not expect any appreciable change to the state.

2.2.4.5.2 Cost to Local Governments

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this 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.

2.2.4.6 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed code change may result in unintended consequences. The Statewide CASE Team has not found any information showing that specific persons would be impacted by this proposal.

2.3 Energy Savings

2.3.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented in this report used the TDV factors that are consistent with the TDV factors presented during the Energy Commission's March 27, 2020 workshop on compliance metrics. (California Energy Commission 2020). The electricity TDV factors include the 15 percent retail adder and the natural gas TDV factors include the impact of methane leakage on the building site. The electricity TDV factors used in the energy savings analyses were obtained via email from Energy and Environmental Economics, Inc. (E3), the contractor that is developing the 2022 TDV factors for the Energy Commission, in a spreadsheet titled "Electric TDVs 2022 - 15 pct Retail Adj Scaled by Avoided Costs.xlsx". The natural gas TDV factors used in the energy savings analyses were obtained via email from E3 in a spreadsheet titled "2022_TDV_Policy_Compliant_CH4Leak_FlatRtlAdd_20191210.xlsx". The electricity demand factors used in the energy savings analysis were obtained via email from E3 in a spreadsheet titled "2022 TDV Demand Factors.xlsx". The final TDV factors that the Energy Commission released in June 2020 use 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. The 20-year GWP values increased the TDV factors slightly. As a result, the TDV energy savings presented in this report are lower than the values that are expected if the final TDV that use 20-year GWP values were used in the analysis. The proposed code changes will be more cost effective using the revised TDV. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

2.3.2 Energy Savings Methodology

2.3.2.1 *Energy Savings Methodology per Prototypical Building*

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 10. The Statewide CASE Team considered any nonresidential building prototypes that included air handling systems that had variable air volume controls. If a prototype model included non-VAV systems, those systems were not modified.

Table 10: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
ApartmentHighRise [a] (College dormitories)	10	93,632	10 story apartment building with a basement and elevator penthouse, 75 residential units and other common spaces including lobby, office, multipurpose room, exercise center, laundry, and storage
OfficeLarge	13	498,589	12 story + 1 basement office building with 5 zones and a ceiling plenum on each floor. Window-to-Wall-Ratio (WWR)-0.40
OfficeMedium	3	53,628	3 story office building with 5 zones and a ceiling plenum on each floor. WWR-0.33
OfficeMediumLab	3	53,628	3 story office building with 5 zones and a ceiling plenum on each floor. WWR-0.33
SchoolSecondary	2	210,866	High school with WWR of 35% and SRR 1.4%

a. The Nonresidential “ApartmentHighRise” prototypical model is used to model college dormitories which account for 25% of the “Colleges” building type based on square footage.

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of 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 that the 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 it assumes the energy features that the software user describes with user inputs. To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building. 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, Part 6 requirements. As indicated in Section 140.4(d)2-Space-conditioning Zone Controls, the volume of primary air in the deadband shall not exceed the larger of 20 percent of the peak primary airflow or the design zone outdoor airflow rate as specified by Section 120.1(c)3.

The Statewide CASE Team discovered that the Standard Design developed from CBECC-Com utilizes a 20 percent minimum air flow for every zone, despite the dual criteria. The Statewide CASE Team modified the Standard Design to match the current code requirements using a lookup table that references requirements listed in Section 120.1(c)3. The Proposed Design was identical to this *modified* Standard Design in all ways except for the revisions that represent the proposed changes to the code. Table 11 presents precisely which parameters were modified and what values were used in the Standard Design and Proposed Design. Specifically, the proposed conditions assume the design zone outdoor airflow rate is used in the deadband, instead of the larger of 20 percent peak airflow or the design outdoor air flow rate, in each climate zones as specified by Section 120.1(c)3.

Comparing the energy impacts of the Standard Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

Table 11: 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
ApartmentHighRise (College dormitories)	All	Flow Minimum	Larger of 20 percent of peak primary airflow or design zone outdoor airflow rate	design zone outdoor airflow rate
OfficeLarge	All	Flow Minimum	Larger of 20 percent of peak primary airflow or design zone outdoor airflow rate	design zone outdoor airflow rate
OfficeMedium	All	Flow Minimum	Larger of 20 percent of peak primary airflow or design zone outdoor airflow rate	design zone outdoor airflow rate
OfficeMediumLab	All	Flow Minimum	Larger of 20 percent of peak primary airflow or design zone outdoor airflow rate	design zone outdoor airflow rate
SchoolSecondary	All	Flow Minimum	Larger of 20 percent of peak primary airflow or design zone outdoor airflow rate	design zone outdoor airflow rate

CBECC-Com calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). It then applies the 2022 time dependent valuation (TDV) factors to calculate annual energy use in kilo British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Com also generates TDV energy cost savings values measured in 2023 present value dollars (2023 PV$).

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

Per-unit energy impacts for nonresidential buildings are presented in savings per square foot. Annual energy and peak demand impacts for each prototype building were translated into impacts per square foot by dividing by the floor area of the prototype building. This step allows for an easier comparison of savings across different building types and enables a calculation of statewide savings using the construction forecast that is published in terms of floor area by building type.

2.3.2.2 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts provided by the Energy Commission (California Energy Commisison 2020). The Statewide Construction Forecasts estimate new construction that would occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Com, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 12 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

For alterations and additions, statewide energy savings were calculated using a similar methodology which applied these savings to the existing building stock assuming 5 percent of applicable building prototypes were impacted. This assumes that the useful life of VAV equipment is 20 years and that every year one-twentieth (or 5 percent) of the VAV systems would be replaced in an alteration that triggers code compliance.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 12: Nonresidential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Small Office	OfficeSmall	100%
Large Office	OfficeMedium	50%
	OfficeLarge	50%
Restaurant	RestaurantFastFood	100%
Retail	RetailStandAlone	10%
	RetailLarge	75%
	RetailStripMall	5%
	RetailMixedUse	10%
Grocery Store	Grocery	100%
Non-Refrigerated Warehouse	Warehouse	100%
Refrigerated Warehouse	RefrigWarehouse	N/A
Schools	SchoolPrimary	60%
	SchoolSecondary	40%
Colleges	OfficeSmall	5%
	OfficeMedium	15%
	OfficeMediumLab	20%
	PublicAssembly	5%
	SchoolSecondary	30%
	ApartmentHighRise	25%
Hospitals	Hospital	100%
Hotel/Motels	HotelSmall	100%

2.3.3 Per-Unit Energy Impacts Results

Energy savings and peak demand reductions per-unit are presented in Table 13 through

Table 17. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. Per-unit savings for the first year are expected to range from 0.006 to 0.052 kWh/ft^2 in electrical savings and –0.006 to 0.009 therms/ft^2 in gas savings depending upon climate zone and prototype model. Most of the savings are a result of fan system electrical savings. There are two impacts on natural gas consumption; decreased gas consumption because of lower airflow rate, and either an increase or decrease in gas consumption because of less fan heat. Natural gas use is reduced in cooling-dominated climates (cooling load is reduced) and increased in heating-dominated climates (heating load is increased). The most pronounced instance of reduced cooling load resulting in increased energy savings (negative natural gas

savings because heating is provided by a gas system) is the OfficeLarge simulation of Climate Zone 1 (Arcata, CA), which showed a 0.801 kBtu/ft² penalty. The overall impacts on gas consumption depend on climate zones and prototypical buildings.

In all simulated prototypes and climate zones except four, the total TDV energy savings is positive. That is, in all but four simulations, the electricity savings from the fan system outweigh the increased natural gas use from the heating systems. In these four simulated results, total energy use would increase as would energy costs. The Statewide CASE Team will be working with the Energy Commission to review these four instances and determine a path forward that will consider the implications of potentially increasing energy use in some buildings with concerns about the complexity of the code (code would be more complex with exceptions for building types or climate zones).

The tables below show the first-year per prototype impacts. Any instances of negative values are denoted in red with ( ) in the tables below.

Table 13: First-Year Energy Impacts Per Square Foot – ApartmentHighRise

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.033	0.000	(0.000)	0.607
2	0.032	0.000	(0.000)	0.698
3	0.026	0.000	(0.000)	0.588
4	0.021	0.000	(0.000)	0.480
5	0.021	0.000	(0.000)	0.476
6	0.011	0.000	0.000	0.280
7	0.011	0.000	0.000	0.281
8	0.012	0.000	0.000	0.334
9	0.017	0.000	(0.000)	0.405
10	0.016	0.000	0.000	0.392
11	0.030	0.000	(0.000)	0.688
12	0.027	0.000	(0.000)	0.626
13	0.026	0.000	(0.000)	0.589
14	0.021	0.000	(0.000)	0.410
15	0.010	0.000	(0.000)	0.279
16	0.020	0.000	(0.000)	0.359

Table 14: First-Year Energy Impacts Per Square Foot – OfficeLarge

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.023	0.000	(0.006)	(0.801)
2	0.027	0.000	(0.000)	0.568
3	0.027	0.000	0.003	1.636
4	0.022	0.000	0.004	1.438
5	0.028	0.000	0.000	0.844
6	0.035	0.000	0.008	2.908
7	0.032	0.000	0.009	3.396
8	0.032	0.000	0.007	2.670
9	0.024	0.000	0.006	1.988
10	0.025	0.000	0.005	1.751
11	0.022	0.000	0.001	0.849
12	0.026	0.000	0.003	1.367
13	0.020	0.000	0.001	0.830
14	0.020	0.000	0.001	0.559
15	0.006	0.000	0.005	1.460
16	0.022	0.000	(0.001)	0.493

Table 15: First-Year Energy Impacts Per Square Foot – OfficeMedium

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.020	0.000	(0.004)	(0.298)
2	0.023	0.000	(0.003)	(0.335)
3	0.026	0.000	(0.002)	0.591
4	0.025	0.000	(0.001)	0.330
5	0.024	0.000	(0.002)	0.432
6	0.052	0.000	0.001	1.788
7	0.046	0.000	0.001	2.152
8	0.045	0.000	0.001	1.368
9	0.031	0.000	(0.000)	0.585
10	0.027	0.000	(0.000)	0.544
11	0.023	0.000	(0.001)	0.305
12	0.025	0.000	(0.001)	0.258
13	0.020	0.000	(0.001)	0.153
14	0.012	0.000	(0.002)	(0.341)
15	0.016	0.000	0.001	0.846
16	0.021	0.000	(0.003)	0.086

Table 16: First-Year Energy Impacts Per Square Foot – OfficeMediumLab

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.010	0.000	(0.001)	0.123
2	0.016	0.000	0.001	0.529
3	0.016	0.000	0.001	0.790
4	0.020	0.000	0.002	0.844
5	0.014	0.000	0.001	0.686
6	0.033	0.000	0.003	1.611
7	0.030	0.000	0.003	1.677
8	0.032	0.000	0.003	1.597
9	0.025	0.000	0.003	1.250
10	0.025	0.000	0.003	1.268
11	0.020	0.000	0.002	0.966
12	0.020	0.000	0.002	0.896
13	0.018	0.000	0.002	0.881
14	0.017	0.000	0.002	0.880
15	0.019	0.000	0.003	1.269
16	0.022	0.000	0.001	0.889

Table 17: First-Year Energy Impacts Per Square Foot – SchoolSecondary

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.010	0.000	(0.001)	0.068
2	0.012	0.000	(0.000)	0.220
3	0.016	0.000	(0.000)	0.418
4	0.011	0.000	0.000	0.305
5	0.010	0.000	(0.000)	0.252
6	0.011	0.000	0.001	0.515
7	0.010	0.000	0.001	0.572
8	0.011	0.000	0.001	0.472
9	0.010	0.000	0.000	0.351
10	0.009	0.000	0.000	0.309
11	0.011	0.000	(0.000)	0.286
12	0.012	0.000	(0.000)	0.296
13	0.008	0.000	0.000	0.226
14	0.010	0.000	(0.000)	0.168
15	0.006	0.000	0.001	0.338
16	0.016	0.000	(0.001)	0.478

2.4 Cost and Cost Effectiveness

2.4.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis. In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 15 years.

This measure also applies to alterations and additions. Energy cost savings for this measure are assumed to be the same as that for new construction.

2.4.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings and alterations that are realized over the 15-year period of analysis are presented in present value (PV) 2023 dollars in Table 18 through Table 22 (see Appendix N for similar tables in nominal dollar terms).

The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

This measure is not expected to impact peak demand and the majority of savings should result from reduced fan energy during mild weather conditions. However, the model indicated peak demand showed a slight increase within the prototype models (on the order of 10-5). Any instances of negative values are denoted in red with ( ) in the tables below.

Table 18: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - ApartmentHighRise

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV $)	15-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15-Year TDV Energy Cost Savings (2023 PV $)
1	$0.06	($0.01)	$0.05
2	$0.07	($0.00)	$0.06
3	$0.06	($0.00)	$0.05
4	$0.04	($0.00)	$0.04
5	$0.05	($0.00)	$0.04
6	$0.03	($0.00)	$0.02
7	$0.02	$0.00	$0.02
8	$0.03	($0.00)	$0.03
9	$0.04	($0.00)	$0.04
10	$0.04	($0.00)	$0.03
11	$0.06	($0.00)	$0.06
12	$0.06	($0.00)	$0.06
13	$0.06	($0.00)	$0.05
14	$0.04	($0.00)	$0.04
15	$0.03	($0.00)	$0.02
16	$0.04	($0.01)	$0.03

Table 19: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV $)	15-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15-Year TDV Energy Cost Savings (2023 PV $)
1	$0.06	($0.14)	($0.07)
2	$0.07	($0.02)	$0.05
3	$0.09	$0.06	$0.15
4	$0.06	$0.07	$0.13
5	$0.08	($0.01)	$0.08
6	$0.10	$0.16	$0.26
7	$0.12	$0.18	$0.30
8	$0.09	$0.15	$0.24
9	$0.06	$0.12	$0.18
10	$0.07	$0.09	$0.16
11	$0.06	$0.01	$0.08
12	$0.07	$0.05	$0.12
13	$0.05	$0.02	$0.07
14	$0.05	($0.00)	$0.05
15	$0.02	$0.11	$0.13
16	$0.07	($0.03)	$0.04

Table 20: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV $)	15-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15-Year TDV Energy Cost Savings (2023 PV $)
1	$0.06	($0.08)	($0.03)
2	$0.04	($0.07)	($0.03)
3	$0.09	($0.04)	$0.05
4	$0.05	($0.02)	$0.03
5	$0.09	($0.05)	$0.04
6	$0.14	$0.02	$0.16
7	$0.16	$0.03	$0.19
8	$0.11	$0.01	$0.12
9	$0.06	($0.01)	$0.05
10	$0.06	($0.01)	$0.05
11	$0.04	($0.02)	$0.03
12	$0.05	($0.03)	$0.02
13	$0.04	($0.03)	$0.01
14	$0.02	($0.05)	($0.03)
15	$0.04	$0.03	$0.08
16	$0.07	($0.07)	$0.01

Table 21: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV $)	15-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15-Year TDV Energy Cost Savings (2023 PV $)
1	$0.03	($0.02)	$0.01
2	$0.03	$0.01	$0.05
3	$0.05	$0.02	$0.07
4	$0.04	$0.03	$0.08
5	$0.04	$0.02	$0.06
6	$0.08	$0.06	$0.14
7	$0.09	$0.06	$0.15
8	$0.08	$0.07	$0.14
9	$0.05	$0.06	$0.11
10	$0.06	$0.06	$0.11
11	$0.04	$0.04	$0.09
12	$0.04	$0.04	$0.08
13	$0.04	$0.04	$0.08
14	$0.03	$0.04	$0.08
15	$0.04	$0.07	$0.11
16	$0.06	$0.02	$0.08

Table 22: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV $)	15-Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15-Year TDV Energy Cost Savings (2023 PV $)
1	$0.03	($0.03)	$0.01
2	$0.03	($0.01)	$0.02
3	$0.04	($0.01)	$0.04
4	$0.03	($0.00)	$0.03
5	$0.03	($0.01)	$0.02
6	$0.03	$0.02	$0.05
7	$0.03	$0.02	$0.05
8	$0.03	$0.01	$0.04
9	$0.02	$0.01	$0.03
10	$0.02	$0.00	$0.03
11	$0.03	($0.00)	$0.03
12	$0.03	($0.00)	$0.03
13	$0.02	$0.00	$0.02
14	$0.02	($0.01)	$0.01
15	$0.02	$0.01	$0.03
16	$0.06	($0.02)	$0.04

2.4.3 Incremental First Cost

Incremental first cost is the initial cost to adopt more efficient equipment or building practices when compared to the cost of an equivalent baseline project. Therefore, it was important that the Statewide CASE Team consider first costs in evaluating overall measure cost effectiveness. Incremental first costs are based on data available today and can change over time as markets evolve and professionals become familiar with new technology and building practices.

The Statewide CASE Team expects zero incremental cost as this submeasure is a simple change to minimum damper position setpoint and can be implemented utilizing the existing controls capabilities required under Section 140.4(d) Space-conditioning Zone Controls which have been required since 2008. In a poll during the October 15, 2019 stakeholder meeting, a majority of participants (five of eight) agreed that implementation costs would be zero. The Statewide CASE Team then reiterated this question at the stakeholder meeting in April 14, 2020 for further detail. In that survey, 14 of 19 said implementation costs would be zero, and the remainder of those polled said they did not know (Statewide CASE Team: HVAC Controls 2020).

2.4.4 Incremental Maintenance and Replacement Costs

Incremental maintenance cost 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 15-year period of analysis. The present value of equipment maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2022 TDV. The present value of maintenance costs that occurs in the nth year is calculated as follows:

$$\mathbf{Present\ Value\ of\ Maintenance\ Cost} = \mathbf{Maintenance\ Cost} \times \left\lfloor \frac{\mathbf{1}}{\mathbf{1+d}} \right\rfloor^{\mathbf{n}}$$

This measure has zero incremental costs because it uses existing controls infrastructure to implement the measure and will not result on any additional wear on the equipment.

2.4.5 Cost Effectiveness

This measure proposes a prescriptive requirement. As such, a cost analysis is required to demonstrate that the measure is cost effective over the 15-year period of analysis. However, costs to implement this measure are assumed to be zero because it is a simple setpoint control and able to be implemented using the existing controls infrastructure. As a result of the zero cost, the benefit-to-cost ratio is infinite and therefore meets the 15-year threshold required by the Energy Commission. As discussed above, in four of the simulations total TDV energy use and energy costs would increase as a result of this proposed code change. The Statewide CASE Team will be reviewing these results with the Energy Commission and determining a path forward that considers the complexity of the code with the potential increased energy use in a small portion of statewide construction.

2.5 First-Year Statewide Impacts

2.5.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction, additions and alterations by multiplying the per-unit savings, which are presented in Section 2.3.3, by assumptions about the percentage of newly constructed and existing buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

The Statewide CASE Team assumed that all VAV terminal boxes are using the larger value between 20 percent airflow and the ventilation requirement, though the Statewide CASE Team is seeking feedback on this assumption. The October 15, 2019 utility-sponsored stakeholder meeting provided a poll question on the matter and was inconclusive with only four respondents split among three responses. The Statewide CASE Team also asked for feedback in the Draft CASE Report and received no stakeholder comments on this issue.

The first-year energy impacts represent the first-year annual savings from all impacted buildings that were completed in 2023. The 15-year energy cost savings represent the energy cost savings over the entire 15-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account. Table 23 and Table 24 present the first-year statewide energy and energy cost savings by climate zone for newly constructed buildings and additions and alterations. A summary of impacts can be found in Table 25. Any instances of negative values are denoted in red with ( ) in the tables below.

Table 23: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.2	0.00	0.00	(0.00)	($0.01)
2	1.2	0.03	0.00	(0.00)	$0.02
3	6.2	0.16	0.01	0.00	$0.54
4	3.2	0.07	0.00	0.00	$0.22
5	0.6	0.01	0.00	(0.00)	$0.03
6	4.1	0.16	0.01	0.02	$0.75
7	2.6	0.08	0.01	0.01	$0.52
8	6.0	0.21	0.02	0.02	$0.96
9	11.0	0.28	0.03	0.03	$1.14
10	3.1	0.06	0.01	0.00	$0.24
11	0.7	0.01	0.00	0.00	$0.03
12	5.3	0.12	0.01	0.00	$0.34
13	1.3	0.02	0.00	0.00	$0.05
14	0.9	0.01	0.00	(0.00)	$0.01
15	0.3	0.00	0.00	0.00	$0.03
16	0.3	0.01	0.00	(0.00)	$0.01
TOTAL	**47.1**	**1.25**	**0.11**	**0.09**	**$4.88**

a. First-year savings from all buildings completed statewide in 2023.

Table 24: Statewide Energy and Energy Cost Impacts – Additions and Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.5	0.01	0.00	(0.00)	($0.02)
2	2.9	0.07	0.00	(0.00)	$0.04
3	14.9	0.37	0.03	0.01	$1.28
4	7.8	0.17	0.01	0.01	$0.53
5	1.5	0.03	0.00	(0.00)	$0.07
6	10.0	0.37	0.03	0.04	$1.75
7	6.9	0.22	0.03	0.03	$1.36
8	14.7	0.49	0.04	0.05	$2.23
9	25.5	0.63	0.06	0.06	$2.53
10	8.6	0.18	0.02	0.01	$0.66
11	1.8	0.04	0.00	0.00	$0.08
12	12.7	0.29	0.02	0.01	$0.79
13	3.2	0.05	0.00	0.00	$0.12
14	2.3	0.03	0.00	(0.00)	$0.03
15	0.9	0.01	0.00	0.00	$0.07
16	0.7	0.01	0.00	(0.00)	$0.02
TOTAL	**114.9**	**2.97**	**0.26**	**0.21**	**$11.54**

a. First-year savings from all alterations completed statewide in 2023.

Table 25: Statewide Energy and Energy Cost Impacts – New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (PV$ million)
New Construction	1.25	0.11	0.09	$4.9
Additions and Alterations	2.97	0.26	0.21	$11.5
TOTAL	**4.22**	**0.38**	**0.30**	**$16.4**

2.5.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO2e per GWh based on the average emission factors for the CACX EGRID subregion.

Table 83 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 2,629 metric tons of carbon dioxide equivalents (metric tons CO2e) would be avoided.

Table 26: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMTherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
VAV Deadband Airflow	4.22	1,014	0.30	1,615	2,629
TOTAL	**4.22**	**1,014**	**0.30**	**1,615**	**2,629**

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.4 MTCO2e/GWh and 5,454 MTCO2e/MMTherms.

2.5.3 Statewide Water Use Impacts

The proposed code change would not result in any significant changes to water usage as the measure will mostly save energy during very mild conditions and will have extremely limited impact on any chilled water systems.

2.5.4 Statewide Material Impacts

The proposed code change would not result in statewide material impacts as the measure utilizes existing controls infrastructure.

2.5.5 Other Non-Energy Impacts

The proposed code change will likely increase thermal comfort based on the findings in the ASHRAE study (ASHRAE, RP-1515 2015).

2.6 Proposed Revisions to Code Language

2.6.1 Guide to Markup 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 red underlining (new language) and ~~strikethroughs~~ (deletions).

2.6.2 Standards

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)

(d) **Space-conditioning Zone Controls.** Each space-conditioning zone shall have controls designed in accordance with 1 or 2:

1. Each space-conditioning zone shall have controls that prevent:

   A. Reheating; and

   B. Recooling; and

   C. Simultaneous provisions of heating and cooling to the same zone, such as mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled either by cooling equipment or by economizer systems; or

2. Zones served by variable air-volume systems that are designed and controlled to reduce, to a minimum, the volume of reheated, recooled, or mixed air are allowed only if the controls meet all of the following requirements:

   A. For each zone with direct digital controls (DDC):

      i. The volume of primary air that is reheated, recooled or mixed air supply shall not exceed the larger of:

         a. 50 percent of the peak primary airflow; or

         b. The design zone outdoor airflow rate as specified by Section 120.1(c)3.

      ii. The volume of primary air in the deadband shall not exceed~~ the larger of:~~

         ~~a. 20 percent of the peak primary airflow; or~~

         ~~b. T~~the design zone outdoor airflow rate as specified by Section 120.1(c)3.

      iii. The first stage of heating consists of modulating the zone supply air temperature setpoint up to a maximum setpoint no higher than 95ºF while the airflow is maintained at the dead band flow rate.

      iv. The second stage of heating consists of modulating the airflow rate from the dead band flow rate up to the heating maximum flow rate.

   B. For each zone without DDC, the volume of primary air that is reheated, re-cooled, or mixed air supply shall not exceed the larger of the following:

      i. 30 percent of the peak primary airflow; or

ii. The design zone outdoor airflow rate as specified by Section 120.1(c)3.

EXCEPTION 1 to Section 140.4(d): Zones with special pressurization relationships or cross-contamination control needs.

EXCEPTION 2 to Section 140.4(d): Zones served by space-conditioning systems in which at least 75 percent of the energy for reheating, or providing warm air in mixing systems, is provided from a site-recovered or site-solar energy source.

EXCEPTION 3 to Section 140.4(d): Zones in which specific humidity levels are required to satisfy exempt process loads. Computer rooms or other spaces where the only process load is from IT equipment may not use this exception.

EXCEPTION 4 to Section 140.4(d): Zones with a peak supply-air quantity of 300 cfm or less.

EXCEPTION 5 to Section 140.4(d): Systems serving healthcare facilities.

2.6.3 Reference Appendices

There are no proposed changes to the Reference Appendices.

2.6.4 ACM Reference Manual

5.6.6 Zone Level Air Flow

5.6.6.1 VAV Air Flow

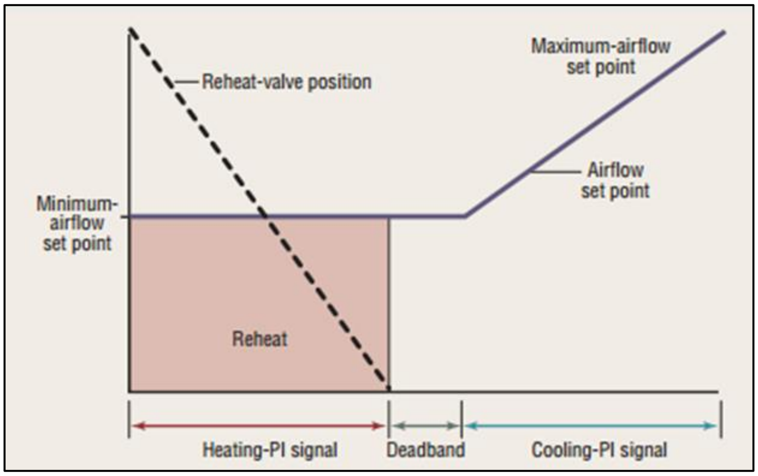
This group of building descriptors applies to proposed design systems that vary the volume of air at the zone level. The building descriptors are applicable for standard design systems 5 and 6.

(sections omitted)

Terminal Minimum Stop	
Applicability	Systems that vary the volume of air at the zone level
Definition	The minimum airflow that will be delivered by a terminal unit before reheating occurs
Units	Unitless fraction of airflow (cfm) or specific airflow (cfm/ft²)
Input Restrictions	Input must be greater than or equal to the outside air ventilation rate
Standard Design	For systems 5 and 6, packaged VAV units and built-up VAV air handling units, set the minimum airflow to be the ~~greater of 20 percent of the peak supply air volume to the zone or the~~ minimum outside air ventilation rate. For laboratories, the minimum airflow fraction shall be fixed at a value equivalent to the greater of the proposed design minimum exhaust requirements or the minimum ventilation rate.
Standard Design: *Existing Buildings*	

Terminal Heating Control Type	
Applicability	VAV boxes with reheat
Definition	The control strategy for the heating mode. Single Maximum: In the single maximum control mode, the airflow is set to a minimum constant value in both the deadband and heating mode. This airflow can vary but is typically 30 to 50 percent of maximum. This control mode typically has a higher minimum airflow than the minimum used in the dual maximum below, resulting in more frequent reheat.

Figure 9: Single Maximum VAV Box Control



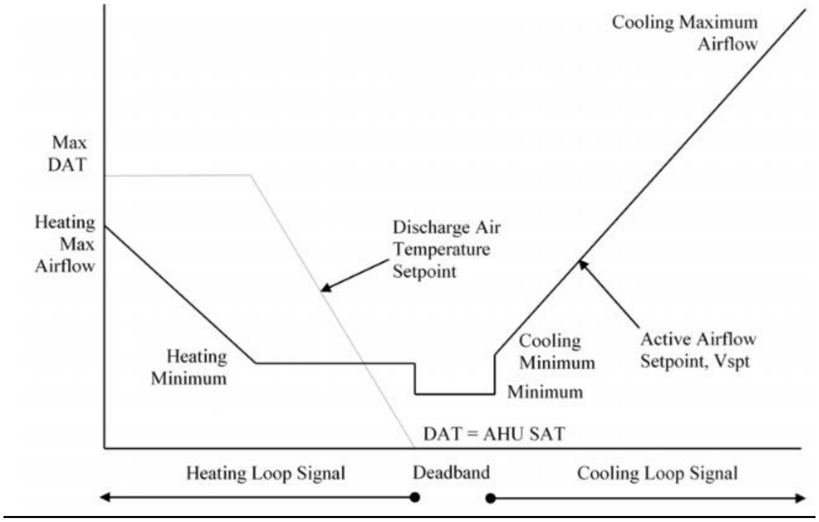
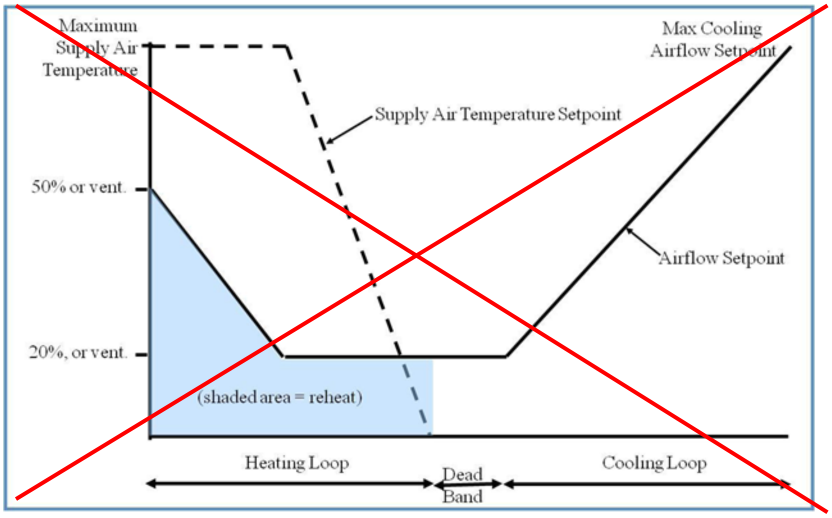
Source: Taylor Engineering

Dual Maximum:

Raises the supply air temperature (SAT) as the first stage of heating, and increases the airflow to the zone as the second stage of heating.

1. The first stage of heating consists of modulating the zone supply air temperature setpoint up to a maximum setpoint no larger than 95°F while the airflow is maintained at the dead band flow rate.
2. The second stage of heating consists of modulating the airflow rate from the dead band flow rate up to the heating maximum flow rate (50 percent of design flow rate).

Figure 10: Dual Maximum Control Sequence with lower zone deadband (amended)

	  ~~Source: Taylor Engineering~~
Units	List: • Single maximum • Dual maximum
Input Restrictions	Fixed at single maximum if control system type is not direct digital control (DDC) control to the zone level
Standard Design	Dual maximum For healthcare facilities, same as the Proposed Design.
Standard Design: *Existing Buildings*	

2.6.5 Compliance Manuals

Chapter 4 of the Nonresidential Compliance Manual would need to be revised. Changes should be made to 4.5.2.1 Prescriptive Requirements Space Conditioning Zone Controls to indicate the removal of the 20 percent minimum flowrate including the example calculation in Example 4-35 as well as the graphic indicating the VAV box controls:

4.5.2.1 Space Conditioning Zone Controls

§140.4(d)

Each space-conditioning zone shall have controls that prevent:

- Reheating of air that has been previously cooled by mechanical cooling equipment or an economizer.
- Recooling of air that has been previously heated. This does not apply to air returned from heated spaces.
- Simultaneous heating and cooling in the same zone, such as mixing supply air that has been previously mechanically heated with air that has been previously cooled, either by mechanical cooling or by economizer systems.

Zones served by VAV systems that are designed and controlled to reduce the volume of reheated, recooled or mixed air to a minimum. The controls must meet all of the following:

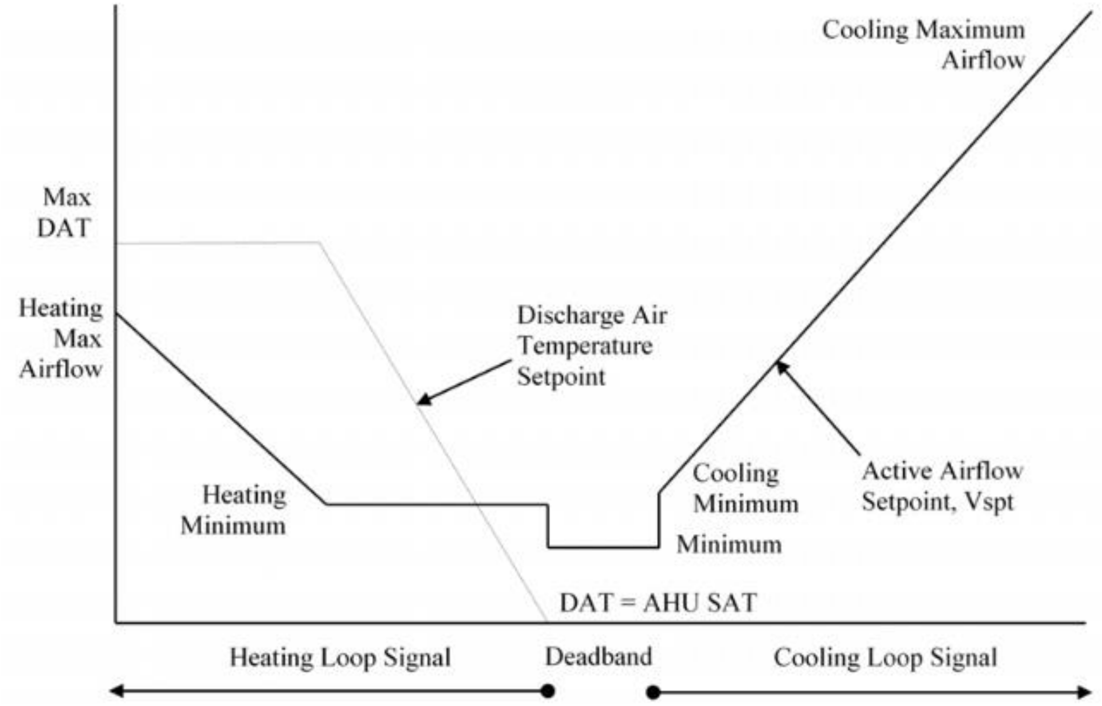
a. For each zone with DDC:
    1. The volume of primary air that is reheated, re-cooled, or mixed air supply shall not exceed the larger of 50 percent of the peak primary airflow or the design zone outdoor airflow rate, per Section 4.3.
    2. The volume of primary air in the deadband shall not exceed ~~the larger of 20 percent of the peak primary airflow or~~ the design zone outdoor airflow rate, per Section 4.3.
        ii. The first stage of heating consists of modulating the zone supply air temperature set point up to a maximum set point no higher than 95 degrees F while the airflow is maintained at the deadband flow rate.
        iii. The second stage of heating consists of modulating the airflow rate from the deadband flow rate up to the heating maximum flow rate.
        iv. For each zone without DDC, the volume of primary air that is reheated, re-cooled, or mixed air supply shall not exceed the larger of 30 percent of the

peak primary airflow or the design zone outdoor airflow rate, per Section 4.3.

For systems with DDC to the zone level, the controls must be able to support two different maximums -- one each for heating and cooling. This control is depicted in Figure 1 below. In cooling, this control scheme is similar to a traditional VAV reheat box control. The difference is what occurs in the deadband between heating and cooling and in the heating mode. With traditional VAV control logic, the minimum airflow rate is typically set to the largest rate allowed by code. This airflow rate is supplied to the space in the deadband and heating modes. With the "dual maximum" logic, the minimum rate is the lowest allowed by code (e.g. the minimum ventilation rate) or the minimum rate the controls system can be set to (which is a function of the VAV box velocity pressure sensor amplification factor and the accuracy of the controller to convert the velocity pressure into a digital signal). As the heating demand increases, the dual maximum control first resets the discharge air temperature (typically from the design cold deck temperature up to 85 or 90 degrees F) as a first stage of heating then, if more heat is required, it increases airflow rate up to a “heating” maximum airflow set point, which is the same value as what traditional control logic uses as the minimum airflow set point. Using this control can save significant fan, reheat and cooling energy while maintaining better ventilation effectiveness as the discharge heating air is controlled to a temperature that would minimize stratification.

This control requires a discharge air sensor and may require a programmable VAV box controller. The discharge air sensor is very useful for diagnosing control and heating system problems even if they are not actively used for control.

Figure 1: Dual-Maximum VAV Box Control Diagram with Lower Zone Deadband (amended)



For systems without DDC to the zone (such as electric or pneumatic thermostats), the airflow that is reheated is limited to a maximum of either 30 percent of the peak primary airflow or the minimum airflow required to ventilate the space, whichever is greater.

A. **Certain exceptions exist for space conditioned zones with one of the following:**
   1. Special pressurization relationships or cross contamination control needs (laboratories are an example of spaces that might fall in this category)
   2. Site-recovered or site-solar energy providing at least 75 percent of the energy for reheating, or providing warm air in mixing systems
   3. Specific humidity requirements to satisfy exempt process needs (computer rooms are explicitly not covered by this exception)
   4. Zones with a peak supply air quantity of 300 cfm or less
   5. Systems with healthcare facilities

Example 4-35

Question

What are the limitations on VAV box minimum airflow set point for a 1,000 square foot office having a design supply of 1,100 cfm and eight people?

Answer

For a zone with pneumatic thermostats, the minimum cfm cannot exceed the larger of:

a. 1,100 cfm x 30 percent = 330 cfm; or

b. The minimum ventilation rate which is the larger of

1) 1,000 ft^2 x 0.15 cfm/ft^2 = 150 cfm; and

2) 8 people x 15 cfm/person = 120 cfm

Thus the minimum airflow set point can be no larger than 330 cfm.

For a zone with DDC to the zone, the minimum cfm in the deadband cannot exceed the ~~larger of:~~

~~a. 1,100 cfm x 20 percent = 220 cfm; or~~

~~b. The~~ minimum ventilation rate which is the larger of

1) 1,000 ft^2 x 0.15 cfm/ft^2 = 150 cfm; and

2) 8 people x 15 cfm/person = 120 cfm

Thus the minimum airflow set point in the deadband can be no larger than ~~220~~ 150 cfm. And this can rise to 1100 cfm X 50 percent or 550 cfm at peak heating.

For either control system, based on ventilation requirements, the lowest minimum airflow set point must be at least 150 cfm, or transfer air must be provided in this amount.

2.6.6 Compliance Documents

Compliance documents 2019-NRCC-MCH-E would need to be revised. Section K. Terminal Box Controls should be amended to indicate that there would no longer be 20 percent zonal airflow requirement per referenced changes to Section 140.4(d).

3. Expand Economizer Requirements

3.1 Measure Description

3.1.1 Measure Overview

An air-side economizer is an add-on device for HVAC systems that automatically adjusts the amount of outside air entering a building when mild weather conditions are detected. This reduces the overall amount of energy required from an HVAC system. Economizers are a proven energy savings measure and have been part of national energy codes through ASHRAE Standard 90.1 since at least 1989. Economizers are especially effective for most of California's mild, dry climates. Air-side economizers consist of a damper to modulate flow between a return air duct and outside air intake, an actuator to mechanically operate the damper, and several temperature sensors and a controller to determine the correct operation based on real-time weather conditions. Several code advances regarding economizers have occurred over the decades and have included adding integration with the mechanical cooling to provide free cooling even when mechanical cooling is needed, damper leakage requirements, damper reliability requirements, and most recently automated fault detection diagnostics (FDD).

This measure would update existing prescriptive requirements for economizers in two ways. First, it would require economizers on lower capacity units by reducing the threshold requiring an economizer from 54,000 Btu/h to 33,000 Btu/hr. To prevent unintended impacts on the growing variable refrigerant flow (VRF) market segment and other large indoor units, an exception is proposed in the language that systems meet new dedicated outside air system (DOAS) prescriptive requirements as described in Section 4 in order to not require an economizer. Second, this measure incorporates code clean-up language from Table 6.5.1-2 of ASHRAE Standard 90.1 which clarifies the efficiency improvement percentage for different efficiency metrics. This proposal incorporates the latest draft which was submitted to the ASHRAE Standard 90.1 mechanical subcommittee. The Statewide CASE Team incorporated this language into "Table 140.4-D: Economizer Trade-Off Table for Cooling Systems" of Title 24, Part 6, Section 140.4(e)(1) and will monitor and apply changes to align with the eventual language that gets adopted.

The combined impact of these measures would result in higher ventilation rates for buildings while simultaneously decreasing the energy usage.

3.1.2 Measure History

Prescriptive requirements for air-side economizers being addressed in this measure were last updated under two separate 2013 Title 24 CASE efforts, Fan Control and Economizers (CASE: Fan Control and Economizer 2011) and Light Commercial Unitary

HVAC (CASE: Light Commercial Unitary 2011). These changes were adopted in June 2012. At that time, three main changes were made:

1. The existing capacity requirement for economizers was adjusted downward from 75,000 Btu/h to 54,000 Btu/h.
2. Minimum compressor displacement (Table 140.4-F). Which required package units to have multiple stages and minimum displacement requirements in order to take advantage of free cooling.
3. Fault Detection and Diagnostics (FDD) capabilities were introduced which required automatic detection of poor economizer operation to improve persistence and performance.

The first two requirements have not been updated since the 2013 code cycle despite significant advancements in compressor technology noted by the two recent phases (2018 and 2023) of federal efficiency standards advancements covering most classes of air-cooled air conditioning and heat pump equipment (U.S. DOE Final Rule 2016).

In addition, economizers have also continued to make significant reliability improvements as industry practices from both manufacturers and installers have improved and the incorporation of FDD capabilities has improved maintenance and awareness.

3.1.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the standards, Reference Appendices, ACM Reference Manuals, and compliance documents would be modified by the proposed change. See Section 3.6 of this report for detailed proposed revisions to code language.

3.1.3.1 Summary of Changes to the Standards

This proposal would modify the sections of the California Energy Code shown below. See Section 3.6.2 of this report for marked-up code language.

Section 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Subsection 120.2(i) Economizer Fault Detection and Diagnostics (FDD). The purpose of this code change is to amend the existing threshold level for cooling capacity room 54,000 Btu/h to 33,000 Btu/h.

Section 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

Subsection 140.4(e) Economizers. The purpose of this code change is to amend existing requirements in two ways. One, by lowering the minimum capacity requirement for systems requiring an economizer from 54,000 Btu/h to 33,000 Btu/h. This change would also be accompanied by changes to an existing exception which would exempt the economizer requirements if a system utilizes a decoupled system that meets the DOAS prescriptive requirements. Two, the measure would incorporate code clean-up language for Table 140-4-D Economizer Trade-Off Table for Cooling-Systems.

3.1.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the sections of the Reference Appendices identified below. See Section 3.6.5 of this report for the detailed proposed revisions to the text of the reference appendices.

Joint Appendix (JA) 6.3 Economizer Fault Detection and Diagnostics. A minor change would be made to the existing JA 6.3 text to change the reference capacity sited in the text from 54,000 Btu/h to 33,000 Btu/h to match the change being sought for section 120.2(i)

3.1.3.3 Summary of Changes to the Nonresidential ACM Reference Manual

This proposal would modify the following sections of the Nonresidential ACM Reference Manual as shown below. See Section 3.6.5 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Minor changes to **Section 5.7.4 Outside Air Controls and Economizer** would need to be made to address the capacity requirement changes for the following three tables:

Section 5.7.4.1 Outside Air Controls: Maximum Outside Air Ratio
Section 5.7.4.2 Air Side Economizer: Economizer Control Type
Section 5.7.4.2 Air Side Economizer: Economizer Integration Level

3.1.3.4 Summary of Changes to the Nonresidential Compliance Manual

The proposed code change would modify the following sections of the Nonresidential Compliance Manual. See Section 3.6.5 of this report for the detailed proposed revisions to the text of the compliance manuals.

- 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
- Section 10.4.3.1 Economizers

3.1.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 3.6.5.

For the Expand Economizer Requirements measure, compliance document CEC-NRCC-MCH-E would need to be revised to ensure verification of the HVAC System section will verify economizers on the smaller units.

3.1.4 Regulatory Context

3.1.4.1 Existing Requirements in the California Energy Code

Applicable code requirements that impact this measure can be found in the California Energy Code (Title 24, Part 6 2019): Section 120.2(i) and Section 140.4(e). Air handling systems with mechanical cooling over 54,000 Btu/h shall include an economizer per Section 140.4(e) and include FDD per Section 120.2(i). If comfort cooling systems have a cooling efficiency that meets or exceeds the cooling efficiency improvements presented in Table 140.4-D do not need to have an economizer.

3.1.4.2 Relationship to Requirements in Other Parts of the California Building Code

Prescriptive requirements for economizers are listed 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).

3.1.4.3 Relationship to Local, State, or Federal Laws

Most HVAC equipment effected by this code change proposal have standards, certification, and testing regulated as part of the U.S. federal Energy Policy Act of 2005 (EPCA 2005). However, economizers are not inclusive of any specific federal requirements.

3.1.4.4 Relationship to Industry Standards

Existing industry standards for economizers are set by ASHRAE, in particular Standard 90.1. These standards are adopted into model codes by the International Code Council which publish both 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 table below:

Table 27: Economizer Requirements from Various Industry Standards

Relevant Requirement	Title 24, Part 6 (2019)	(ASHRAE, Standard 90.1 2019)	(IECC 2018)	(IgCC 2018) / ASHRAE 189.1	Title 24, Part 6 (Proposed)
Capacity threshold to require an economizer	54,000 Btu/h	54,000 Btu/h	54,000 Btu/h	33,000 Btu/h	33,000 Btu/h

3.1.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** During the design phase, the mechanical engineers would need to ensure that small air handlers would be designed with economizers or utilize the appropriate exception and as well as the necessary system controls.
- **Permit Application Phase:** At this phase, plan-checkers with the authority having jurisdiction would need to ensure that HVAC package units are specified with an economizer down to 33,000 Btu/hr or utilize the appropriate exception. Under this phase, NRCC-MCH-E Certificate of Compliance would need to be filled out and verified that the specified equipment would meet the economizer requirements.
- **Construction Phase:** During this phase, the general/installing contractor must complete the NRCI-MCH-01-E form to declare that equipment was installed properly and meets or exceeds HVAC requirements documented in the NRCC. Under this phase, any after-market economizers would have to be installed and incorporated if they are not included in the package unit.
- **Inspection Phase:** Under this phase, an acceptance testing technician will need to complete acceptance testing of and fill out the NRCA-MCH-05 form. Economizers are put through functional testing including fault detection and diagnostics.

As outlined above, this measure would have limited changes to the existing design and construction process and therefore the Statewide CASE Team does not expect implementation of this measure to add substantive changes to the existing code compliance process.

3.2 Market Analysis

3.2.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. It then considered how the proposed standard may impact the market in general as well as individual market actors. Information was gathered about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during three public stakeholder meetings that the Statewide CASE Team held on November 5, 2019 (Statewide CASE Team: HVAC Part 2 2019) and April 14, 2020 (Statewide CASE Team: HVAC Controls 2020). Presentation slides, meeting notes, and summary of the code change language can be found in the resources section of this report.

The primary market actors for this measure are HVAC system manufacturers and design engineers. The main impacts from the lower capacity economizing measure would be to HVAC designers as this would require economizing on smaller units which would modify current design practices and encourage placement of smaller units closer to exterior walls to comply with the economizer requirements for smaller units or decoupled systems to utilize the new exception for DOAS units. This may be particularly important for an additions and alterations scenarios which may eliminate exclude certain like-for-like replacement in situations with no return ducting system or areas which may be space-constrained environments. The Statewide CASE Team is aware of this potential issue and also propose a modification to Section 140.4(e)1, Exception 6 which would exempt economizer requirements if the DOAS prescriptive requirements are met for the same space in order to strike an appropriate balance between energy savings and designer flexibility. The Statewide CASE Team would appreciate feedback from designers and other building practitioners on this exception.

HVAC system manufacturers would face limited impact from this proposal as most existing product lines already incorporate economizers and are not expected to require significant changes. However, the timing of this proposal would coincide with both new requirements from the California Air Resources Board on low global warming potential (low GWP) refrigerants and new federal efficiency requirements for minimum efficiency requirements all which take place in 2023, which would also lead to manufacturers to make revisions to product offerings.

Secondary market actors include building operators and code enforcement professionals. The main impact to building operators is that smaller capacity units will now require economizers that feature FDD and will need to be aware of and then modify their maintenance plans to incorporate those changes. The main impacts to plan checkers will be to learn the new code requirements and look for them in the product specifications including validating smaller units will feature an economizer and FDD. Contractors will need to conduct functional testing related to economizers on smaller sized units. For units that are utilizing 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.

3.2.2 Technical Feasibility, Market Availability, and Current Practices

3.2.2.1 Technical Feasibility

Air-side economizers feature a damper, actuator, sensors, and a controller. The controller uses real-time information from temperature sensors to operate an actuator to open or close outside air and return air dampers to reduce the need for mechanical cooling. This is a mature, well-understood technology that has been required as part of ASHRAE 90.1 since at least 1989. Economizers have been required on smaller units as the technology has matured and are offered as an option by most manufacturers down to 33,000 Btu/h.

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 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.

3.2.2.2 Current Practices and Market Trends

Air-side economizers are a feature of many HVAC systems and utilized in a wide variety of building types in California. Air-side economizers adjust the ratio of fresh outside air and air returning from a building to reduce energy usage and minimizing the amount of mechanical cooling required. They can be shipped from the manufacturer with an economizer or retrofitted in the field with an after-market product. A 2016 Department of Energy (U.S. DOE) rulemaking on small, large, and very large commercial packaged air conditioners and heat pumps utilized data from the Air Conditioning, Heating, and Refrigeration Institute (AHRI) which found market penetration of units shipped with manufacturer-installed economizers to be from 60 percent to the high 70s depending on the equipment capacity.

Table 28: AHRI Data Economizer 2014 Shipment Volumes (2016 U.S. DOE Final Rule, Technical Support Documentation)

Equipment Category	% Units with Economizers
Small Commercial Packaged AC and HP (Air-Cooled) - ≥ 65,000 Btu/h and <135,000 Btu/h Cooling Capacity	60%
Small Commercial Packaged AC and HP (Air-Cooled) - ≥ 135,000 Btu/h and <240,000 Btu/h Cooling Capacity	67%
Small Commercial Packaged AC and HP (Air-Cooled) - ≥ 240,000 Btu/h and <760,000 Btu/h Cooling Capacity	77%

Similar data on economizer market penetration was not available from DOE for units below 65,000 Btu/h. Instead, the Statewide CASE Team worked with AHRI to obtain additional data on the market prevalence of economizers. AHRI conducted an anonymized manufacturer survey to collect data on behalf of the Statewide CASE Team. AHRI contacted 34 manufacturers and received responses from nine. Based on their survey, AHRI estimates that 40 percent of units in this capacity range were sold with a factory-installed economizer in California – indicating market readiness and feasibility for economizers in this capacity range. One manufacturer commented that these numbers may be understated because some installers may prefer field-installations for inventory flexibility.

Economizers are especially impactful in California which features relatively mild weather year-round which can utilize economizers to reduce cooling load throughout the year. The market is well developed within California and while there has been significant growth in alternative system types such as VRF systems with DOAS, an HVAC package unit with airside economizers remains the primary configuration in California.

3.2.3 Market Impacts and Economic Assessments

3.2.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California's construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 29).[10] In 2018, total payroll was $80 billion. Nearly 17,000 establishments and 344,000 employees focus on the commercial sector.

Table 29: California Construction Industry, Establishments, Employment, and Payroll

Construction Sectors	Establishments	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 change to Nonresidential HVAC Controls would likely affect commercial builders and nonresidential electrical, HVAC, and plumbing contractors but would not significantly impact other building trades. The effects on the commercial building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 30 shows the commercial building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report as they are related directly related to the purchase and installation of HVAC equipment.

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

Table 30: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code

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.)

3.2.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. 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 compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 31 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for Nonresidential HVAC Controls to affect firms that focus on nonresidential construction.

There is not a North American Industry Classification System (NAICS)[11] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of

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[11] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of 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 Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

residential and nonresidential buildings.[12] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 31 provides an upper bound indication of the size of this sector in California.

Table 31: California Building Designer and Energy Consultant Sectors

Sector	Establishments	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 establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;

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

3.2.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

3.2.3.4 Impact on Building Owners and Occupants (Including Homeowners and Potential First-Time Homeowners)

Commercial Buildings

The commercial building sector includes a wide array of building types, including offices, restaurants and lodging, retail, and mixed-use establishments, and warehouses (including refrigerated) (Kenney 2019). Energy use by occupants of commercial

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[12] Establishments in this sector include businesses primarily engaged in evaluating a building's structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily 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.

buildings also varies considerably with electricity used primarily for lighting, space cooling and conditioning, and refrigeration. Natural gas consumed primarily for heating water and for space heating. According to information published in the 2019 California Energy Efficiency Action Plan, there is more than 7.5 billion square feet of commercial floor space in California and consumes 19 percent of California's total annual energy use (Kenney 2019). 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.

Estimating Impacts

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 Statewide CASE Team does not expect the proposed code change for the 2022 code cycle to impact building owners or occupants adversely.

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

The Statewide CASE Team does not expect any significant impacts on manufacturers and distributors of these products.

3.2.3.6 Impact on Building Inspectors

Table 32 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 32: Employment in California State and Government Agencies with Building Inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs[a]	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

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

a. Administration of Housing Programs (NAICS 925110) comprises government establishments 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 establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

3.2.3.7 Impact on Statewide Employment

The Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 3.2.4, the Statewide CASE Team 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 Statewide CASE Team 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.

3.2.4 Economic Impacts

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial building industry, architects, energy consultants, and building inspectors. The Statewide CASE Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2022 code cycle regulations would result in additional spending by those businesses.

Table 33: Estimated Impact that Adoption of the Proposed Measure would have on the California Commercial Construction Sector

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 34: Estimated Impact that Adoption of the Proposed Measure would have on the California Building Designers and Energy Consultants Sectors

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

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.1	**5**	**$0.38**	**$0.52**	**$0.71**

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

3.2.4.1 Creation or Elimination of Jobs

The Statewide CASE Team 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. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 3.2.4 would lead to modest changes in employment of existing jobs.

3.2.4.2 Creation or Elimination of Businesses in California

As stated above, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to HVAC Controls which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes.

3.2.4.3 Competitive Advantage or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is incorporated inside or outside of the state.[13] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2022 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

3.2.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[14] As Table 36 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, with an average of 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 36: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
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.)

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[13] 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.

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

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in investment in any directly or indirectly affected sectors of California's economy.

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

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

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government would be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs 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 Statewide CASE Team does not expect any appreciable change to the state.

Cost to Local Governments

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this 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.

3.2.4.6 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed code change may result in unintended consequences. The Statewide CASE Team has not found any information showing that specific persons would be impacted by this proposal.

3.3 Energy Savings

3.3.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented in this report used the TDV factors that are consistent with the TDV factors presented during the Energy Commission's March 27, 2020 workshop on compliance metrics. (California Energy Commission 2020). The electricity TDV factors include the 15 percent retail adder and the natural gas TDV factors include the impact of methane leakage on the building site. The electricity TDV factors used in the energy savings analyses were obtained from Energy and Environmental Economics, Inc. (E3), the contractor that is developing the 2022 TDV factors for the Energy Commission, in a spreadsheet titled "Electric TDVs 2022 - 15 pct Retail Adj Scaled by Avoided Costs.xlsx". The natural gas TDV factors used in the energy savings analyses were obtained from E3 in a spreadsheet titled "2022_TDV_Policy_Compliant_CH4Leak_FlatRtlAdd_20191210.xlsx". The electricity demand factors used in the energy savings analysis were obtained from E3 in a spreadsheet titled "2022 TDV Demand Factors.xlsx". The final TDV factors that the Energy Commission released in June 2020 use 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. The 20-year GWP values increased the TDV factors slightly. As a result, the TDV energy savings presented in this report are lower than the values that are expected if the final TDV that use 20-year GWP values were used in the analysis. The proposed code changes will be more cost effective using the revised TDV. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

The Statewide CASE Team used EnergyPlus to conduct the energy savings for all code change proposals. Energy models are sourced from the CBECC-Com prototypical building models and are modified to include the proposed changes to the energy standards. The prototype models utilize auto-sized air handler attributes which automatically scale to meet the design criteria necessary to meet the climatic variations for each of the reference cities representing each of the sixteen climate zones. As a result of the variations of the equipment specifications, the impacted air handlers vary by both climate zone and prototype since the criteria for requiring economizers is based on the unit capacity.

3.3.2 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 37. Energy modeling was conducted on prototypical building models that had a direct expansion (DX) cooling coil of between 33,000 Btu/h and 54,000 Btu/h in the model. After investigating all air handlers on CBECC-Com prototype models, the Statewide CASE Team found four building types that would be impacted (note that the HotelSmall prototype model was excluded in this analysis because the impacted units in the only serve corridors which would likely be served by DOAS units in the future and were not likely to be representative of unit performance based on low loading and high outdoor air fraction).

As noted, in Section 3.2.2.2, the Statewide CASE Team worked with AHRI to obtain additional market data through a manufacturer survey. Based on that data, AHRI estimates the California market for products in this capacity range to be greater than 5,000 units.

Table 37: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
RestaurantFastFood	1	2,501	Fast food restaurant with a small kitchen and dining areas. 14% WWR. Pitched roof with an unconditioned attic.
RetailMixedUse	1	9,375	Retail building with WWR -10%. Roof is adiabatic
RetailStripMall	1	9,375	Strip Mall building with WWR -10%
SchoolPrimary	1	24,413	Elementary school with WWR of 0.36

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change 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 that the 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 it assumes the energy features that the software user describes with user inputs. To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building. 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.

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 38 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 energy impacts of the Standard Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

Table 38: 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
RestaurantFast Food	All	Economizer Controls: Control Method	NoEconomizer	DifferentialDryBulb
RetailMixedUse	All except Climate Zone 15 [a]	Economizer Controls: Control Method	NoEconomizer	DifferentialDryBulb
RetailStripMall	All except Climate Zones 6, 7, 10, and 15 [a]	Economizer Controls: Control Method	NoEconomizer	DifferentialDryBulb
PrimarySchool	All except Climate Zones 8, 9, 10, 11, 13, 14, 15 and 16 [a]	Economizer Controls: Control Method	NoEconomizer	DifferentialDryBulb

a. Note: The design cooling capacity of air handlers varies based on the climate zone and several climate zones for the same prototype were not applicable.

CBECC-Com calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). It then applies the 2022 time dependent valuation (TDV) factors to calculate annual energy use in thousands of Btu per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Com also generates TDV energy cost savings values measured in 2023 present value dollars (2023 PV$).

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

Per-unit energy impacts for nonresidential buildings are presented in savings per square foot. Annual energy and peak demand impacts for each prototype building were translated into impacts per square foot by dividing by the floor area of the prototype building. This step allows for an easier comparison of savings across different building types and enables a calculation of statewide savings using the construction forecast that is published in terms of floor area by building type.

3.3.3 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the Energy Commission provided. The Statewide Construction Forecasts estimate new construction that would occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Com, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 39 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 39: Nonresidential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Small Office	OfficeSmall	100%
Large Office	OfficeMedium	50%
	OfficeLarge	50%
Restaurant	RestaurantFastFood	100%
Retail	RetailStandAlone	10%
	RetailLarge	75%
	RetailStripMall	5%
	RetailMixedUse	10%
Grocery Store	Grocery	100%
Non-Refrigerated Warehouse	Warehouse	100%
Refrigerated Warehouse	RefrigWarehouse	N/A
Schools	SchoolPrimary	60%
	SchoolSecondary	40%
Colleges	OfficeSmall	5%
	OfficeMedium	15%
	OfficeMediumLab	20%
	PublicAssembly	5%
	SchoolSecondary	30%
	ApartmentHighRise	25%
Hospitals	Hospital	100%
Hotel/Motels	HotelSmall	100%

3.3.4 Per-Unit Energy Impacts Results

Energy savings and peak demand reductions are presented in Table 40 through Table 43, which summarizes energy savings results from the impacted prototypes. Any instances of negative values are denoted in red with ( ) in the tables below. As noted in Table 38 above, the design cooling loads of the air handling units are auto-sized based on the climate zone, which impacted the applicability of the proposed code change both on air handlers within certain prototype buildings and climate zones. When the auto-sizing function caused all air handler unit capacities to be above or below the impacted capacity range from this proposal (33,000 Btu/h to 54,000 Btu/h), the proposed code change would not be relevant and was indicated as such with “N/A”.

The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. As shown below, the electricity savings per square foot for the first year is expected to range from 0.028 to 1.159 kWh/ft²-yr and marginally increases in natural gas usage from 0.000 to 0.016 therms/ft²-yr depending upon climate zone and prototype building type. Savings increase for cooling-dominated climates as the economizer offsets mechanical cooling with free cooling during mild conditions. There are negative heating savings for most of the Climate Zones. In all simulated prototypes and climate zones, the total TDV energy savings is positive. Demand reductions are negligible for all climate zones.

Table 40: First-Year Energy Impacts Per Square Foot – Expand Economizer Requirements – RestaurantFastFood (1 of 4)

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (kW/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.500	0.000	(0.016)	9.889
2	0.724	0.000	(0.013)	15.073
3	0.932	0.000	(0.014)	20.558
4	0.832	0.000	(0.011)	17.712
5	0.944	0.000	(0.016)	24.349
6	1.109	0.000	(0.010)	25.950
7	1.159	0.000	(0.008)	27.715
8	0.943	0.000	(0.008)	21.587
9	0.880	0.000	(0.008)	19.778
10	0.806	0.000	(0.009)	17.866
11	0.548	0.000	(0.009)	10.969
12	0.695	0.000	(0.010)	14.399
13	0.571	0.000	(0.007)	11.521
14	0.627	0.000	(0.010)	12.400
15	0.516	0.000	(0.004)	12.118
16	0.639	0.000	(0.012)	13.460

Table 41: First-Year Energy Impacts Per Square Foot – Expand Economizer Requirements – RetailMixedUse (2 of 4)

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (kW/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.267	0.000	(0.006)	4.479
2	0.378	0.000	(0.004)	7.504
3	0.577	0.000	(0.002)	12.566
4	0.439	0.000	(0.002)	9.060
5	0.569	0.000	(0.003)	13.804
6	0.624	0.000	(0.000)	14.496
7	0.732	0.000	0.000	17.534
8	0.486	0.000	(0.000)	10.870
9	0.436	0.000	(0.001)	9.559
10	0.366	0.000	(0.001)	7.817
11	0.249	0.000	(0.002)	4.661
12	0.335	0.000	(0.003)	6.589
13	0.268	0.000	(0.002)	5.366
14	0.310	0.000	(0.003)	5.919
15	N/A	N/A	N/A	N/A
16	0.296	0.000	(0.003)	6.126

Table 42: First-Year Energy Impacts Per Square Foot – Expand Economizer Requirements – RetailStripMall (3 of 4)

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (kW/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.156	0.000	(0.007)	1.757
2	0.287	0.000	(0.004)	4.924
3	0.458	0.000	(0.004)	9.092
4	0.351	0.000	(0.003)	8.251
5	0.453	0.000	(0.005)	9.873
6	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A
8	0.345	0.000	(0.002)	6.537
9	0.331	0.000	(0.002)	6.809
10	N/A	N/A	N/A	N/A
11	0.176	(0.000)	(0.003)	2.578
12	0.250	0.000	(0.003)	4.603
13	0.209	0.000	(0.002)	3.867
14	0.225	0.000	(0.003)	3.859
15	N/A	N/A	N/A	N/A
16	0.249	0.000	(0.004)	4.839

Table 43: First-Year Energy Impacts Per Square Foot – Expand Economizer Requirements – PrimarySchool (4 of 4)

Climate Zone	Electricity Savings (kWh/ft2)	Peak Electricity Demand Reductions (kW/ft2)	Natural Gas Savings (therms/ft2)	TDV Energy Savings (TDV kBtu/ft2)
1	0.028	0.000	(0.001)	0.367
2	0.047	0.000	(0.000)	0.902
3	0.071	0.000	(0.000)	1.441
4	0.060	0.000	(0.000)	1.191
5	0.067	0.000	(0.000)	1.517
6	0.070	(0.000)	(0.000)	1.172
7	0.086	0.000	(0.000)	2.002
8	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A
12	0.049	0.000	(0.000)	0.951
13	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A
15	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A

3.4 Cost and Cost Effectiveness

3.4.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in Section 3.3.2. TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis (30 years for residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 15 years.

3.4.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings and alterations that are realized over the 15-year period of analysis are presented in PV 2023 dollars in the following tables (see Appendix N for similar tables in nominal dollar terms). The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 44: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis, Per Square Foot Analysis – Expand Economizer Requirements – RestaurantFastFood (1 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$1.23	($0.35)	$0.88
2	$1.63	($0.29)	$1.34
3	$2.14	($0.31)	$1.83
4	$1.82	($0.24)	$1.58
5	$2.52	($0.35)	$2.17
6	$2.53	($0.22)	$2.31
7	$2.65	($0.19)	$2.47
8	$2.11	($0.18)	$1.92
9	$1.95	($0.19)	$1.76
10	$1.80	($0.20)	$1.59
11	$1.18	($0.21)	$0.98
12	$1.51	($0.23)	$1.28
13	$1.20	($0.17)	$1.03
14	$1.35	($0.24)	$1.10
15	$1.18	($0.10)	$1.08
16	$1.46	($0.27)	$1.20

Table 45: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis, Per Square Foot Analysis – Expand Economizer Requirements – RetailMixedUse (2 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.53	($0.13)	$0.40
2	$0.75	($0.08)	$0.67
3	$1.18	($0.06)	$1.12
4	$0.86	($0.05)	$0.81
5	$1.31	($0.08)	$1.23
6	$1.30	($0.01)	$1.29
7	$1.56	($0.00)	$1.56
8	$0.98	($0.01)	$0.97
9	$0.87	($0.02)	$0.85
10	$0.73	($0.04)	$0.70
11	$0.47	($0.06)	$0.41
12	$0.65	($0.06)	$0.59
13	$0.52	($0.05)	$0.48
14	$0.60	($0.07)	$0.53
15	N/A	N/A	N/A
16	$0.62	($0.07)	$0.55

Table 46: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis, Per Square Foot Analysis – Expand Economizer Requirements – RetailStripMall (3 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.31	($0.15)	$0.16
2	$0.54	($0.10)	$0.44
3	$0.90	($0.09)	$0.81
4	$0.81	($0.08)	$0.73
5	$0.98	($0.11)	$0.88
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	$0.62	($0.04)	$0.58
9	$0.65	($0.05)	$0.61
10	N/A	N/A	N/A
11	$0.30	($0.07)	$0.23
12	$0.48	($0.07)	$0.41
13	$0.40	($0.06)	$0.34
14	$0.42	($0.08)	$0.34
15	N/A	N/A	N/A
16	$0.52	($0.09)	$0.43

Table 47: 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis, Per Square Foot Analysis – Expand Economizer Requirements – PrimarySchool (4 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	$0.05	($0.02)	$0.03
2	$0.09	($0.01)	$0.08
3	$0.14	($0.01)	$0.13
4	$0.11	($0.01)	$0.11
5	$0.15	($0.01)	$0.14
6	$0.11	($0.01)	$0.10
7	$0.18	($0.00)	$0.18
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	$0.09	($0.01)	$0.08
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

3.4.3 Incremental First Cost

Incremental first cost is the initial cost to adopt more efficient equipment or building practices when compared to the cost of an equivalent baseline project. Therefore, it was important that the Statewide CASE Team consider first costs in evaluating overall measure cost effectiveness. Incremental first costs are based on data available today and can change over time as markets evolve and professionals become familiar with new technology and building practices.

Incremental first cost was determined by comparing a minimally code compliant unit with a similar capacity model representing the proposed code change, in this case, an economizer for a smaller system. In most cases, these changes are expected to occur with the manufacturer prior to equipment delivery. One manufacturer commented that field-accessory installations are common for some installers which also occurring for this market, for the purposes of calculating incremental first cost, the Statewide CASE Team expected 100 percent of the costs to occur with the manufacturer for both the cost of the economizer and the costs of FDD. After reaching out to several manufacturers on incremental costs, most manufacturers requested for information to be collected anonymously by the trade association AHRI.

In July and August of 2020, the Statewide CASE Team worked with AHRI to develop a survey to obtain incremental cost information from their members. Nine out of 34 manufacturer responded to the survey with cost information. The data indicated that costs were higher than our initial IMC from the Draft CASE Report which utilized RSMeans and to adjust data obtained from previous CASE studies. As a result, the IMC has been increased to reflect this finding.

The Statewide CASE Team understands that economizers have seen significant changes over the previous nine years when the Statewide CASE Team collected these costs with many manufacturers moving to higher quality damper construction and advanced digital controls. While first costs appear to have increased on many units, the CASE team also expects those changes will reduce failure rate and decrease the maintenance costs and recommend future studies to verify to the degree to which those efforts have reduced maintenance needs.

3.4.4 Incremental Maintenance and Replacement Costs

Incremental maintenance cost 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 15-year period of analysis. The present value of equipment maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2022 TDV. The present value of maintenance costs that occurs in the n^{th} year is calculated as follows:

$$\textbf{Present Value of Maintenance Cost} = \textbf{Maintenance Cost} \times \left\lfloor \frac{\mathbf{1}}{\mathbf{1 + d}} \right\rfloor^{\mathbf{n}}$$

Incremental Maintenance and Replacement Costs are based on the previous CASE Report on Light Commercial Unitary HVAC, which used data from PG&E’s AirCare Plus maintenance program to determine the failure rate of economizers to be 48 percent over a 15-year useful life of the equipment. Maintenance costs assumed 48 percent of the cost at the halfway point of the useful life, resulting in a cost of

$$\textbf{Economizer Replacement Costs}: \$\mathbf{292} = \mathbf{48\%}\ \mathbf{x}\ \$\mathbf{760} \times \left\lfloor \frac{\mathbf{1}}{\mathbf{1 + 0.3}} \right\rfloor^{\mathbf{7.5}}$$

However, as noted in Section 3.2.2.1, economizers have been steadily improving in quality which would reduce the economizer failure rates for new systems. Under the FDD measure in 2013, these capabilities were expected to reduce annual service costs by $30/kW which were conservatively reduced by 50 percent to $15/kW or $16 per ton of cooling, representing a cost savings of $44 to $72 for the units being considered. The cost savings result from reduced service costs due to replacing certain types of preventative maintenance with automated fault detection. After scaling the costs using RS Means historical data, a cost of $57 to $94 depending on the unit capacity was determined.

In combining both the costs of a replacement economizer in year 7.5 and the annual cost savings from maintenance savings from FDD, the total incremental maintenance savings over the 15-year analysis period is $410 per year. As noted in the previous section, the Statewide CASE Team is currently working with AHRI to obtain additional data on the incremental costs of economizers and would use that to validate and update the assumptions within this report.

3.4.5 Cost Effectiveness

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

The Energy Commission establishes the procedures for calculating cost effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. The incremental first cost and incremental maintenance costs over the 15-year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were also included in the evaluation.

Design costs were not included nor were the incremental costs of code compliance verification.

According to the Energy Commission's definitions, a measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 15 years by the total incremental costs, which includes maintenance costs for 15 years. The B/C ratio was calculated using 2023 PV costs and cost savings. Results of the per-unit cost-effectiveness analyses for Expand Economizer Requirements are presented in Table 48 through Table 51.

The proposed measure saves money over the 15-year analysis period relative to the existing conditions. Analysis of the lower capacity economizing measure found four impacted prototype models and 51 combinations of prototype models and climate zones which had air handlers impacted by this measure. Of the 51 prototype-climate zone scenarios impacted, only two instances (4 percent) had a B/C ratio below 1, the RetailStripMall prototype for Climate Zone 1 (Eureka) and Climate Zone 11 (Red Bluff). Per-square-foot costs and savings are in relation to the full area of the prototype models which have varying amounts of the building area impacted and account for the large differences between prototype models such as the PrimarySchool prototype which had only one small air handler impacted for the eight climate zone runs analyzed.

Table 48: 15-Year Cost-Effectiveness Summary Per Square Foot – Expand Economizer Requirements – RestaurantFastFood (1 of 4)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.88	$0.32	2.78
2	$1.34	$0.32	4.24
3	$1.83	$0.32	5.79
4	$1.58	$0.32	4.99
5	$2.17	$0.32	6.86
6	$2.31	$0.32	7.31
7	$2.47	$0.32	7.80
8	$1.92	$0.32	6.08
9	$1.76	$0.32	5.57
10	$1.59	$0.32	5.03
11	$0.98	$0.32	3.09
12	$1.28	$0.32	4.05
13	$1.03	$0.32	3.24
14	$1.10	$0.32	3.49
15	$1.08	$0.32	3.41
16	$1.20	$0.32	3.79

Table 49: 15-Year Cost-Effectiveness Summary Per Square Foot – Expand Economizer Requirements – RetailMixedUse (2 of 4)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.40	$0.25	1.58
2	$0.67	$0.25	2.64
3	$1.12	$0.25	4.42
4	$0.81	$0.25	3.19
5	$1.23	$0.25	4.86
6	$1.29	$0.25	5.10
7	$1.56	$0.25	6.17
8	$0.97	$0.25	3.82
9	$0.85	$0.25	3.36
10	$0.70	$0.25	2.75
11	$0.41	$0.25	1.64
12	$0.59	$0.25	2.32
13	$0.48	$0.25	1.89
14	$0.53	$0.25	2.08
15	N/A	N/A	N/A
16	$0.55	$0.25	2.16

Table 50: 15-Year Cost-Effectiveness Summary Per Square Foot – Expand Economizer Requirements – RetailStripMall (3 of 4)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.16	$0.25	0.62
2	$0.44	$0.25	1.73
3	$0.81	$0.25	3.20
4	$0.73	$0.25	2.90
5	$0.88	$0.25	3.47
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	$0.58	$0.25	2.30
9	$0.61	$0.25	2.40
10	N/A	N/A	N/A
11	$0.23	$0.25	0.91
12	$0.41	$0.25	1.62
13	$0.34	$0.25	1.36
14	$0.34	$0.25	1.36
15	N/A	N/A	N/A
16	$0.43	$0.25	1.70

Table 51: 15-Year Cost-Effectiveness Summary Per Square Foot – Expand Economizer Requirements – PrimarySchool (4 of 4)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$0.03	$0.03	1.01
2	$0.08	$0.03	2.48
3	$0.13	$0.03	3.96
4	$0.11	$0.03	3.27
5	$0.14	$0.03	4.17
6	$0.10	$0.03	3.22
7	$0.18	$0.03	5.50
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	$0.08	$0.03	2.61
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

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

Table 52: Construction Area Weighted Average Benefit-to-Cost Ratio Summary – Expand Economizer Requirements

Climate Zone	Statewide Construction Forecast (Million Square Feet)	Construction Area Weighted Average Benefit-to-Cost Ratio
1	0.08	1.99
2	0.45	3.29
3	1.91	4.85
4	0.97	4.00
5	0.20	5.54
6	1.33	6.39
7	1.09	7.09
8	1.89	4.98
9	2.87	4.61
10	2.30	4.44
11	0.47	2.34
12	2.12	3.06
13	1.02	2.58
14	0.50	2.90
15	0.29	3.41
16	0.17	3.11

3.5 First-Year Statewide Impacts

3.5.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per-unit savings, which are presented in Section 3.3.4 by assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type). Savings for alterations and additions assumed a 20-year lifecycle for HVAC package equipment and applied that replacement rate to the existing building stock of applicable building types.

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2023. The 15-year energy cost savings represent the energy cost savings over the entire 15-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account. Table 53 presents the first-year statewide energy and energy cost savings from newly constructed buildings by climate zone. Energy and costs savings for alterations and additions can be found in Table 54.

Table 53: Statewide Energy and Energy Cost Impacts – New Construction – Expand Economizer Requirements

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.1	0.02	0.00	(0.00)	$0.02
2	0.5	0.14	0.01	(0.00)	$0.24
3	1.9	0.80	0.06	(0.01)	$1.53
4	1.0	0.34	0.01	(0.00)	$0.65
5	0.2	0.08	0.01	(0.00)	$0.18
6	1.3	0.71	0.05	(0.00)	$1.45
7	1.1	0.53	0.03	(0.00)	$1.12
8	1.9	0.87	0.03	(0.01)	$1.75
9	2.9	1.33	0.06	(0.01)	$2.62
10	2.3	0.79	0.04	(0.01)	$1.55
11	0.5	0.08	0.00	(0.00)	$0.14
12	2.1	0.58	0.03	(0.01)	$1.04
13	1.0	0.19	0.00	(0.00)	$0.35
14	0.5	0.15	0.01	(0.00)	$0.26
15	0.3	0.05	0.00	(0.00)	$0.10
16	0.2	0.04	0.00	(0.00)	$0.08
TOTAL	**17.6**	**6.69**	**0.34**	**(0.06)**	**$13.08**

a. First-year savings from all buildings completed statewide in 2023.

Table 54: Statewide Energy and Energy Cost Impacts – Alterations & Additions – Expand Economizer Requirements

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.178	0.03	0.00	(0.00)	$0.05
2	1.060	0.28	0.02	(0.00)	$0.50
3	4.451	1.64	0.11	(0.02)	$3.14
4	2.265	0.70	0.02	(0.01)	$1.32
5	0.469	0.17	0.02	(0.00)	$0.38
6	3.574	1.64	0.10	(0.01)	$3.34
7	2.589	1.19	0.06	(0.01)	$2.52
8	5.066	1.98	0.08	(0.01)	$3.96
9	7.833	2.97	0.12	(0.02)	$5.87
10	6.142	2.00	0.10	(0.02)	$3.91
11	1.112	0.18	0.01	(0.00)	$0.30
12	5.052	1.26	0.06	(0.02)	$2.26
13	2.506	0.41	0.01	(0.00)	$0.74
14	1.366	0.37	0.01	(0.01)	$0.63
15	0.769	0.11	0.01	(0.00)	$0.23
16	0.441	0.11	0.01	(0.00)	$0.19
TOTAL	**45**	**15.02**	**0.75**	**(0.13)**	**$29.35**

a. First-year savings from all buildings completed statewide in 2023.

Table 55: Statewide Energy and Energy Cost Impacts – New Construction, Alterations, and Additions – Expand Economizer Requirements

Construction Type	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (PV$ million)
New Construction	7	0.34	(0.06)	13.1
Additions and Alterations	15	0.75	(0.13)	29.3
TOTAL	**22**	**1.09**	**(0.19)**	**42.4**

a. First-year savings from all alterations completed statewide in 2023.

3.5.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO2e per GWh based on the average emission factors for the CACX EGRID subregion.

Table 56 below presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 4,159 metric tons of carbon dioxide equivalents (metric tons CO2e) would be avoided.

Table 56: First-Year Statewide GHG Emissions Impacts for Expand Economizer Requirements

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMTherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Million Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Million Metric Tons CO2e)
TOTAL	21.7	5,220	(0.2)	(1,061)	4,159

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.36 MTCO2e/GWh and 5454.42 MTCO2e/MMTherms.

3.5.3 Statewide Water Use Impacts

The proposed code change would not result in water savings.

3.5.4 Statewide Material Impacts

This measure would increase the amount of steel needed to provide economizers on the approximately 3,000 units that would now require economizers. In order to calculate statewide impacts, the Statewide CASE Team determined the number of air handler units impacted for each prototype and climate zone combination. A value of 60 lbs was used to estimate the amount of steel that would be added.

Table 57: First-Year Statewide Impacts on Material Use

Material	Impact (I, D, of NC)a	Impact on Material Use (per year)	
		Per-Unit Impacts (lbs/ft2)	First Year[b] Statewide Impacts (pounds)
Steel	I	0.002241	190,746

a. Material Increase (I), Decrease (D), or No Change (NC) compared to base case (lbs/yr).

b. First-year savings from all buildings completed statewide in 2023.

3.5.5 Other Non-Energy Impacts

Indoor air quality would improve with the higher fresh air rates during hours the mild hours economizer is providing free cooling.

3.6 Proposed Revisions to Code Language

3.6.1 Guide to Markup 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 red underlining (new language) and ~~strikethroughs~~ (deletions).

3.6.2 Standards

SECTION 120.2 – REQUIRE CONTROLS FOR SPACE-CONDITIONING SYSTEMS

(i)**Economizer Fault Detection and Diagnostics (FDD).** All newly installed air handlers with a mechanical cooling capacity~~ greater than ~~over~~54,000 Btu/hr~~33,000 Btu/hr and an installed air economizer shall include a stand-alone or integrated Fault Detection and Diagnostics (FDD) system in accordance with Subsections 120.2(i)1 through 120.2(i)8.

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)

(e) **Economizers.**

1. Each cooling air handler that has a design total mechanical cooling capacity over 33,000 ~~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 100 percent of the design supply air quantity as outside-air; or

B. A water economizer capable of providing 100 percent of the expected system cooling load, at outside air temperatures of 50°F dry-bulb and 45°F wet-bulb and below.

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.

EXCEPTION 6 to Section 140.4(e)1: Systems providing cooling and heating decoupled from ventilation and that utilize a dedicated outdoor air system for ventilation in accordance with 140.4(p)1B. ~~design to operate at 100 percent outside air at all times.~~

TABLE 140.4-C CHILLED WATER SYSTEM COOLING CAPACITY

Climate Zones	Total Building Chilled Water System Capacity, Minus Capacity of the Cooling units with Air Economizers	
	Building Water-Cooled Chilled Water System	Air-Cooled Chilled Water Systems or District Chilled Water Systems
15	≥ 960,000 Btu/h (280 kW)	≥ 1,250,000 Btu/h (365 kW)
1-14	≥720,000 Btu/h (210 kW)	≥940,000 Btu/h (275 kW)
16	≥1,320,000 Btu/h (385 kW)	≥1,720,000 Bu/h (505 kW)

TABLE 140.4-D ECONOMIZER TRADE-OFF TABLE FOR COOLING SYSTEMS

Climate Zone	Efficiency Improvement [a]
1	70%
2	65%
3	65%
4	65%
5	70%
6	30%
7	30%
8	30%
9	30%
10	30%
11	30%
12	30%
13	30%
14	30%
15	30%
16	70%

[a] If a unit is rated with an annualized or part-load metric ~~IPLV, IEER or SEER~~, then to eliminate the required ~~air or water~~ economizer, only the ~~applicable~~ annualized or part-load minimum cooling efficiency of the ~~HVAC~~ unit must be increased by the percentage shown. If the ~~HVAC~~ unit is only rated with a full load metric, ~~such as~~ like EER or COP cooling, then that metric must be increased by the percentage shown. To determine the efficiency required to eliminate economizer, when the unit *equipment efficiency* is rated with an energy-input divided by work-output metric, the metric shall first be converted to COP prior to multiplying by the *efficiency* improvement percentage and then converted back to the rated metric.

3.6.3 Reference Appendices

Appendix JA6 – HVAC System Fault Detection and Diagnostic Technology

JA 6.3 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 33,000 ~~54,000~~ Btu/hr cooling capacity, with the ability to detect the faults specified in Section 120.2(i). Each air conditioning system manufacturer, controls supplier, or FDD supplier wishing to certify that their FDD analytics conform to the FDD requirements of Title 24, Part 6, may do so in a written declaration. This requires that a letter be sent to the California Energy Commission declaring that the FDD conforms to Title 24, Part 6, Section 120.2(i). The declaration at the end of this section shall be used to submit to the California Energy Commission.

(sections omitted)

3.6.4 ACM Reference Manual

5.7.4 Outdoor Air Controls and Economizers

5.7.4.1 Outside Air Controls

Maximum 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	1.0 for all systems above 33,000 ~~54,000~~ Btu/h cooling capacity; 0.9 for other systems.
Standard Design	1.0 for all systems above 33,000 ~~54,000~~ Btu/h cooling capacity; 0.9 for other systems
Standard Design: Existing Buildings	

(tables with no changes have been 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 air enthalpy. • Differential dry-bulb and enthalpy. The system shifts to 100 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.
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 <33,000 ~~54,000~~ 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)
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 33,000 ~~54,000~~ Btu/h at Air-Conditioning, Heating, and Refrigeration Institute (AHRI) conditions
Standard Design: Existing Buildings	

(tables with no changes have been omitted)

3.6.5 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 reflect the change in economizer requirement threshold from 54,000 Btu/h to 33,000 Btu/h in the beginning of Section 4.5.2.2.

3.6.6 Compliance Documents

Changes to NRCC-MCH-E would be needed to incorporate both the lower capacity requirement as well as the related DOAS exception (exception 6).

4. Dedicated Outdoor Air Systems (DOAS)

4.1 Measure Description

4.1.1 Measure Overview

The proposed codes changes would add a prescriptive section to 140.4 specifically for all nonresidential dedicated outside air system unit (DOASu) to require:

1. A minimum level of ventilation energy recovery with bypass (free cooling) capabilities. If a DOASu (see definition in Section 4.1.2 of this report) does not have these capabilities, there would be an exemption requiring the heating and cooling system to include an economizer.
2. DOASu fan speed control capabilities.
3. Heating and cooling system terminal fans that cycle off when not in use.
4. Requiring ventilation air be directly supply to each space or downstream of any terminal cooling or heating coil.
5. A maximum reheat limit on ventilation supply air for DOASus with active cooling, such as DX-DOAS.
6. Total system fan power requirements in sync with enhanced fan power criteria proposed in a different CASE measure in 140.4 (c) on fans both above 1 kW.

The proposal would also expand current acceptance testing to include DOAS units. The proposal would require enhancements to the ACM to define a DOAS system and changes to the code compliance software CBECC-Com for DOAS.

The proposal would ensure the efficiency of all types of DOAS installations, while also making appropriate allowances to accommodate the wide range of products and configurations in California. The savings and cost effectiveness could be significant, with the statewide savings estimated around 40 GWh in the first year. The proposed prescriptive code measure could also help form the basis of reach codes and incentive programs to continue increasing efficiency thresholds as the technology matures.

4.1.2 Measure History

DOAS have high potential to reduce HVAC energy usage in nonresidential buildings and are also a key solution for all-electric buildings. They are used in a majority of California nonresidential net zero energy projects. Also, DOAS are becoming increasingly popular in California and nationwide because they offer more flexibility for designers and building owners. The Statewide CASE Team research found that the market share of DOAS projects in California between 2012 and 2019 jumped from 9 percent to 19 percent for new construction and from three percent to five percent for alterations (ConstructConnect Research 2020). However, Title 24, Part 6 does not currently have a definition or prescriptive requirements for DOAS. The proposed code changes would generate cost-effective energy savings, help protect consumers, and support state goals to move towards carbon neutral buildings.

DOAS refers to supplying only outdoor air, as opposed to mixed air systems that supply a blend of outdoor and return air. In this proposal, consistent with ASHRAE educational materials, “DOASu” would refer to the unit supplying the outdoor air, and the term “DOAS system” would refer to the DOASu plus the space heating and cooling system (heating and cooling system) that provides comfort control in each of the zones within the building.

DOASu’s can be designed to supply outdoor air that is:

- Filtered only
- Tempered as needed by recovering dry sensible heat from the return air (heat recovery ventilators)
- Tempered as needed by recovering dry and moist heat from the return air (energy recovery ventilators)
- Actively dehumidified and conditioned (DX-DOAS or custom DOAS).

The primary energy savings come from 1) the ability to turn off zone heating and cooling systems when not needed while still ventilating and 2) using heat recovery or energy recovery to pre-condition ventilation air. The technology in all the above types is well understood. In a survey of 35 projects with DOAS in California, 54 percent included ventilation heat recovery. Of those, 26 percent also had the ability to bypass the recovery equipment when the outside air temperature did not need to be changed (known as “free cooling”.) Based on the analysis presented in this report, in some climate zones DOAS with the recommended prescriptive criteria can reduce source energy by 20 percent to 30 percent with the same or lower operational energy costs as a mixed air system.

DOAS is already recognized as a key strategy for reducing energy in HVAC systems in several other energy codes. See Table 58.

Table 58: DOAS Requirements in Other Codes

Energy Codes Outside California	**Summary of DOAS Requirements**
Washington State Energy Code	Sets DOAS as the primary prescriptive pathway for nonresidential buildings with detailed criteria on DOASu and heating and cooling system controls.
IECC 2018 Energy Code	Includes DOAS as an enhanced energy efficiency credit in a list of additional efficiency packages to be selected. The code stipulates what type of DOASu and controls this would include.
ASHRAE 90.1 2019	Includes equipment efficiencies for DX-DOAS packaged equipment. Sets efficiency criteria on components only and does not specify DOAS as a prescriptive section explicitly. Includes a general fan power requirement. Includes supply air reset controls for units with dehumidification. Includes requirements on exhaust air heat recovery.

California code enhancement teams have recognized a need to address DOAS in Title 24, Part 6 since 2016. Below is a summary of studies done specifically to lay the groundwork:

- PG&E Code Readiness field efforts to monitor market typical DOAS and advanced low energy DOAS (2016 – ongoing).
- Northwest Energy Efficiency Alliance (NEEA) Pilot sites for Very High Efficiency (VHE) DOAS.

Both efforts helped to inform technical details and limits where building codes and standards can play an important role.

4.1.3 Technical Description

4.1.3.1 Main types of DOASU

The main types of DOASu's are those that:

- Only ventilate and filter air (unit ventilators)
- Recover dry sensible heat only (heat recovery ventilators (HRV))
- Recover dry and moist heat (energy recovery ventilators (ERV))
- Actively dehumidify and condition ventilation (DX-DOAS or custom DOAS).

DX-DOAS, which are manufactured products which includes a direct-expansion refrigerant system for just the ventilation air, is commonly used in relatively humid climates in conjunction with VRF heat pumps. These products are rated based on their moisture removal efficiency (MRE) using the AHRI 920 standard.

When installed in California, which is relatively dry, active conditioning of the ventilation air with a DX-DOAS or custom DOASu's tends to represent about half the installations of DOAS observed in a sample of 35 projects. Small commercial buildings, under 30,000 sf, tend towards HRV or ERV for ventilation verses DX-DOAS or custom which suggest active conditioning units are more expensive and only cost effective in larger applications.

Many ERV and HRV products are used as the DOASu to recover ventilation energy in California. They use various types of energy recovery cores or wheels. For most nonresidential buildings the outdoor air is dry enough to manage moisture and only recover sensible heat (HRV).

In some small nonresidential buildings outdoor air is brought in directly to each heating and cooling system, such as a heat pump unit and mixed with return air in each zone. For units which do not require an economizer, the outdoor duct is sized for ventilation only. While this is a rational strategy in buildings with few thermal zones it can be scaled to multi-zoned buildings with the use of multi-headed heat pumps or what is commonly known as Variable Refrigerant Flow (VRF) systems as demonstrated in Figure 1.

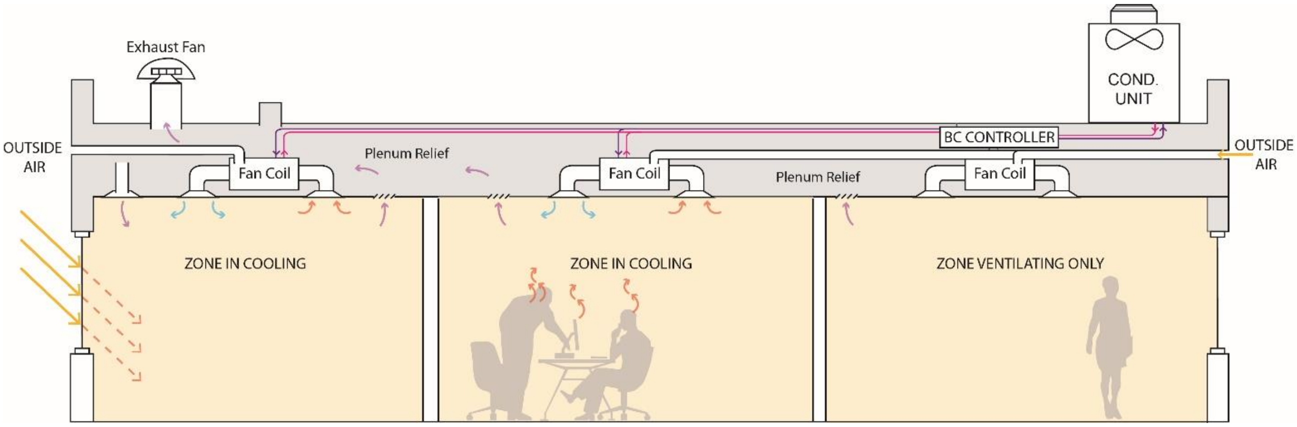

Figure 1: Small nonresidential HVAC system with directly ducted outdoor air to fan coils.

While ducting each indoor fan coil is sometimes the lowest cost, such designs use much more energy than a central DOASu, especially in regions with more extreme temperatures, which can maintain ventilation and operate independently of the heating and cooling systems to allow zone fans to cycle on and off. The proposed code enhancement would dis-incentivize the use of such designs in new construction.

4.1.3.2 Code Readiness Data Findings

In field studies conducted by PG&E's Code Readiness Program team from 2016 and ongoing, several systems were monitored with various configurations of DOAS and a demonstration project of a high efficiency HRV system. All sites utilized a DOAS with a separate heating and cooling system. These sites provided a detailed set of reference information on how DOAS configurations are designed, controlled, and operated for several types of DOAS units and configurations. The findings from initial data review of the sites, which are still ongoing as of 6/1/2020, recommends setting minimum DOAS fan and supply air control capabilities and defining a decoupled ventilation configurations between the DOAS unit and zone heating and cooling system to ensure a level of efficient operations. Key features observed included in Table 59.

Table 59: DOAS Field Site Observations

Observation from Study	Impact on Statewide CASE Team Proposal
Half the sites monitored used once through ventilation with a DX-DOAS and no ventilation heat recovery and the other half used central HRVs with ventilation heat recovery.	The proposal needed to accommodate both configurations, and is the basis of the exception included linked to 140.4 e.
Sites with a form of ventilation heat recovery were able to reduce their operational HVAC morning and afternoon peak demand by recovering heat, even in mild climates such as Climate Zones 3 and 4.	Provided a reference point for operational savings.
In sites where DOASu fans did not have modulating fan speed capabilities, fans were set to the required design airflow rate by increasing the static pressure and reducing the airflow from a nominal rated capacity to the design. This resulted in excess DOASu fan energy for units selected at sizes much lower than their capacity.	Provided a reference point for modulating fan capabilities for DOASu improves operations.
In sites with heating and cooling system fan coils for space conditioning most fans were set to run at constant volume or at a minimum speed of 1/3 or ½ capacity. This resulted in zone fans running during all hours of occupancy even if no active cooling or heating was being requested.	Provided a reference point for energy use in operations of this configuration.
In one of the DX-DOAS sites, supply air controls were not properly configured during installation and the system was operating against the space heating and cooling system for over 6 months until discovered. Criteria on unit inspection and supply air control could have caught this situation during installation.	Provided a reference point for importance of system inspection at startup. Currently DOAS units are not required to be inspected for all functionalities.
In a site with a high efficiency HRV with bypass and free cooling controls the operational cost was reduced by 33% from an equivalent variable speed roof top unit solution in Climate Zone 12 in Davis, CA.	Provided a range of energy savings potential in small existing buildings from using DOAS.

4.1.4 Summary of Proposed Changes to Code Documents Summary of Proposed Changes to Code Documents

This measure would add prescriptive requirements for DOAS units in nonresidential buildings to include a minimum level of efficiency criteria and control capabilities and an exception to require airside economizing if additional DOAS efficiency measures are included. A DOAS in this context is defined as a HVAC system which delivers 100 percent ventilation air separately from any heating and cooling system. The components to be required for a DOAS are summarized below.

General requirement: this would apply to all DOAS systems being used as a buildings primary means of ventilation of any size in a nonresidential application.

The sections below summarize how the standards, Reference Appendices, ACM Reference Manuals, and compliance documents would be modified by the proposed change. See Section 4.6 of this report for detailed proposed revisions to code language.

4.1.4.1 Summary of Changes to the Standards

This proposal would modify the following sections of the California Energy Code as shown below. See Section 4.6 of this report for marked-up code language.

Subsection 100.1: The purpose of this code change is to add definitions for DX-DOAS, ISCOP, and ISMRE. These definitions are included even though they are not referenced elsewhere in the proposed code language in anticipation of Energy Commission adopting DX-DOAS efficiency standards matching DOE and ASHRAE 90.1-2019.

Subsection 120.1 (h): The purpose of this code change is to ensure that Section 120.2 (f) is required for all DOASu, including units without mechanical cooling or heating.

Subsection 140.4 (c): The purpose of this code change is to add additional pressure credits for systems without heating or cooling components. For HRV/ERV systems, this would reduce the fan power allowance and is in line with ASHRAE 90.1. Alternatively, the fan power pressure credit and fan FEI CASE measure may supersede this recommendation.

Subsection 140.4 (e): The purpose of this code change is to add additional language to the exception for DOAS systems to require an airside economizer to reference the criteria of Section 140.4 (p), which would be added to the code.

Subsection 140.4 (p): The purpose of this code change is to add a new section for prescriptive criteria to be applied to any DOAS used as a building’s primary means of ventilation. Criteria include:

1. A separate cooling system with an economizer or a DOAS unit with a minimum level of ventilation sensible energy recovery with bypass capabilities for free cooling, lower thresholds for demand control ventilation, and an

increase in the designed capacity of the system to 150% airflow (see 4.2.2.6).

2. DOAS unit fan systems shall have the ability to modulate fan speed for system balancing and future flexibility.
3. Zone terminal fans for cooling or heating must cycle to off if no call for conditioning.
4. Decoupled ventilation pathway for outdoor air to each space.
5. DX-DOAS or DOAS with active cooling must have a maximum reheat limit of 60F when in cooling mode.
6. A total system fan power in line with prescriptive fan power tables in 140.4 (c).

4.1.4.2 Summary of Changes to the Reference Appendices

JOINT APPENDICIES

The definitions in the joint appendices would be updated to match the standard for DOAS and DX-DOAS. Nonresidential acceptance tests would be modified to include DOAS units and control sequences.

4.1.4.3 Summary of Changes to the Nonresidential ACM Reference Manual

This proposal would modify the following sections of the Nonresidential ACM Reference Manual as shown below. See Section 4.6.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

4.1.4.4 Summary of Changes to the Nonresidential Compliance Manual

The proposed code change would modify the following section of the Nonresidential Compliance Manual:

An example problem for DOAS prescriptive criteria and pathways would be developed to demonstrate when the criteria of each is required based on a small office. See Section 4.6.5 of this report for the detailed proposed revisions to the text of the Compliance Manuals.

4.1.4.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 4.6.6.

Document 1 NRCA MCH02-A – Modify the outdoor air test to include the ability to validate a DOAS unit. Minor modifications to allow the form to be completed.

Document 2 NRCA MCH05-A – Add a component to the economizer controls test to validate bypass or free cooling capabilities of a DOAS with ventilation heat recovery. Fundamentally the test procedure is very similar and would expand the test only for those units.

NRCC-MCH-E would need to be revised to document new prescriptive requirements specific to DOAS.

Compliance documents for performance software would be modified to reflect key inputs of a DOAS unit. Current compliance via the performance path does not do this.

4.1.5 Regulatory Context

4.1.5.1 Existing Requirements in the California Energy Code

Currently, DOASu are only referenced in an existing exception to economizing. The code effectively states that the DOASu itself does not need an economizer, since it is 100 percent outdoor air and does not modulate return air of any kind. This exception is not in relation to any separate heating and cooling system and is purely for the ventilation unit itself.

Outside of this direct reference to the DOASu, the energy code indirectly addresses heating and cooling systems which traditionally are installed in conjunction with a DOASu. In 140.4 (e) for economizers, there is an exemption for heating and cooling systems with higher installed efficiencies which is typically used by variable refrigerant flow or mini split systems which do not have an economizer.

Criteria is included in California energy code for fan power allowances which apply to all system types and is utilized to set minimum efficiency criteria on any DOASu fan today which is installed above the 5 hp limit.

Other mentions of a DOAS are included in the Alternative Calculation Method (ACM) as a system type and is now an option for a system type in the ruleset and software, CBECC-Com. The current definitions in the software are fairly basic and still assume the unit provides full space sensible conditioning as well as ventilation.

There are other code change proposals that overlap with fan energy and fan power limits being proposed in the 2022 code cycle. Based on the intent of those measures, the DOAS measure would be adjusted to incorporate those changes and reference the prescriptive sections of code being proposed. Overall, this would not change the outcome of the measure.

4.1.5.2 Relationship to Requirements in Other Parts of the California Building Code

The primary overlap with Title 24, Part 4 of the mechanical building code regarding ventilation rates and equipment efficiencies. Both overlaps existed prior to any additional criteria for DOAS for all space types and mechanical system efficiencies.

4.1.5.3 Relationship to Local, State, or Federal Laws

There are no local, state, or federal laws which direct set minimum whole system efficiency criteria for a DOAS. Federal law is working to develop a test method for rating the moisture removal efficiency of a specific DOASu itself if and when the system includes DX cooling. This specific equipment efficiency rating would not interfere with any proposed additions being recommended to Title 24, Part 6.

Local reach codes are being set in California to move towards new buildings utilizing all electric forms of heating. There is an indirect relationship between DOAS and the ability for local reach codes to encourage and achieve this outcome by means of code compliance on a prescriptive path. Current code would inhibit most systems often considered in all electric nonresidential buildings from taking a prescriptive compliance path. This code change would create a pathway in code for this and ensure a level of energy cost equivalency to build on which would help local jurisdictions adoption reach codes.

4.1.5.4 Relationship to Industry Standards

In IECC, there are requirements for additional energy efficiency options and a DOAS is one of those options. In this code, criteria are stipulated for a level of energy recovery and control.

In ASHRAE 90.1 2019 sets efficiency criteria on components; DOASu would meet the fan power requirement, DOASu supply air reset controls for units with dehumidification, DOASu in select climates would require exhaust air heat recovery.

In ASHRAE 189.1 there is no explicate reference to a DOAS.

In Washington State energy code, there is a mandatory requirement for a DOAS with exceptions for additional efficiency criteria to be included in a mixed air system. This information is provided in the background section of this report.

This measure would rely on the AHRI 1060 test procedure for the ventilation heat recovery component portion of a DOASu.

4.1.6 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

The activities during each phase of the project are described below:

- **Design Phase:** Designers and consultants who select this type of HVAC system would have to check the DOAS unit meets the new criteria and document this on the NRCC documents for nonresidential buildings. A DOAS unit has not been required to be document previously on NRCC documents. This would be a minor change in documentation process and the same amount of effort required for documenting other HVAC systems.
- **Permit Application Phase:** Plan inspectors would have to check any specified DOAS unit meets minimum criteria using the NRCC documents and the permit design documentation. This is in line with other plan check efforts and would now be required for the DOAS units.
- **Construction Phase:** Contractors would be responsible for installing a system as specified and, on some projects, additional controls configurations and setup work to be completed by the controls contractor. This is occurring already if and when this type of system is installed, and the new requirements would create a standard set of sequences to configure.
- **Inspection Phase:** The acceptance technician would be required to complete the NRCI documents or Certificates of Installation documents, and NRCA or Certificate of Acceptance documents for the DOAS unit like other HVAC systems. This acceptance process would be the same set of requirements for a mixed air rooftop unit or air handling unit and now be applied to a DOAS unit. The elements to inspect would be as written in existing documents and adapted to the DOAS unit.

The current process for specifying, installing and inspecting a DOASu is primarily the responsibility of each project team and not directly inspected as part of the permit documentation process. A DOASu does provide ventilation to nonresidential buildings and design documents today must convey this information to plan check departments. DOASu with fans that exceed 5hp for the system must meet and document their overall fan power for Title 24, Part 6. No other ventilation system components besides fans have standard permit documentation processes.

The measure would require a minor increased effort by mechanical designers and contractors to specify, install, and configure a DOASu that meets the minimum prescriptive criteria. This includes a mechanical designer considering how ventilation air is ducted to any zone terminal cooling and heating systems and how those systems would operate to be able to turn terminal fans off while still maintaining ventilation. In some building configurations, the ducting options may limit the type of DOASu that can be installed. The code is written to allow any duct configuration though it gives more options to DOAS which complete separate supply ducting of ventilation air from heating and cooling air. It is the recommendation of this report to add additional documentation requirements in the NRCC documents to capture the DOASu itself. In the current code, Title 24 2019, it is unclear in current energy standards if a DOASu providing only ventilation is required to be documented in NR code compliance tables or just on design document plan sets. In reviewing several design documents, most do not document the unit at all and some use other forms for other information to reflect the equipment. By adding a clear table, it is believed the effort to document key attributes would be reduced by making this system clearly defined for designers.

In the testing stage, the changes would be minor and require the installing contractor or technician to inspect and document a DOASu was installed as specified and meets a minimum set of control capabilities. In several existing acceptance tests rooftop units and mixed air air-handing units are tested and inspected for outdoor air, supply fan control, demand control ventilation, and supply air temperature control. Existing forms would be enhanced to capture a DOASu and provide clear guidance. Initial testing of these revised Acceptance Tests has been started by the PG&E Code Readiness Program team in select demonstration projects in 2019-2020 which has improved initial language and been able to be followed by initial field teams. Compliance Improvement Subject Matter Experts have been part of the Code Readiness Program field acceptance test DOAS process.

4.2 Market Analysis

The Statewide CASE Team performed a market analysis to identify current technology availability, current product availability, and market trends. Potential impact on the market in general as well as individual market actors was evaluated, and information about the incremental cost of compliance was gathered. Estimates of market size and measure applicability were identified through research and outreach to stakeholders including utility staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during a public stakeholder meeting that the Statewide CASE Team held on October 15, 2019 with materials made publicly available.

4.2.1 Market Structure

Builders

This measure would create more opportunities for builders to utilize DOAS on projects prescriptively. Projects currently using this technology would be required to meet a minimum set of criteria. These new requirements for the DOASu would primarily be implemented by the product manufacturer and specifying engineer to pick the proper unit which meets these minimum criteria.

Building Designers and Energy Consultants

This measure would require building designers to select a DOASu with minimum efficiency components and control capabilities. The impact would be minor since many standard products have the prescribed controls features.

Impact on Occupational Safety and Health

While this code change would not require DOAS, it would promote DOAS designs. Having ventilation come from 100 percent outdoor air is generally positive for air quality.

Impact on Building Owners and Occupants

Additional documentation and inspections of the DOASu itself would now be required before the building can be occupied. This would add very minor impacts as this unit is primarily the smallest part of the overall HVAC system which already required documentation and inspection.

Building Component Retailers (Including Manufacturers and Distributors)

DOASu would now be able to be differentiated by California building energy codes in meeting some, all, or none of the criteria required. This can help to align products for use in California and Washington State markets for DOAS projects.

Building Inspectors

This would add additional equipment to be inspected on DOAS projects which are currently not inspected. This would be the same level of effort as a standard building with a mixed air handler or rooftop unit. Overall, this should make building HVAC inspections more consistent in that all major equipment is inspected.

4.2.2 Technical Feasibility, Market Availability, and Current Practices

4.2.2.1 Current Practices

In California, DOAS continues to grow in nonresidential buildings and is consistently a choice in all-electric buildings being built. 8 of the 17 zero net energy case studies reported by PG&E used some form of DOAS (Dean and Turnbull 2018). Project examples cited in the appendices of this report throughout California climate zones were gathered, ranging from office buildings, laboratories, and schools implementing various forms of DOAS in both coastal and inland climate zones. Several more recent projects surveyed found they were being deployed as a means to achieve energy savings, simplicity in controls, and elimination of all gas infrastructure to reduce first costs.

In net zero buildings as of 2016, 64 percent of the projects built or in design used radiant systems with a DOAS system to address ventilation needs (New Buildings

Institute 2016). In 2019, the same team at New Buildings Institute identified DOAS as the second highest of *“off-the-shelf, market-ready” technologies applied in the zero energy (ZE) building set”* after heat pumps (New Buildings Institute 2019). The system continues to be a top selection for reach codes in many jurisdictions using the IGCC and IECC structure and list of options (Denver GOV 2019).

In current practice there are many compliance routes in California energy code used to install decoupled air conditioning systems. Here are three examples, ranked in order of energy efficiency:

1. Configurations with no DOASu or economizer. These directly duct ventilation air from the outside and have zone heating and cooling units with capacities under 54,000 Btu to avoid the economizer requirement. They can be the lowest cost, but they are also the least efficient. Common in very small buildings though functionally they are being used in larger buildings with the application of multi-headed refrigerant heat pumps.
2. Systems with a DX-DOAS unit but no energy recovery or economizer. These avoid the economizer by either using zone heating and cooling units with capacities under 54,000 Btu, or by increasing the rated EER and COP of the conditioning system to use other economizer exceptions.
3. High efficiency solutions with centralized ventilation air and some form of ventilation energy recovery. These often use a performance compliance pathway to demonstrate the heating and cooling system meets or exceeds the whole building energy level.

Based on the current practices observed, the Statewide CASE Team proposal aims to encourage designs with ventilation energy recovery with bypass for free cooling and no economizer. This solution was found to meet or exceed operational energy costs (using a TDV metric) in buildings under 150,000 ft^2 or 5 stories and is the common solution used in several low energy buildings today. However, the proposal still allows for other design approaches.

4.2.2.2 Global Trends

The global DOAS market is estimated to be growing at an 8 percent compound annual growth rate forecasted from 2019 through 2024 (Markets and Markets 2019). The report summary sites increased adoption of these systems, in reference to primarily DX-DOAS products, for the energy savings potential they hold.

The study sites key product developments announced by manufacturing over the last several years including:

- In March 2019, Greenheck Fan (US) introduced its DOAS product line. The company’s product models such as RV-110 and RVE-180 with capacities of up to

18,000 cfm, up to 70 tons of packaged cooling and 1,200 MBH indirect gas-fired heating. The company’s DOAS units meet the demands for heating, cooling, dehumidification, and ventilation requirements.

- In February 2018, Nortek (US) launched Reznor ZQYRA Series, a low cost, high efficiency dedicated outdoor air system (DOAS) for adding outdoor air requirements for educational, healthcare, office, retail, and other light commercial spaces.
- In January 2018, Ingersoll Rand (Ireland) acquired ICS Group Holdings Limited (ICS Cool Energy). The acquired business is specialized for the company’s Trane business and provides products to customers of commercial and industrial buildings across Europe.

4.2.2.3 California Trends

The Statewide CASE Team analyzed an online database of construction projects called ConstructConnect Insight which suggests DOAS new construction projects have been increasing from 9 percent in 2012 to 19 percent in 2019 and from 3 percent to 5 percent in alteration projects. This database was searched using the terms DOAS, DX-DOAS, ERV, HRV, “Energy Recovery Ventilator", or Decoupled. While this database may not reflect all of construction it does provide an independent sample of projects for this time period.

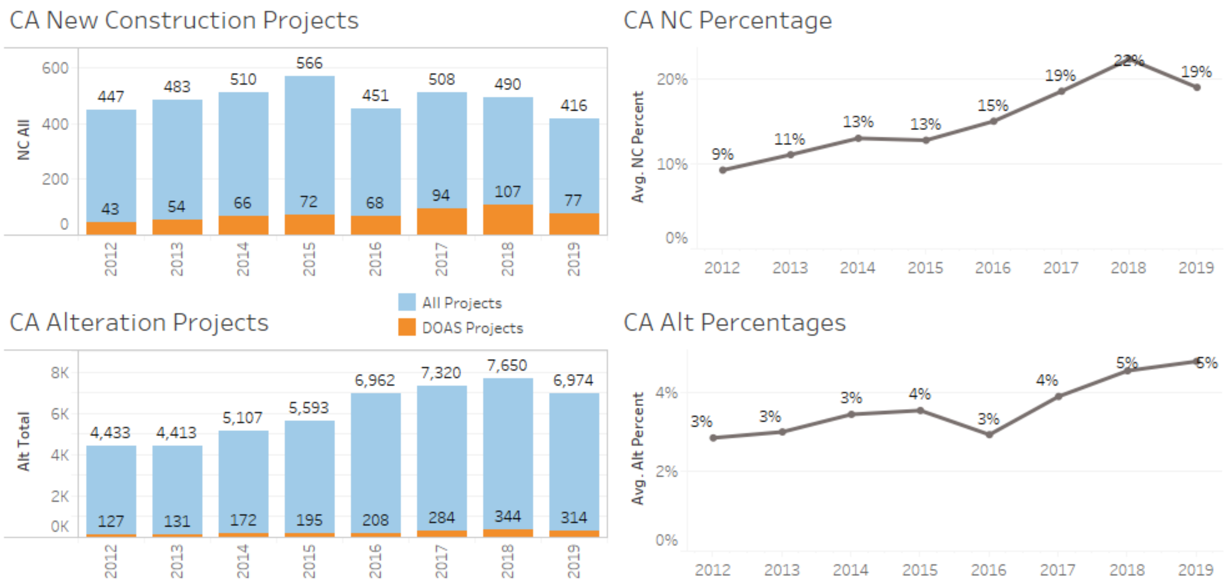

Figure 2: California online database or a sample set of construction projects, searched for key terms to determine all projects and those with DOAS.

This data was used to provide market size estimates for new and alterations in California. The same data set provided a breakdown of project type by key industries. These project types were used to further estimate the market size of key sectors such as office and school. This data is included in the appendix of this report.

4.2.2.4 Market Forecast of DX-DOAS in U.S.

DX-DOAS units, which are one of the many DOAS units, is becoming increasingly important component of commercial ventilation systems due to trends in the construction industry towards decoupled systems. In California research from online database completed by the California IOUs aggregated information about industrial construction projects in the U.S.. A search for projects with the terms “DOAS,” “dedicated outside air,” or “dedicated outdoor air” was conducted and yielded the data shown in the Figure 3.

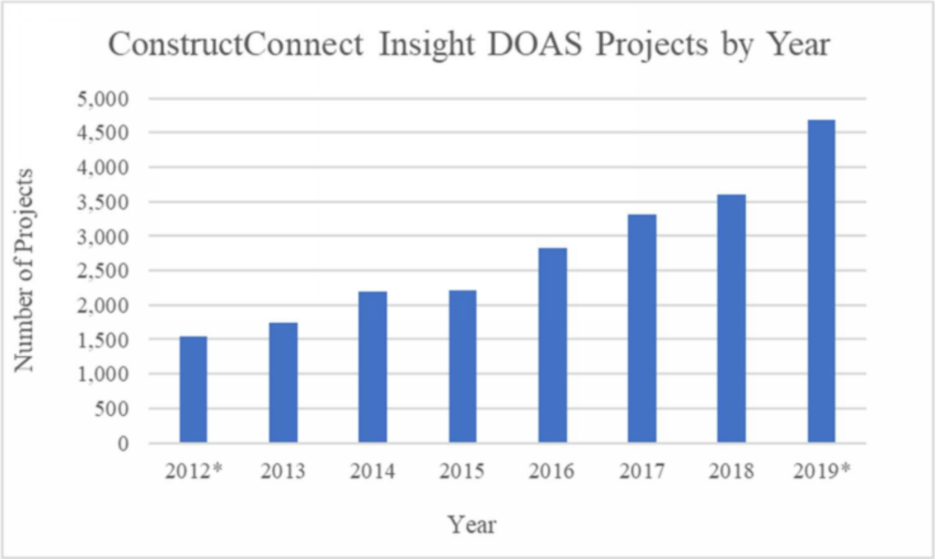

Figure 1: ConstructConnect Insight results for DOAS projects by year.

Source: ConstructConnect Insight.

Note: 2012* and 2019* were incomplete years and extrapolated to full 12-month periods for comparison purposes.

Figure 3: Market historical data of DOAS projects over years.

Figure 3 has an estimate of the number of construction projects from ConstructConnect. It has not been confirmed if this represents the entire industry, though the trend from 2012 to 2019 shows a clear increase in the number of DOAS projects.

4.2.2.5 Design and Construction Ongoing Survey

A survey of California system specifiers and design consultants is being conducted currently to gauge the frequency of a DOAS consideration and installation in nonresidential buildings. The survey aims to convey the market size and growth rate of these systems in key building types. This survey is planned to be distributed in March with results collected by April 2020. The survey asks several questions including how often the system is considered as well as how often the system is selected.

4.2.2.6 Net Zero and High Performance Building System Trends

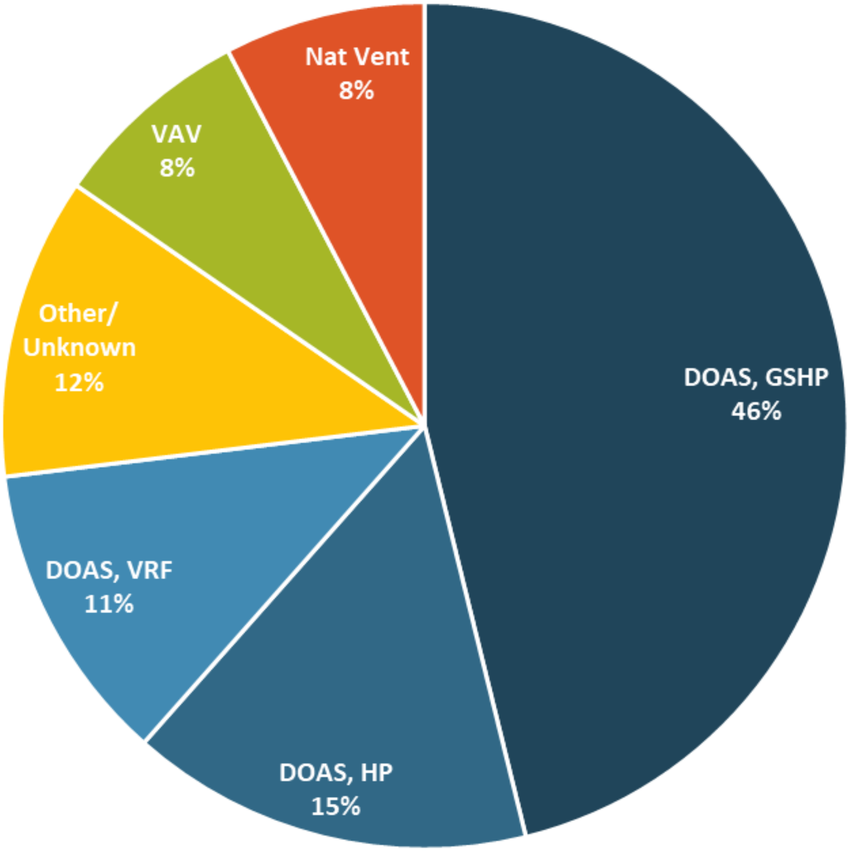

Figure 4: HVAC system configuration used in a sample set of net zero energy buildings.

From a simple survey of 26 buildings provided by New Buildings Institute which were designed to Net Zero Energy over 73 percent (19 projects) used some form of a DOAS as the primary means of ventilation. Figure 4 shows the fraction of projects and their ventilation distribution systems. Projects with DOAS units were configured with different heating and cooling systems depending on the project, including radiant in-slab, VRF, or ground source heat pumps. The exact type of DOAS unit, either DX-DOAS, HRV, or ERV, was not documented.

Of 23 buildings reviewed from the ASHRAE High Performance Building Magazine blog 15 out of 23 projects included some form of a DOAS.

A strategy seen in some Net Zero Energy and market typical DOAS buildings is to increase the ventilation air flow rate, providing a level of increased air quality and provide more hours of economizing capabilities. As part of PG&E's Code Readiness

DOAS Field Monitoring project, five buildings, most of which were commercial office and one university building, had installed a DOAS ventilation system with a capacity was between 165% and 240% of code minimum ventilation for the building use. The building sample represents a mix of projects, two targeting net zero energy and three build for a mix of specific tenants or speculative office use. This suggests that an increase in ventilation capacity in DOAS is a cost-effective energy efficiency strategy and provides future flexibility for ventilation needs.

4.2.2.7 Technical Feasibility and Market Availability

Technical feasibility of energy efficiency components and controls for DOAS has been proven in both field and laboratory testing of the components in the system. In the field, many DOAS sites exist which provide high efficiency examples of a DOASu and high efficiency examples of heating and cooling systems.

HRV and ERV technology has been in use for years even if not required in California energy codes. Modulating controls and capabilities in a DOASu have also been possible for many years and were referenced in several technical design guides.

The Statewide CASE Team reviewed 24 manufactures of DOASu's (see Appendix H) and found that all have a product which would meet the minimum prescriptive requirements proposed by the code change proposal. 13 of the 24 manufactures offer products that would also meet the requirements for ventilation heat recovery and bypass for free cooling.

Most DX-DOAS products do not include ventilation heat recovery and only cool and heat the air using DX, a heat pump, and or a furnace. Of product literature surveyed, most packaged DX-DOAS do include an option for ventilation heat recovery though it is not universal across all manufacturers. Some only sell products without ventilation heat recovery. Two pathways are included in the recommended prescriptive language to specifically address this

In energy recovery ventilators and heat recovery ventilators products were evaluated for the types of control capabilities and levels of energy recovery and sensible recovery capable. For energy recovery, product data was pulled from the AHRI database for both packaged equipment in the air to air recovery category and component equipment in the air to air recovery section. This data review was used to establish technical ranges of products available on the market today.

4.2.3 Persistence of Energy Savings Measures

A 15-year measure life is reasonable given the field sites observed and based on the life span of DOAS components. Since ventilation is separate from heating and cooling faults or degradation of performance can be more readily noticed and fixed. For instance, ventilation is centrally controlled in most DOAS and the monitoring of just this unit being on or off is all that is needed. In spaces, when any system is not able to meet the heating or cooling needs zone thermostats or occupants would be able to identify exactly which part of the heating and cooling system is not working.

The largest barrier is the ongoing maintenance of system wide controls, as is the case in any HVAC system. DOAS with ventilation energy recovery tends to be more forgiving and would still maintain a level of energy efficiency if not perfectly functioning. The solution to degraded performance is to have a routine for sensor calibration and monitoring as well as a way for occupants to be educated on how to control their heating and cooling system.

4.2.4 Market Barriers and Solutions

Table 60 captures technical and market barriers and potential solutions to this submeasure as identified by the Statewide CASE Team.

Table 60: Potential Barriers and Solutions

Potential Barriers	Solutions
Lack of clear DOAS definition as a system	Develop a code definition for the system typology in the energy standard including a DOAS unit and DOAS heating and cooling components.
Not all DOAS units or configurations have ventilation energy recovery	Set criteria for ventilation heat recovery to be optional using an exception linked to economizers. Select a level of heat recovery able to maintain efficiency and within market availability of products today.
Not all DOAS units have free cooling bypass controls	Set free cooling and bypass controls as energy efficiency trade-offs with other mechanical prescriptive code options of equivalency.
Some DOAS configurations require terminal fans operate to ventilate	Develop a DOAS configuration which primarily requires terminal fans to not have to run for continuous ventilation and add an equivalent exception if absolutely required.
Designer education on DOAS controls is limited	Stipulate basic efficiency controls and capabilities to differentiate DOAS units which do or do not meet code.
First Cost market perception	Identify the common DOAS configurations which would have marginal first cost difference and use lifecycle cost analysis to demonstrate the savings from DOAS configurations sold today which eliminate key components to save cost.
Code compliance metrics historically favor gas over electric energy consumption	New 2022 Time Dependent Value Metrics in draft release have made significant changes to the lifecycle cost of gas and electric. This change does impact DOAS and makes units which meet the ventilation energy recovery criteria meet or exceed an alternate system with an economizer.

4.2.5 Market Impacts and Economic Assessments

4.2.5.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California’s construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 61).[15] In 2018, total payroll was $80 billion. Nearly 17,000 establishments and 344,000 employees focus on the commercial sector.

Table 61: California Construction Industry, Establishments, Employment, and Payroll

Construction Sectors	Establishments	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 change to nonresidential HVAC controls would likely affect commercial builders and nonresidential electrical, HVAC, and plumbing contractors but would not significantly impact other building trades. The effects on the commercial building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 62 shows the commercial building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report as they are related directly related to the purchase and installation of HVAC equipment.

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

Table 62: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code

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.)

4.2.5.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. 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 compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 63 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for Nonresidential HVAC Controls to affect firms that focus on nonresidential construction.

There is not a North American Industry Classification System (NAICS)[16] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of

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[16] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of 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 Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

residential and nonresidential buildings.[17] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 63 provides an upper bound indication of the size of this sector in California.

Table 63: California Building Designer and Energy Consultant Sectors

Sector	Establishments	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 establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;

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

4.2.5.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

4.2.5.4 Impact on Building Owners and Occupants

Commercial Buildings

The commercial building sector includes a wide array of building types, including offices, restaurants and lodging, retail, and mixed-use establishments, and warehouses (including refrigerated) (Kenney 2019). Energy use by occupants of commercial buildings also varies considerably with electricity used primarily for lighting, space

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[17] Establishments in this sector include businesses primarily engaged in evaluating a building's structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily 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.

cooling and conditioning, and refrigeration. Natural gas consumed primarily for heating water and for space heating. According to information published in the 2019 California Energy Efficiency Action Plan, there is more than 7.5 billion square feet of commercial floor space in California and consumes 19 percent of California's total annual energy use (Kenney 2019). 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.

Estimating Impacts

Building owners and occupants would benefit from lower energy bills. As discussed in Section 4.2.6.1, 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 Statewide CASE Team does not expect the proposed code change for the 2022 code cycle to impact building owners or occupants adversely.

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

The Statewide CASE Team does not expect any significant impacts on manufacturers and distributors of these products.

4.2.5.6 Impact on Building Inspectors

Table 64 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 64: Employment in California State and Government Agencies with Building Inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs[a]	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

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

a. Administration of Housing Programs (NAICS 925110) comprises government establishments 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 establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

4.2.5.7 Impact on Statewide Employment

The Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 4.2.6, the Statewide CASE Team 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 Statewide CASE Team 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.

4.2.6 Economic Impacts

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial building industry, architects, energy consultants, and building inspectors. The Statewide CASE Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2022 code cycle regulations would result in additional spending by those businesses.

Table 65: Estimated Impact that Adoption of the Proposed Measure would have on the California Commercial Construction Sector

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions)
Direct Effects (Additional spending by Commercial Builders)	57	$3.75	$5.0	$8.2
Indirect Effect (Additional spending by firms supporting Commercial Builders)	12	$0.90	$1.4	$2.8
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	25	$1.39	$2.5	$4.1
Total Economic Impacts	**94**	**$6.04**	**$8.9**	**$15.1**

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

Table 66: Estimated Impact that Adoption of the Proposed Measure would have on the California Building Designers and Energy Consultants Sectors

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions)
Direct Effects (Additional spending by Building Designers & Energy Consultants)	3	$0.30	$0.30	$0.53
Indirect Effect (Additional spending by firms supporting Bldg. Designers & Energy Consult.)	2	$0.12	$0.17	$0.26
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	2	$0.13	$0.23	$0.37
Total Economic Impacts	**7**	**$0.55**	**$0.69**	**$1.16**

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

Table 67: Estimated Impact that Adoption of the Proposed Measure would have on California Building Inspectors

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**	**$0.39**	**$0.52**	**$0.71**

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

4.2.6.1 Creation or Elimination of Jobs

The Statewide CASE Team 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. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 4.2.6 would lead to modest changes in employment of existing jobs.

4.2.6.2 Creation or Elimination of Businesses in California

As stated above, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to HVAC Controls which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes.

4.2.6.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is incorporated inside or outside of the state.[18] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2022 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

4.2.6.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[19] As Table 68 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, with an average of 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 68: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
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.)

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[18] 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.

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

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in investment in any directly or indirectly affected sectors of California's economy.

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

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

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government would be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs 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 Statewide CASE Team does not expect any appreciable change to the state.

Cost to Local Governments

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this 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.

4.2.6.6 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed code change may result in unintended consequences. The Statewide CASE Team has not found any information showing that specific persons would be impacted by this proposal.

4.3 Energy Savings

4.3.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented in this report used the 2022 TDV factors. The electricity TDV factors include the 15 percent retail adder and the natural gas TDV factors include the impact of methane leakage on the building site. The electricity TDV factors used in the energy savings analyses were obtained from Energy and Environmental Economics, Inc. (E3), the contractor that is developing the 2022 TDV factors for the Energy Commission, in a spreadsheet titled “Electric TDVs 2022 - 15 pct Retail Adj Scaled by Avoided Costs.xlsx”. The natural gas TDV factors used in the energy savings analyses were obtained from E3 in a spreadsheet titled “2022_TDV_Policy_Compliant_CH4Leak_FlatRtlAdd_20191210.xlsx”. The electricity demand factors used in the energy savings analysis were obtained from E3 in a spreadsheet titled “2022 TDV Demand Factors.xlsx”. The final TDV factors that the Energy Commission released in June 2020 use 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. The 20-year GWP values increased the TDV factors slightly. As a result, the TDV energy savings presented in this report are lower than the values that are expected if the final TDV that use 20-year GWP values were used in the analysis. The proposed code changes would be more cost effective using the revised TDV. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

Energy savings is calculated based on a market standard DOAS system configuration, based on field research and a literature review of system installations since these systems currently are not defined explicitly in 2019 Title 24, Part 6, and a proposed DOAS system configuration as outlined in the code change proposal. Two market standard systems were observed: a heat recovery or energy recovery ventilation system without bypass and a DX-DOAS system without energy recovery and a neutral supply air temperature control. Detailed inputs are presented in Table 71. Energy comparisons are also provided for DOAS compared to mixed air system baselines for each prototype. This comparison was done to evaluate the equivalent energy consumption of the DOAS measures with standard mixed air with economizers and understand the energy cost and source energy use.

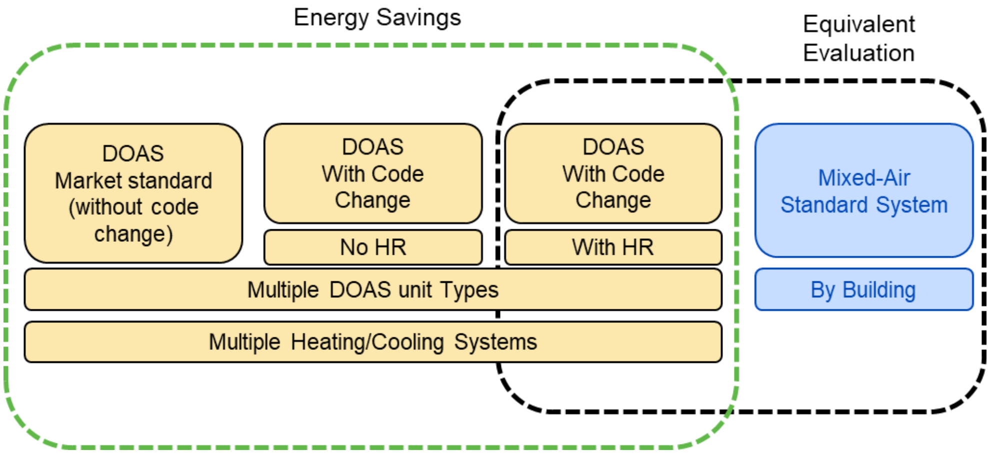

Figure 5: DOAS Venn diagram of energy savings calculations and comparisons included.

Statewide energy savings are very sensitive to market size estimates of how frequently these systems are installed by building type. Appendix A includes market data of DOAS installations estimates by building type for new building and alterations in California and is used to establish percentage forecasts. In new the data estimates between 12 percent and 18 percent of construction is DOAS and in alterations 2% to 6% of projects. Building types used in the energy analysis included office buildings, schools, retail, and hotel, however it is common to see these systems being used in other building types such as medical office buildings in the healthcare sector.

The energy savings and comparison with the market standard DOAS and the proposed prescriptive requirements depends on the following primary assumptions about how the system is configured and operated:

1. Heat recovery or energy recovery ventilation is primarily used in DOAS as stand-alone systems and is not commonly installed in DX-DOAS units in California.
2. Zone terminal unit fans are commonly set to operate continuously during occupied hours and do not turn off when zone temperatures are within the thermostat deadband, or when thermostats have no deadband. This is often the case in systems where the ventilation path includes the zone terminal unit and the fan cannot turn off without interrupting ventilation.
3. Most heat recovery or energy recovery ventilators do not get configured with economizer or free cooling bypass controls specific to their climates.

4.3.2 Energy Savings Methodology

4.3.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 69.

As DOAS HVAC is not the baseline system in any of the prototypes, individual prototypes were modified to replace the Standard Design HVAC system with the code enhancements for DOAS and separate heating and cooling system. The systems were defined based on research of common practice in DOAS buildings today and to current 2019 Title 24, Part 6 requirements for equipment nominal efficiencies and controls. These are referend to as the Proposed Design system and meets the criteria of the code enhancement recommendations. Prototype models of nonresidential buildings were modified to create the DOAS baseline buildings for new construction as shown in Table 69. For prototypes where multiple DOAS system configurations were developed the results were reviewed individually for each configuration and ultimately all configurations for a given building type are combined by averaging the annual energy use to create a single reference design DOAS baseline. See Table 70 for more detail.

Table 69: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (ft^2)	Description
OfficeSmall	1	5,502	Three models were created to account for different DOAS HVAC configurations found most often: • DOAS HRV with Mini Splits • DOAS with RTU • DOAS with VRF
Office Medium	3	53,628	Three models were created to account for different DOAS HVAC configurations found most often: • DX-DOAS with furnace and VRF • DX-DOAS with heat pump and VRF • HRV-DOAS with VRF
School Primary	1	24,413	Models created to account for difference in DOAS HVAC configurations: • DX-DOAS with furnace and VRF.
School Secondary	2	210,866	Models created to account for difference in DOAS HVAC configurations: • DX-DOAS with furnace and VRF • HRV-DOAS with FPFC
Retail StandAlone	1	24,563	Three models were created to account for different DOAS HVAC configurations found most often: • DX-DOAS with furnace and VRF • DX-DOAS with heat pump and VRF • HRV-DOAS with VRF
HotelSmall	4	93,632	Three models were created to account for different DOAS HVAC configurations found most often and only applied to: • DX-DOAS with furnace and VRF • DX-DOAS with heat pump and VRF • HRV-DOAS with VRF
RetailLarge	1	240,000	Three models were created to account for different DOAS HVAC configurations found most often and only applied to: • DX-DOAS with furnace and VRF • DX-DOAS with heat pump and VRF • HRV-DOAS with VRF

The same set of prototype models that were modified to create a Reference Design DOAS configurations based on market research of typical DOAS configurations installed today. Since the DOASu in a DOAS system is not directly regulated in past energy codes, the two Reference Design configurations were developed as follows:

Table 70: DOASu Configurations for Reference Design System and Proposed Designs

Configuration Tier	Description
Reference DOASu-1	DOAS without ventilation heat recovery. Zone terminal unit fans that run continuously during occupied hours. DOAS with cooling reheat air when in cooling mode.
Reference DOASu-2	DOAS with ventilation heat recovery at 50% effectiveness, no bypass, and with zone terminal unit fans that run continuously during occupied hours.
Proposed DOASu-1	DOAS without ventilation heat recovery. Zone terminal unit fans cycle on and off to maintain thermostat. DOAS with cooling coils reheat air only to 60F when in cooling mode.
Proposed DOASu-2	DOAS with ventilation heat recovery sized and operating at 150% of the code minimum ventilation rate. Heat recovery is set to 60% effectiveness and bypass when within economizer limits. Zone terminal unit fans cycle on and off to maintain thermostat. DOAS with cooling coils reheat air only to 60F when in cooling mode.

Results from each reference design were averaged together for scenario 1 and scenario 2 to create a single energy use reference point. Results from each proposed configuration were also averaged together to create one single energy use proposed point. Individual DOAS configurations were reviewed independently to observe consistent performance and a level of energy savings with the Reference. In the case where a prototype included multiple configurations of a DOAS and separate heating and cooling systems all Reference and Proposed simulated results were averaged accordingly to produce this same final energy savings calculation.

For the CASE Report energy savings from these prototype models were used on a savings per square foot basis to reflect savings from additions and/or alterations in existing buildings. The same prescriptive criteria would be required by these buildings if the whole system were being replaced.

Assumptions for DOAS Reference Models

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using EnergyPlus 9.0.1 with the base input files being generated from the 2022 Research Version of the California Building Energy Code Compliance (CBECC) software for commercial buildings (CBECC-Com).

There are component efficiency requirements in Title 24, Part 6 that cover attributes of the DOAS, though the whole system and control features are not specified. The Statewide CASE Team modified the Standard Design to reflect the most common current DOAS system design practice, or industry standard practice.

The Standard Design models were modified to have a DOASu and separate heating and cooling systems. Several heating and cooling system options were simulated depending on the specific building type.

The modified Standard Design models that now include a market typical DOASu is henceforth referred to as the Reference DOASu, and the energy models that incorporate the DOASu's are henceforth referred to as the Reference models. These Reference Design models with the Reference DOASu's serve as the baseline for evaluating energy and demand impacts of the proposed measures.

System Sizing

All capacity and flow fields in the model files were set to "autosize" and the system capacity sizing factors were set to 1 for heating and cooling to reflect standard energy modeling sizing practices. The DOAS was sized for ventilation only in every case which reflects how these systems are designed in nonresidential buildings. This sizing factor was set for the draft report to avoid DOASu from oversizing the ventilation airflow in addition to heating and cooling capacities. Models were reviewed to ensure thermostat requirements were satisfied within a measure of reason of no greater than 300 hours a year.

Changes between Proposed and Reference DOAS Models

The Proposed Design was identical to the Reference Design in all ways except for the revisions that represent the proposed changes to the code. Table 71 presents precisely which parameters were modified and what values were used in the Reference Design and Proposed Design. Specifically, the proposed conditions assume four changes to the energy models:

1. Enabling zone terminal fans for heating or cooling to shut off when there is no call for active conditioning.
2. If the DOAS unit has heat recovery it includes the ability to bypass the heat recovery device based on outdoor air temperature and supply air temperature control reset based on outdoor air.
3. If the DOAS unit has heat recovery it is also assumed the unit meets pathway B and increases the ventilation to 150% of code minimum for each space.
4. DOAS units, such as DX-DOAS or CHW-DOAS, with active cooling are only able to reheat air to 60F when the unit is in cooling mode.

Comparing the energy impacts of the Reference Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that follows industry typical practices.

Table 71: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Reference Case	Climate Zone	Parameter Name	Market Typical Design Parameter Value	Proposed Design Parameter Value
All	Reference 1 & Proposed 1	All	Ventilation Heat Recovery	No sensible heat recovery	No sensible heat recovery
			Ventilation Heat Recovery Bypass Control	None	None
			Ventilation Rate	100% T24	100% T24
			Zone Fan Control	On Continuous	Cycle with Thermostat
All	Reference 2 & Proposed 2	All	Ventilation Heat Recovery	DX-DOAS: 50% sensible heat recovery HRV-DOAS: 50% sensible heat recovery	DX-DOAS: 60% sensible heat recovery HRV-DOAS: 60% sensible heat recovery
			Ventilation Heat Recovery Bypass Control	None	Control to Supply Air Temperature
			Ventilation Rate	100% T24	150% T24
			Zone Fan Control	On Continuous	Cycle with Thermostat

EnergyPlus calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). The Statewide CASE Team then applied the 2022 time dependent valuation (TDV) factors to calculate annual energy use in kilo British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). The Statewide CASE Team also calculated the TDV energy cost savings values measured in 2023 present value dollars (2023 PV$).

The energy impacts of the proposed code changes do vary by climate zone. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the climate-zone specific TDV factors when calculating energy and energy cost impacts.

Per-unit energy impacts for nonresidential buildings are presented in savings per square foot. Annual energy and peak demand impacts for each prototype building were translated into impacts per square foot by dividing by the floor area of the prototype building. This step allows for an easier comparison of savings across different building types and enables a calculation of statewide savings using the construction forecast that is published in terms of floor area by building type.

4.3.3 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the Energy Commission provided (California Energy Commisison 2020). The Statewide Construction Forecasts estimate new construction that would occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Com, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 39 presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 72: Nonresidential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Simulated for DOAS Report	Weighting Factors for Statewide Impacts Analysis	New Construction DOAS Market Share	Alterations DOAS Market Share
Small Office	OfficeSmall	Yes	100%	14%	3%
Large Office	OfficeMedium	Yes	50%	14%	3%
	OfficeLarge	N/A	50%	14%	3%
Restaurant	RestaurantFastFood	N/A	100%	N/A	N/A
Retail	RetailStandAlone	Yes	10%	14%	4%
	RetailLarge	No	75%	14%	4%
	RetailStripMall	No	5%	14%	4%
	RetailMixedUse	No	10%	14%	4%
Grocery Store	Grocery	N/A	100%	N/A	N/A
Non-Refrigerated Warehouse	Warehouse	N/A	100%	N/A	N/A
Refrigerated Warehouse	RefrigWarehouse	N/A	N/A	N/A	N/A
Schools	SchoolPrimary	Yes	60%	18%	6%
	SchoolSecondary	Yes	40%	18%	6%
Colleges	OfficeSmall	Yes	5%	14%	3%
	OfficeMedium	Yes	15%	14%	3%
	OfficeMediumLab	No	20%	16%	9%
	PublicAssembly	No	5%	12%	2%
	SchoolSecondary	Yes	30%	18%	6%
	ApartmentHighRise	N/A	25%	N/A	N/A
Hospitals	Hospital	N/A	100%	N/A	N/A
Hotel/Motels	HotelSmall	Yes	100%	17%	6%

Market estimates of 5 percent overall for alterations was assumed first with the percent shown applied after. Documentation on statewide savings and market size percentages is included in Appendix A.

4.3.4 Per-Unit Energy Impacts Results vs Reference Design

A summary of the energy savings and peak demand reduction per-unit area are presented in the following table for the prototype buildings used. Additional results by each climate zone for each building are included in Appendix G. Energy results are a comparison between market typical DOAS and the proposed DOAS with code enhancements. The peak demand is estimated to be reduced in most building types and increased slightly in one of the prototypes for primary schools. Over a 15 year period, the total energy cost savings for each building per square foot are included in TDV kBtu/ft^2.

Table 73: First-Year Energy Impact per Square foot per Building Type vs Reference Design – Construction-weighted Average All Prototype

	Electricity Savings (kWh/ft^2)	**Peak Electricity Demand Reductions (kW/ft^2)**	**Natural Gas Savings (therms/ft^2)**	**TDV Energy Savings (TDV kBtu/ft^2)**
OfficeSmall				
New Construction	1.72	0.16	(0.00)	43.1
Alterations	1.72	0.16	(0.00)	43.2
OfficeMedium				
New Construction	2.58	0.29	0.00	71.9
Alterations	2.58	0.29	0.00	71.9
RetailStandAlone				
New Construction	1.15	0.08	0.00	26.1
Alterations	1.15	0.08	0.00	25.9
RetailLarge				
New Construction	1.15	0.08	0.00	38.3
Alterations	1.15	0.08	0.00	38.2
SchoolPrimary				
New Construction	0.35	0.09	0.02	17.7
Alterations	0.35	0.09	0.02	17.4
SchoolSecondary				
New Construction	1.79	0.21	0.00	51.6
Alterations	1.79	0.21	0.00	51.5
OfficeLarge				
New Construction	2.74	0.33	(0.01)	72.8
Alterations	2.74	0.33	(0.01)	72.7
HotelSmall				
New Construction	0.74	0.08	0.00	18.9
Alterations	0.74	0.08	0.00	18.9

These prototypes do not represent the entire market potential and additional prototypes which may be utilized to evaluate energy impacts include:

- Retail Mixed Use
- Retail Strip Mall
- Medium Office Lab

4.3.5 Per-Unit Energy Impacts Results vs Mixed-Air Systems with Airside Economizers

Part of the DOAS proposal is an inclusion of a new exception for economizing if a building system utilizes a DOASu with ventilation energy recovery. As part of the due-diligence process of this recommendation energy analysis was done to evaluate the impacts of this Proposed Design for equivalency or increased performance of this system type vs a mixed-air system with an economizer, referred to as the Airside Economizer Design.

In California, a DOAS HVAC configuration can save energy in two main ways:

1. DOAS would save on heating energy from ventilation heat recovery. Compared to mixed air systems with multi-zone reheat, a DOAS HVAC configuration would also eliminating space conditioning reheat with an HRV-DOAS or, minimizing system reheat with a DX-DOAS.
2. DOAS saves cooling peak demand by reducing the thermal cooling load with ventilation heat recovery. Compared to a mixed air system with multi-zone reheat, a DOAS HVAC configuration provides zone level cooling and can further reduce peak cooling loads by eliminating over-cooling of spaces during peak times.

In large buildings, DOAS with zone cooling can utilize waterside economizing if built around a chilled water plant and hydronic solution. In smaller buildings, DOAS with zone cooling would lose the ability to airside economize; however, they gain the ability to utilize sensible only cooling which can have a greater thermal efficiency than a cooling system which must also dehumidify. Multi-speed compression or variable refrigerant flow systems utilizing active refrigerant controls can adjust refrigerant pressures and temperatures to best match thermal loads and reduce compressor power. Multiple cooling systems were investigated with DOAS, including air cooled chillers, variable refrigerant flow, and recirculating rooftop units.

The mixed-air systems with economizers were built from the prototype models and enhanced to include economizers if they were not included and additional functionality to represent airflow control and fan pressure. See Appendix L for more detail.

The analysis found DOAS configurations to be as energy efficient as mixed-air systems with airside economizers. The analysis found this to be true for mixed-air systems with air source cooling systems, including single zone packaged units and multi-zoned DX variable air volume systems. DOAS with air cooled equipment was found to be less efficient than a mixed-air system with a chilled water cooling plant. The analysis did not include water cooled configurations of DOAS at this time. A limit was set for when the exception for airside economizing would be available based on the Title 24 HVAC systems map of building size and number of stories at the limits which determine when a system would generally select a chilled water plant instead of air sourced cooling.

The first-year energy savings per square foot between the Proposed Design DOAS and the Airside Economizer Design are included to document the ability of this exception to meet or exceed the level of performance compliance of the current standard.

Table 74: First-Year Energy Equivalency per Square foot per Building Type Airside Economizer Design

	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
OfficeSmall				
New Construction	0.10	0.27	0.06	13.7
Alterations	0.11	0.27	0.06	13.5
OfficeMedium				
New Construction	0.04	0.24	0.03	5.3
Alterations	0.05	0.22	0.03	4.9
RetailStandAlone				
New Construction	N/A	N/A	N/A	N/A
Alterations	N/A	N/A	N/A	N/A
RetailLarge				
New Construction	N/A	N/A	N/A	N/A
Alterations	N/A	N/A	N/A	N/A
SchoolPrimary				
New Construction	0.09	0.05	0.01	12.4
Alterations	0.09	0.05	0.01	12.1
SchoolSecondary				
New Construction	0.45	0.70	0.04	27.2
Alterations	0.46	0.69	0.04	27.3
HotelSmall				
New Construction	N/A	N/A	N/A	N/A
Alterations	N/A	N/A	N/A	N/A

The following is a sample of energy results per individual building and climate zone. All results are included in Appendix L.

Prototype Summary of Energy Impacts

For Medium Offices, multiple configurations of a DOAS were simulated to reflect the most commonly built systems. Four types of DOAS were simulated with the proposed code changes:

1. DX-DOAS with a furnace and Air Source Variable Refrigerant Flow (VRF)
2. DX-DOAS with a heat pump and Air Source VRF
3. HRV with Four Pipe Fan Coils (FPFC), Air Cooled Chiller, and Boiler
4. HRV with Air Source VRF

These configurations were simulated with Reference conditions to serve as a baseline for energy savings. The results in Climate Zone 9 for only one combination of DOAS, Four Pipe Fan Coil (FPFC) with DOAS, using less TDV energy than the Reference Design. Complete tables for each prototype and DOAS configuration are included in the Appendix G.

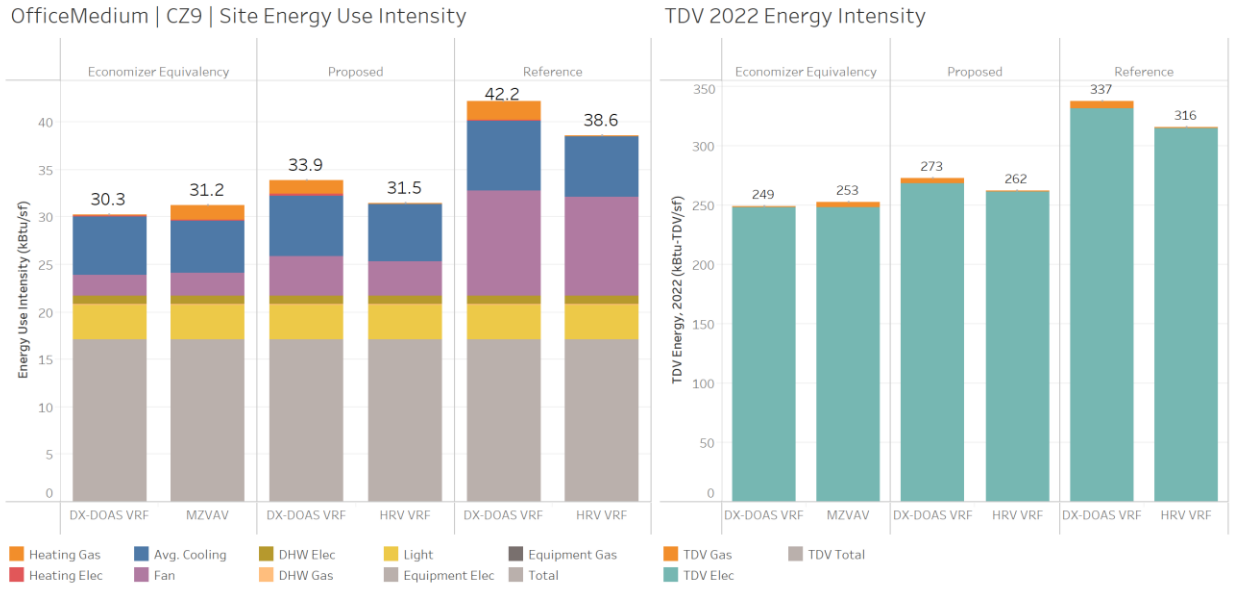

Figure 6: TDV energy and site energy results, Medium Office Climate Zone 9.

The primary school was simulated with only one proposed configuration of DOAS; a more conservative DOAS configuration with a DX-DOAS unit and zone heating and cooling using VRF. Based on running other prototype modeling configurations, this type of DOAS unit and type of heating and cooling on average use more energy than other configurations such as HRV or ERV DOAS units and zone heating and cooling with FPFC or radiant cooling and heating. The primary school Standard Design system is several single-zone mixed-air rooftop units. In comparison, a DOAS would reduce fan energy by running a smaller ventilation only system continuously and cycling heating and cooling room fans on only when needed.

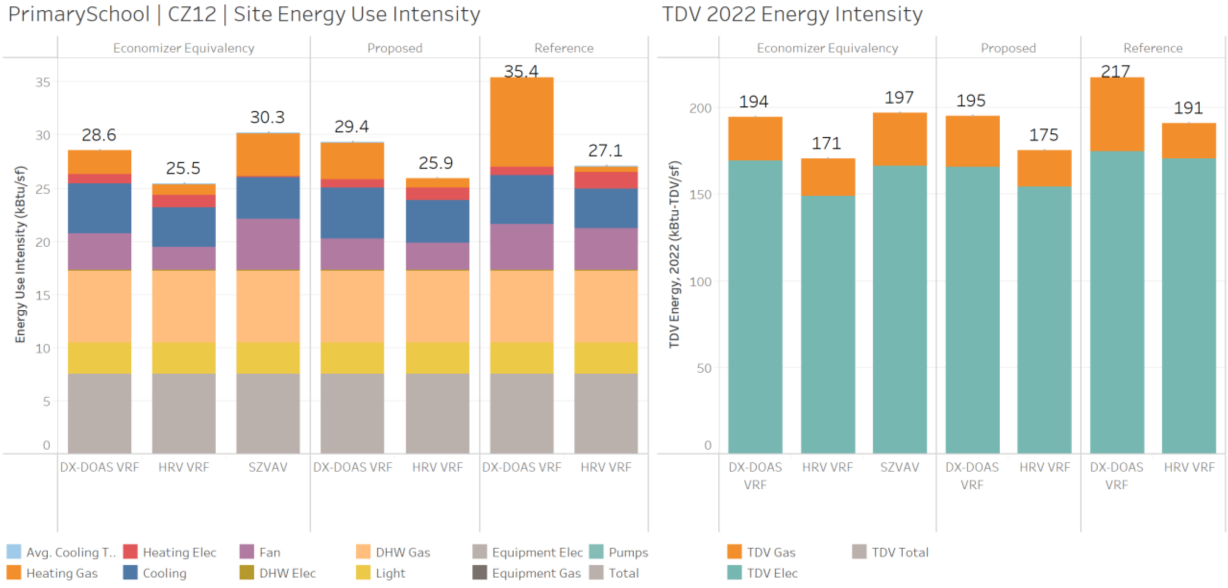

Figure 7: TDV energy and site energy results, Primary School Climate Zone 12.

The secondary school prototype was simulated with only one Reference DOAS to represent the most conservative DOAS scenario for energy use. In the secondary school, the Standard Design is a central air handling unit with zone variable air volume control and a central plant. In mild climate zones such as Climate Zone 3 shown in Figure 8: TDV energy and site energy results, Secondary School Climate Zone 3. The Reference DOAS configuration increases the cooling energy of the building while decreasing other end uses such as pumps and heating. Overall, the TDV operational energy cost is reduced.

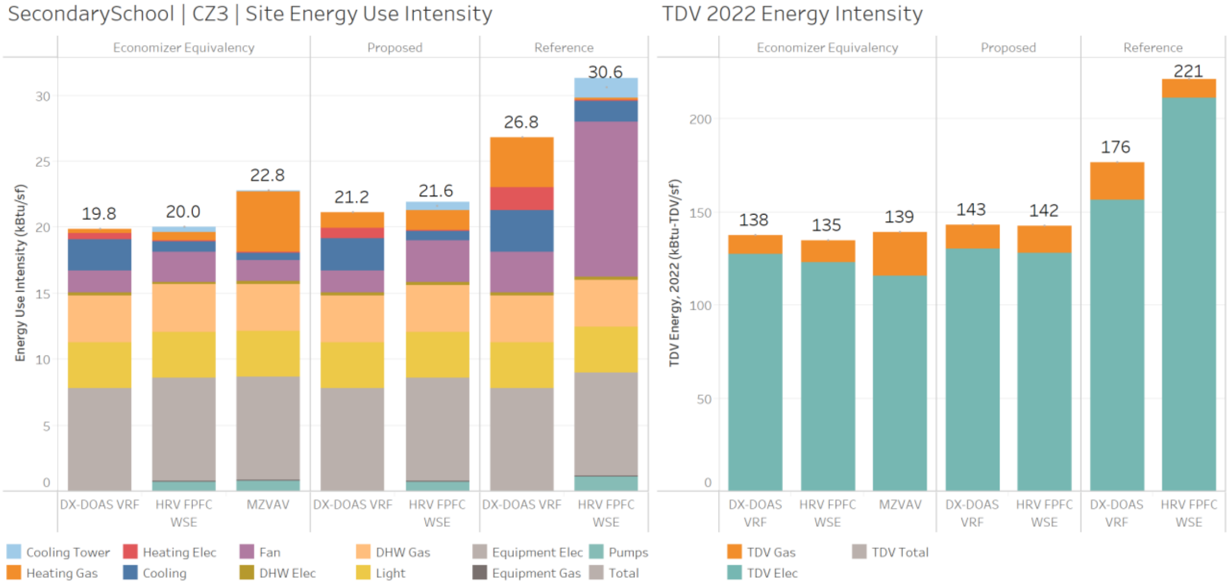

Figure 8: TDV energy and site energy results, Secondary School Climate Zone 3.

The standalone retail prototype was simulated with only one configuration of proposed DOAS with an HRV and VRF space conditioning. The results are compared with the Reference DOAS and with the Standard Design mixed air system. In both comparisons, the proposed DOAS configuration reduces energy use and source energy. In this prototype, savings are primarily driven by saving heating and fan energy. Cooling energy is higher than both the Standard Design and the Reference DOAS model due to decreased economizer capabilities from ventilation heat recovery with overall lower consumption.

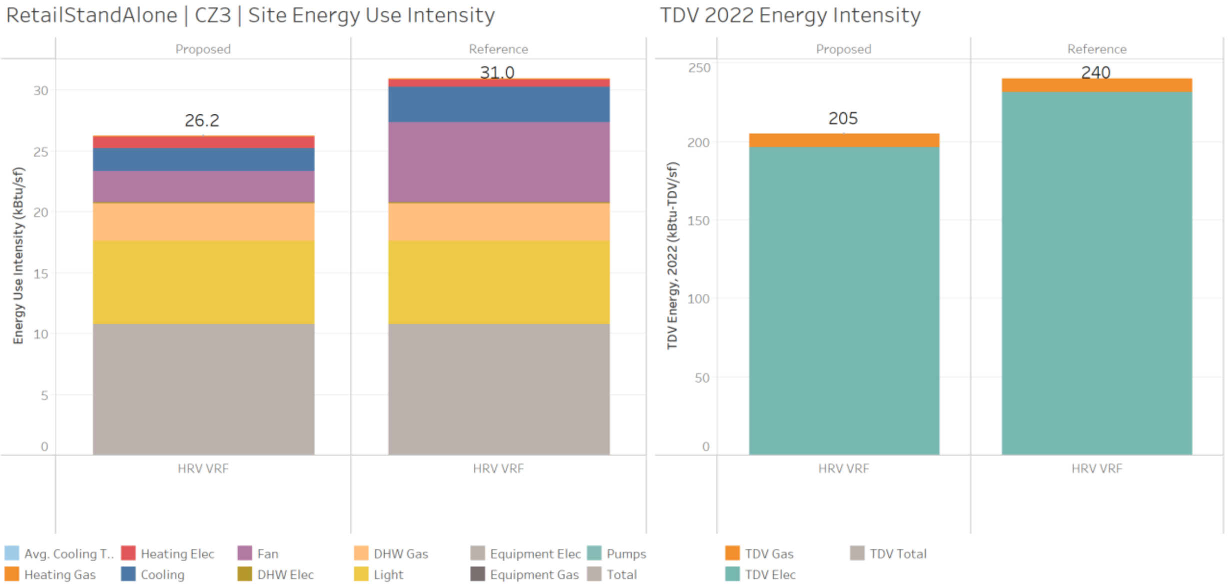

Figure 9: TDV energy and site energy results, Retail Stand Alone, Climate Zone 3.

The small office prototype was configured with three Reference DOAS scenarios to represent typical installations observed in practice. The Reference DOAS systems are HRV with mini splits, HRV with recirculated two speed RTUs, and HRV with VRF. In all three DOAS scenarios overall energy is reduced as well as source energy. Reference 1 and 2 are included for two of the scenarios and represent the energy range observed in Reference DOAS with tier 1 and 2 configurations.

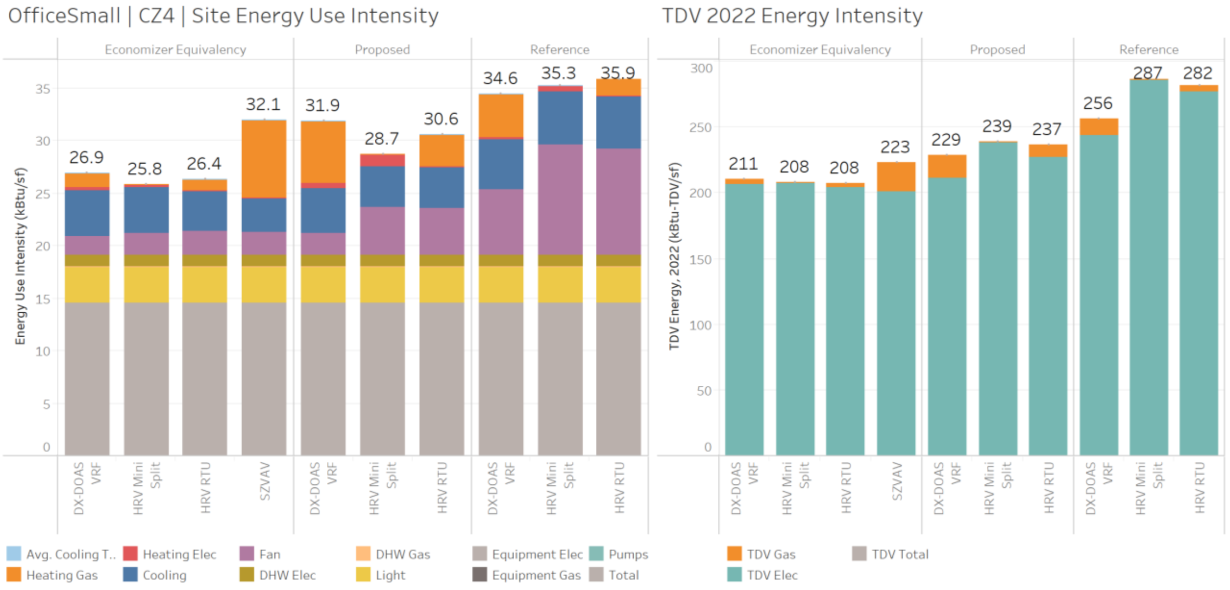

Figure 10: TDV energy and site energy results, Small Office, Climate Zone 4.

DOAS results of each prototype are included in tables below. In all climate zones and prototype configurations of the Proposed DOAS reduces energy use compared with Reference DOAS.

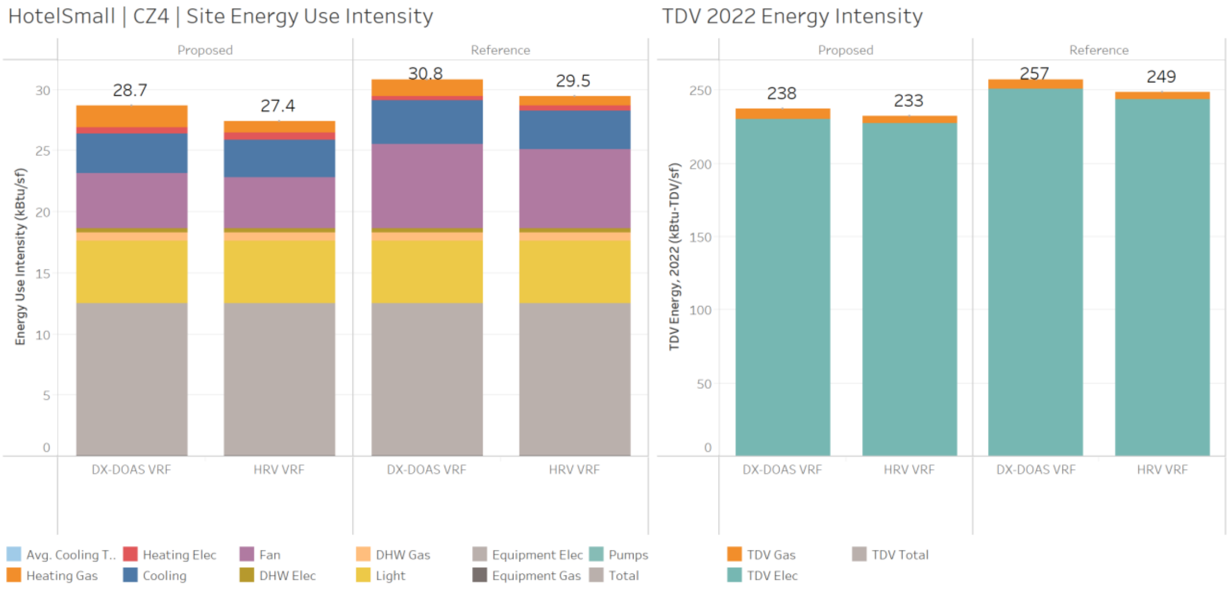

Figure 11: TDV energy and site energy results, Small Hotel, Climate Zone 4.

Tables of Energy Impact per Square Foot per Prototype and Climate Zone

This measure reduces total energy use by 10 to 15 percent depending on the prototype and climate zone. Savings are conservative based on a comparison of Reference DOAS with the proposed DOAS enhancements.

4.4 Cost and Cost Effectiveness

4.4.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in Section 4.3.2. TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis (30 years for residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 15 years.

This code change proposal would apply to alterations and/or additions assuming a whole HVAC system is replaced and installed to trigger the requirements.

4.4.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings and alterations that are realized over the 15-year period of analysis are presented in PV 2023 dollars the following tables and additional tables by prototype are included in the appendix and include data on both nominal dollars and PV 2023 dollars.

The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 75: Present Value TDV Energy Cost Savings Over 15-Year Period of Analysis –Total – New Construction (DOAS market percentages applied)

Climate Zone	15-Year TDV Electricity Cost Savings	15-Year TDV Natural Gas Cost Savings	Total 15-Year TDV Energy Cost Savings
	(2023 Millions PV$)	(2023 Millions PV$)	(2023 Millions PV$)
1	$0.25	($0.00)	$0.25
2	$1.55	($0.00)	$1.54
3	$8.10	($0.01)	$8.08
4	$4.01	($0.02)	$3.99
5	$0.79	($0.00)	$0.79
6	$5.42	$0.01	$5.43
7	$3.94	$0.03	$3.97
8	$7.54	($0.02)	$7.52
9	$13.46	($0.13)	$13.33
10	$4.96	$0.01	$4.97
11	$1.13	$0.00	$1.13
12	$7.17	($0.10)	$7.07
13	$2.01	$0.00	$2.01
14	$1.38	($0.02)	$1.36
15	$0.67	$0.00	$0.68
16	$0.47	($0.01)	$0.46

Table 76: Present Value TDV Energy Cost Savings Over 15-Year Period of Analysis –Total – Alterations (DOAS market percentages applied)

Climate Zone	15-Year TDV Electricity Cost Savings	15-Year TDV Natural Gas Cost Savings	Total 15-Year TDV Energy Cost Savings
	(2023 Millions PV $)	(2023 Millions PV $)	(2023 Millions PV $)
1	$0.15	$0.00	$0.15
2	$0.92	$0.01	$0.93
3	$4.69	$0.06	$4.75
4	$2.29	$0.02	$2.30
5	$0.47	$0.00	$0.47
6	$3.25	$0.04	$3.29
7	$2.49	$0.03	$2.52
8	$4.40	$0.04	$4.44
9	$7.54	($0.00)	$7.54
10	$3.44	$0.04	$3.48
11	$0.71	$0.01	$0.71
12	$4.11	($0.02)	$4.09
13	$1.28	$0.01	$1.29
14	$0.90	($0.00)	$0.89
15	$0.45	$0.00	$0.45
16	$0.31	($0.00)	$0.30

4.4.3 Incremental First Cost

Incremental first cost is the initial cost to adopt more efficient equipment or building practices when compared to the cost of an equivalent baseline project. Therefore, it was important that the Statewide CASE Team consider first costs in evaluating overall measure cost effectiveness. Incremental first costs are based on data available today and can change over time as markets evolve and professionals become familiar with new technology and building practices.

Incremental costs were estimated for the proposed DOAS efficiency components. This included:

- Incremental costs for including bypass or free cooling controls with energy recovery DOAS units.
- Incremental cost for DOAS units with modulating fan speed controls.
- Incremental cost for additional duct work or duct configurations to enable terminal unit fans to have separate supply pathways for terminal unit fans to cycle off.

There is assumed to be no incremental cost for a set fan power limit since this is already set in building codes for fan systems.

Reheat requirements on DOAS units with active cooling and is considered a controls configuration which can be done as part of a typical installation and not increase the cost of a system.

Appendix J includes documentation on assumptions and sources of incremental costs for each item. Costs were estimated for each prototype building based on floor area.

Table 77: DOAS Incremental Cost by Building Type

Building Prototype	Ventilation cfm/sf	Free Cooling / Energy Recovery Cost [$/sf]	Modulating Fan Speed Cost [$/sf]	Added Duct Work [$/sf]	Total Incremental Cost per Building [$/sf]
Small Office	0.15	$0.17	$0.01	$0.70	$0.88
Medium Office	0.15	$0.17	$0.01	$0.70	$0.88
Large Office	0.15	$0.17	$0.01	$0.70	$0.88
Retail Stand Alone	0.23	$0.17	$0.01	$0.70	$0.88
Secondary School	0.35	$0.17	$0.01	$0.70	$0.88
Primary School	0.35	$0.17	$0.01	$0.70	$0.88

This estimate or any modification to enhance this estimate would be the same as the first costs for an addition or alteration to a system. Where system components are reused, the incremental costs would be the same between a Reference Design DOAS and the Proposed Design DOAS.

The additional duct work was increased to represent an increase of 10% of distribution duct work to be a conservative estimate of the necessary ducting. This increased the cost $/sf from $0.18/sf in the draft report to $0.70/sf. This cost is potentially over estimated by a factor of 2 and was chosen to represent a conservative scenario.

4.4.4 Incremental Maintenance and Replacement Costs

Incremental maintenance cost 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 15-year period of analysis. The present value of equipment maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2022 TDV. The present value of maintenance costs that occurs in the nth year is calculated as follows:

$$\textbf{Present Value of Maintenance Cost} = \textbf{Maintenance Cost} \times \left\lfloor \frac{\mathbf{1}}{\mathbf{1+d}} \right\rfloor^{\mathbf{n}}$$

For a DOAS system, maintenance once a year to inspect the unit is required. The expected useful life of the equipment is 10-15 years based on engineering experience of installations. The maintenance cost is assumed to be the same for a Reference Design DOAS and Proposed Design DOAS and no incremental cost for operations was assumed.

4.4.5 Cost Effectiveness

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

The Energy Commission establishes the procedures for calculating cost effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. The incremental first cost and incremental maintenance costs over the 15-year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were also included in the evaluation.

Design costs were not included nor were the incremental costs of code compliance verification.

According to the Energy Commission’s definitions, a measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 15 years by the total incremental costs, which includes maintenance costs for 15 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

Results of the per-unit cost-effectiveness analyses are presented in Table 78 and Table 79 for new construction and alterations, respectively.

Table 78: 15-Year Cost-Effectiveness Summary – Total – New Construction Per Square Foot (DOAS market percentages applied)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$3.9	$0.9	4.4
2	$4.0	$0.9	4.5
3	$4.4	$0.9	5.1
4	$4.2	$0.9	4.8
5	$4.3	$0.9	4.9
6	$4.5	$0.9	5.2
7	$4.2	$0.9	4.7
8	$4.4	$0.9	5.0
9	$4.7	$0.9	5.3
10	$3.6	$0.9	4.1
11	$3.6	$0.9	4.1
12	$3.9	$0.9	4.4
13	$3.2	$0.9	3.6
14	$4.1	$0.9	4.7
15	$3.5	$0.9	4.0
16	$4.3	$0.9	4.9

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

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

Table 79: 15-Year Cost-Effectiveness Summary Total – Alterations (DOAS market percentages applied)

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	$3.7	$0.9	4.2
2	$3.8	$0.9	4.3
3	$4.2	$0.9	4.8
4	$4.0	$0.9	4.5
5	$4.1	$0.9	4.7
6	$4.1	$0.9	4.7
7	$3.9	$0.9	4.5
8	$3.9	$0.9	4.5
9	$4.1	$0.9	4.7
10	$3.4	$0.9	3.9
11	$3.4	$0.9	3.9
12	$3.6	$0.9	4.1
13	$3.0	$0.9	3.4
14	$3.7	$0.9	4.2
15	$3.3	$0.9	3.8
16	$4.0	$0.9	4.5

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.

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

4.5 First-Year Statewide Impacts

4.5.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per-unit savings, which are presented in Section 4.3.5 by assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

Energy models of multiple DOAS configurations were created based on the current energy standards and representative field data where information was not available. Field data was used to capture common DOAS configurations and controls sequences. Configurations were applied to typical building models or prototype buildings used to represent statewide new construction typologies. Models were modified to include the new criteria in the code change language and energy savings was determined between the market typical DOAS and the proposed DOAS. The incremental savings were applied to alterations of existing buildings using the same set of models.

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2023. The 15-year energy cost savings represent the energy cost savings over the entire 15-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

The following table presents the first-year statewide energy and energy cost savings from newly constructed buildings by climate zone.

Table 80: DOAS Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15/30-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.1	0.1	0.0	(0.0)	$0.25
2	0.4	0.6	0.1	(0.0)	$1.54
3	1.8	3.1	0.3	(0.0)	$8.08
4	0.9	1.6	0.2	(0.0)	$3.99
5	0.2	0.3	0.0	0.0	$0.79
6	1.2	2.1	0.2	(0.0)	$5.43
7	1.0	1.5	0.2	0.0	$3.97
8	1.7	3.0	0.3	(0.0)	$7.52
9	2.9	5.4	0.6	(0.0)	$13.33
10	1.4	2.0	0.2	0.0	$4.97
11	0.3	0.4	0.0	(0.0)	$1.13
12	1.8	2.9	0.3	(0.0)	$7.07
13	0.6	0.8	0.1	0.0	$2.01
14	0.3	0.5	0.1	(0.0)	$1.36
15	0.2	0.3	0.0	0.0	$0.68
16	0.1	0.2	0.0	(0.0)	$0.46
Total	**14.9**	**24.8**	**2.7**	**(0.0)**	**$62.59**

a. First-year savings from all buildings completed statewide in 2023.

Table 81: DOAS Statewide Energy and Energy Cost Impacts – Alterations

Climate Zone	Statewide Alterations Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15/30-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.0	0.1	0.0	0.0	$0.15
2	0.2	0.4	0.0	0.0	$0.93
3	1.1	1.8	0.2	0.0	$4.75
4	0.6	0.9	0.1	0.0	$2.30
5	0.1	0.2	0.0	0.0	$0.47
6	0.8	1.3	0.1	0.0	$3.29
7	0.6	1.0	0.1	0.0	$2.52
8	1.1	1.7	0.2	0.0	$4.44
9	1.8	3.0	0.3	0.0	$7.54
10	1.0	1.3	0.2	0.0	$3.48
11	0.2	0.3	0.0	0.0	$0.71
12	1.1	1.6	0.2	0.0	$4.09
13	0.4	0.5	0.1	0.0	$1.29
14	0.2	0.3	0.0	0.0	$0.89
15	0.1	0.2	0.0	0.0	$0.45
16	0.1	0.1	0.0	(0.0)	$0.30
Total	**9.7**	**14.7**	**1.6**	**0.0**	**$37.63**

a. First-year savings from all buildings completed statewide in 2023.

Table 82: DOAS Statewide Energy and Energy Cost Impacts – New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (PV$ million)
New Construction	25	2.67	-0.01	62.6
Additions and Alterations	15	1.60	0.01	37.6
TOTAL	**40**	**4.27**	**0.01**	**100.2**

a. First-year savings from all alterations completed statewide in 2023.

4.5.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO2e per GWh based on the average emission factors for the CACX EGRID subregion.

Table 83 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 10,000 metric tons of carbon dioxide equivalents (metric tons CO2e) would be avoided.

Table 83: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMTherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
DOAS Controls	40	9,500	0.01	0	10,000
TOTAL	**40**	**9,500**	**0.01**	0	10,000

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.36 MTCO2e/GWh and 5,454.42 MTCO2e/MMTherms.

4.5.3 Statewide Water Use Impacts

The proposed code change would not result in water savings.

4.5.4 Statewide Material Impacts

The proposed code change is switching like for like equipment with regards to an HVAC system component or controls components. There would be no impact in statewide material use.

4.5.5 Other Non-Energy Impacts

The proposed code change would add increased control capabilities to DOAS which would improve the persistence of indoor air quality and comfort in buildings.

4.6 Proposed Revisions to Code Language

4.6.1 Guide to Markup 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 red underlining (new language) and ~~strikethroughs~~ (deletions).

4.6.2 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

DX-Dedicated Outdoor Air System units (DX-DOAS units)- a type of air-cooled, water-cooled, or water-source factory assembled product that dehumidifies 100 percent outdoor air to a low dew point and includes reheat that is capable of controlling the supply dry-bulb temperature of the dehumidified air to the designed supply air temperature. This conditioned outdoor air is then delivered directly or indirectly to the conditioned spaces. It may precondition outdoor air by containing an enthalpy wheel, sensible wheel, desiccant wheel, plate heat exchanger, heat pipes, or other heat or mass transfer apparatus.

Integrated Seasonal Coefficient of Performance (ISCOP)- A seasonal efficiency number that is a combined value based on the formula listed in AHRI Standard 920 of the two COP values for the heating season of a DX-DOAS unit water or air source heat pump, expressed in W/W.

Integrated Seasonal Moisture Removal Efficiency (ISMRE)- A seasonal efficiency number that is a combined value based on the formula listed in AHRI Standard 920 of the four dehumidification moisture removal efficiency (MRE) ratings required for DX-DOAS units, expressed in lb. of moisture/kWh.

ANSI/AHRI 920 is the Air-Conditioning, Heating, and Refrigeration Institute document titled "Performance Rating of DX-Dedicated Outdoor Air System Units" 2020 (ANSI/AHRI Standard 920-(I-P)-2020).

ANSI/AHRI 1060 is the Air-Conditioning, Heating, and Refrigeration Institute document titled "Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment" 2018 (ANSI/AHRI Standard 106-(I-P)-2018)

(These definitions are included even though they are not referenced in the proposed code language below in anticipation of the Energy Commission adopting DX-DOAS efficiency criteria matching DOE and ASHRAE 90.1-2019.)

SECTION 120.1 – REQUIREMENTS FOR VENTILATION AND INDOOR AIR QUALITY

(h) Ventilation Only Mechanical Systems. HVAC Systems without mechanical cooling or mechanical heating shall meet the requirements of Section 120.2 (f).

SECTION 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

(The following fan power credit additions would not be included pending the fan power budget CASE report criteria is adopted)

(c) Fan Power Limitations.

TABLE 140.4-B – Fan Power Limitation Pressure Drop Adjustment	
Device	Adjustment Credits
Return or exhaust systems required by code or accreditation standards to be fully ducted, or systems required to maintain air pressure differentials between adjacent rooms	0.5 in. of water
Return and/or exhaust airflow control devices	0.5 in. of water
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of the device calculated using fan system design conditions
Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2 x clean filter pressure drop at fan system design conditions
Carbon and other gas-phase air cleaners	Clean filter pressure drop at fan system design conditions
Biosafety cabinet	Pressure drop of device at fan system design conditions
Energy recovery device, other than coil runaround loop	For each airstream [(2.2 x Energy Recovery Effectiveness) – 0.5] in. of water
Coil runaround loop	0.6 in. of water for each airstream
Exhaust systems serving fume hoods	0.35 in. of water
Device	Adjustment Deductions
Systems without central mechanical cooling device	–0.6 in. of water
Systems without central mechanical heating device	–0.3 in. of water
Systems with central electric resistance heat	–0.2 in. of water

(e) Economizers.

1. Each cooling air handler that has a design total mechanical cooling capacity over 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:

b. 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; or

c. A water economizer capable of providing 100 percent of the expected system cooling load, at outside air temperatures of 50°F dry-bulb and 45°F wet-bulb and below.

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.

~~**EXCEPTION 6 to Section 140.4(e)1:** Systems design to operate at 100 percent outside air at all times.~~

EXCEPTION 6 to Section 140.4(e)1: Systems providing cooling and heating decoupled from ventilation and that utilize a dedicated outdoor air system unit for ventilation in accordance with 140.4 (p)1B.

(p) Dedicated Outdoor Air Systems (DOAS). For HVAC Systems which utilize a dedicated outdoor air system (DOAS) to condition, temper, or filter 100 percent outdoor air separate from local or central space-conditioning systems serving the same space shall meet the following criteria:

1. Provide each space with either of the following configurations:
    A. A DOAS unit and a separate independent space-conditioning system which meets the economizer requirements specified by Section 140.4(e)1 and exhaust air heat recovery requirements specified in Section 140.4(p).
    B. A DOAS unit which meets or exceeds the following criteria and a separate space cooling system:
        i. DOAS unit shall be designed at airflow rate no less than 150 percent of the sum of the outdoor airflow rate to each zone as specified in Section 120.1(c)3.
        ii. Ventilation sensible energy recovery ratio of at least 60 percent or energy recovery ratio of at least 50 percent at full flow cooling design conditions

and heating design condition.

   iii. Energy recovery bypass control capabilities to directly economize with ventilation air based on outdoor air temperature limits specified in TABLE 140.4-E.

   iv. DOAS units with airflow rate > 1,000 cfm must meet demand ventilation control requirements in accordance with Sections 120.1(d) 3, 4, 5.

EXCEPTION 1 to Section 140.4(p)1: Systems installed for sole purpose of providing makeup air for exhausting toxic, flammable materials, paint, corrosive fumes or dust, dryer exhaust, or commercial kitchen hoods used for collecting and removing grease vapors and smoke.

2. Ventilation fan systems shall be capable of modulating fan speed control.
3. Heating and cooling equipment fans, heating and cooling circulation pumps, and terminal unit fans shall cycle off and terminal unit primary cooling air shall be shut off when there is no call for heating or cooling in the zone.

EXCEPTION 1 to Section 140.4(p)3: Fans used for heating and cooling using less than 0.12 watts per cfm may operate when space temperatures are within the thermostat deadband to provide destratification and air mixing in the space.

4. The DOAS supply air shall be delivered directly to the occupied space or downstream of the terminal heating/or cooling coils.

EXCEPTION 1 to Section 140.4(p)4: Active chilled beam systems.

EXCEPTION 2 to Section 140.4(p)4: Sensible only cooling terminal units with pressure independent variable airflow regulating devices limiting the DOAS supply air to the greater of latent load or minimum ventilation requirements.

EXCEPTION 3 to Section 140.4(p)4: Terminal heating/or cooling units that comply with the low fan power allowance requirements in Exception 1 to Section 140.4(p)3.

5. DOAS with mechanical cooling providing ventilation to multiple zones and operating in conjunction with zone heating and cooling systems shall not use heating or heat recovery to warm supply air above 60°F when representative building loads or outdoor air temperature indicate that the majority of zones require cooling.
6. DOAS with a total fan system power less than 1 kW shall not exceed a total combined fan power of 1.0 W/cfm. DOAS with fan power greater than or equal to 1 kW shall meet the requirements of Section 140.4 (c).

4.6.3 Reference Appendices

Current enhancements are represented in the code language definitions. The acceptance test for outdoor air as specified in the exhaust air heat recovery measure will be referenced by the DOAS section as well.

4.6.4 ACM Reference Manual

A draft list of the sections below is provided where changes are anticipated to the ACM Reference Manual. The primary areas are in defining the HVAC system components, including the DOAS unit, DOAS unit controls, zone heat and cooling controls, and system integration between them.

- 5.7 HVAC Secondary Systems

  See sections below.

- 5.7.2 System Controls

  Definitions of Supply Air Temperature controls options for HRV/ERV and DX-DOAS.

- 5.7.4 Outdoor Air Controls and Economizers

  Description of the bypass and ventilation economizing functionalities for a DOAS unit.

- 5.7.5.2 Direct Expansion

  Description of the supply air temperature control functionality if a DX-DOAS or other DOAS unit with active cooling is utilized.

4.6.5 Compliance Manuals

A new section describing the DOAS prescriptive criteria would be developed. This would include at least one example problem of how the code is applied and when specific criteria are required. These would be in:

- Chapter 4: Mechanical Systems
- Section 4.2
- Section 4.3
- Section 4.6
- 4.1.1.1.1.5 Prescriptive Compliance Approach

4.6.6 Compliance Documents

Document 1 NRCA MCH02-A – Modify the outdoor air test to include the ability to validate a DOAS unit. Minor modifications to allow the form to be completed.

Document 2 NRCA MCH05-A – Add a component to the economizer controls test to validate bypass or free cooling capabilities of a DOAS with ventilation heat recovery. Fundamentally the test procedure is very similar and would expand the test only for those units.

NRCC-MCH-E would need to be revised to document new prescriptive requirements specific to DOAS.

5. Exhaust Air Heat Recovery (EAHR)

5.1 Measure Description

5.1.1 Measure Overview

This measure would add requirements for exhaust air heat recovery (EAHR) to Title 24, Part 6. Currently there are no requirements specifying heat recovery from general exhaust despite the benefits for certain building types in certain California climate zones. This measure proposes to incorporate a new prescriptive requirement for exhaust air heat recovery informed by the requirements in ASHRAE 90.1-2019 Section 6.5.6, with significant modifications for California's unique microclimates and differing financial metrics. The proposed measure would require heat to be recovered from exhaust air to precondition incoming outdoor air for situations that have been proven to be cost effective.

The Statewide CASE Team assessed the energy savings benefits and incremental costs of exhaust air heat recovery devices to determine which specific building types and climate zones would be cost effective, and therefore, where the requirements should be applied.

There are two main types of exhaust air energy recovery devices:

- Units which recover dry sensible heat only known as heat recovery devices (HRVs)
- Units which recover dry and moist heat known as energy recovery devices (ERVs)

Sensible energy recovery is measured by the dry-bulb air temperature that is recovered. Total energy recovery measures dry-bulb air temperature that is recovered but also includes moisture recovery.[20] Due to California's dry climates, most nonresidential buildings would have outdoor air dry enough such that only sensible energy recovery is needed. The proposed measure applies to new buildings and alterations which replace HVAC systems in climates zones and building types that are cost effective.

The proposed measure would add a new section to Title 24, Part 6's prescriptive requirement based on the template of code requirements found in ASHRAE Standard 90.1 which utilizes a combination of outdoor air fraction, climate zone, and design system airflow, and hours of operation. The measure would apply to both new construction scenarios and alterations and additions. This measure would require a

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[20] Moisture recovery is also known as latent heat recovery. Latent heat is the energy that is either released or absorbed when water is condensed from water vapor to liquid or evaporated from liquid to gas respectively. In this context, latent heat recovery refers to capturing the energy that is released when water vapor is condensed.

minimum sensible energy recovery ratio of 60 percent for all systems that would require exhaust air heat recovery and also include requirements for an economizer bypass.

5.1.2 Measure History

There are no current requirements in Title 24, Part 6 for heat recovery ventilators and there are no concerns for federal preemption as this measure would require exhaust air heat recovery devices which are not a part of federally regulated equipment. A similar measure was proposed in the 2019 Title 24, Part 6 code cycle but was not adopted.

At that time, the Energy Commission expressed concerns during the 2019 code cycle that exhaust air heat recovery was not cost effective enough in all climates and might actually increase energy use under certain conditions. The 2019 proposal only applied to climate zones that had 100 percent outside air, which included a small number of total buildings that would have been affected. Due to the limited number of affected buildings and the concerns over cost effectiveness, the Energy Commission chose not to adopt, however, the Energy Commission adopted the requirement in Title 24, Part 11, CALGreen. The language adopted into CALGreen was nearly identical to language in the 2019 CASE Report.

For this study, the Statewide CASE Team conducted much more extensive modeling to determine which scenarios this measure is cost effective and is not proposing it in areas without positive energy benefits. In the 2019 code cycle, the limited prototype models were the primary reason the energy results were not found to be cost effective.

5.1.3 Summary of Proposed Changes to Code Documents

5.1.3.1 Summary of Changes to the Standards

Section 140.4 – Prescriptive Requirements for Space Conditioning Systems: The proposed change would add a new section to Section 140.4 for exhaust air heat recovery. This section would outline the exhaust air heat recovery requirements modeled on similar requirements and exceptions from ASHRAE 90.1 Section 6.5.6.1 but adapted for California buildings and climate zones. It would also include higher stringency energy recovery requirement than ASHRAE Standard 90.1 and specify requirements only for sensible energy recovery, rather than total energy recovery. The requirements would also require use of a bypass damper to allow air-side economizer operation.

Regarding the potential inclusion for healthcare facilities, the Statewide CASE Team believes this measure should be considered for HVAC systems that serve non-critical areas but will need modified requirements for health care considerations, such as limiting exhaust air leakage to 5 percent or less for certain space types or fully eliminating leakage risk with wrap-around coils.

5.1.3.2 Summary of Changes to the Reference Appendices

NA7.5.4 – Air Economizer Controls: The proposed change would add a requirement to verify presence of an economizer bypass controls for systems with exhaust air heat recovery ventilators has been field or factory calibrated and that manufacturer's startup and testing procedures have been applied. This would be added as a new requirement to NA7.5.4.1.

5.1.3.3 Summary of Changes to the Nonresidential ACM Reference Manual

Section 5.7.6.6 Heat Recovery: The proposed change would update the existing section of the ACM Reference Manual to outline the modeling algorithm for exhaust air heat recovery systems. Specifically, the proposed measure adds the new baseline requirement for heat recovery devices and would require CBECC-Com to be updated to allow heat recovery for systems with less than 100 percent outside air. Currently, CBECC-Com does not include requirements for heat recovery in the Standard Design and heat recovery devices can only be added when the system is a 100 percent outdoor air system.

5.1.3.4 Summary of Changes to the Nonresidential Compliance Manual

The proposed change would add a new section to the Nonresidential Compliance Manual under Section 4.6.2 Prescriptive Requirements. This new section would include an explanation of the new requirement based on the ASHRAE 90.1 User's Manual.

5.1.3.5 Summary of Changes to Compliance Documents

The proposed change would modify the following compliance documents:

NRCC-MCH-E
NRCC-PRF-E
NRCA-MCH-05-A

These compliance documents would be updated to include provisions for heat recovery ventilators and economizer bypass controls.

5.1.4 Regulatory Context

5.1.4.1 Relationship to Requirements in Other Parts of the California Building Code

The proposed measure would require a bypass for the air-side economizer, so it does not interfere with existing economizer operations. The heat recovery ventilator operations should be linked to the economizer's fault detection diagnostics to make sure the device is not interfering with economizer operations. There is no impact from this measure change to other parts of Title 24 beyond Part 6.

Portions of this measure exist as part of an exhaust air heat recovery section A5.203.1.1.5 within Title 24, Part 11, CALGreen. The language adopted into CALGreen was nearly identical to language in the 2019 CASE Report which references section 6.5.6.1 of ASHRAE Standard 90.1 but adapted for California climate zones. The provision requires systems with 80 percent outdoor air fractions and supply airflow of 200 cfm or greater require a heat recovery system for half of California's climate zones (2, 9, 10, 11, 12, 13, 14, and 15). This proposal would necessitate the removal of this language from CALGreen as the requirements cover a wider scope of buildings and systems.

5.1.4.2 Relationship to Local, State, or Federal Laws

There are no other state or federal laws that address the proposed change.

5.1.4.3 Relationship to Industry Standards

The measure would be incorporating ASHRAE 90.1-2019 Section 6.5.6.1 which were last updated in the 2016 version. However, general requirements for exhaust air heat recovery have been within ASHRAE Standard 90.1 since the 2004 version which required a 50 percent energy recovery effectiveness for systems with flow rate of 5,000 CFM or greater and a minimum outdoor air fraction of 70 percent or greater. In 2010, a table was developed that incorporated requirements based on flow rate, percent minimum outdoor air fraction, and climate zone. In 2013, this table was split into separate tables based on hours of operation of the fan systems and this format is the basis of the current standard.

The Statewide CASE Team is basing this proposal on the latest language in ASHRAE Standard 90.1 (2019). This standard has also been adopted into the 2018 version of the 2018 International Energy Conservation Code (IECC) as a mandatory measure (section C403.7.4 Energy recovery ventilation systems) so many states already include this provision in their own energy codes.

AHRI Standard 1060/1061 is a certification standard for factory-made exhaust air heat recovery devices. Currently, this certification standard publishes the sensible and latent effectiveness ratings for heating and cooling at standardized rating conditions and rely on engineers to calculate the equivalent energy recovery ratio as necessary. Comments received from the Draft CASE Report indicated that AHRI Standard 1060 is transitioning to a certified software program starting in 2021 which will eliminate the standardized ratings as currently constructed. Despite this, the Statewide CASE Team maintains that the energy recovery ratio will persist as the primary metric for assessing exhaust air heat recovery devices in building codes. This is supported by the fact that the recently updated ASHRAE 84-2020, "Method of Testing Air-to-Air Heat/Energy Exchangers," added a definition for energy recovery ratio. ASHRAE 84 is the underlying method of test that is referenced by AHRI 1060. Therefore, the Statewide CASE Team is confident that the energy recovery ratio metric will persist and has chosen to align this proposal with the current language in ASHRAE 90.1-2019.

5.1.5 Compliance and Enforcement

This code change proposal affects buildings that use the prescriptive approach to compliance, with the key steps and changes to the compliance process summarized below.

- **Design Phase:** Changes to the existing design phase are anticipated for buildings and climates that would newly require heat recovery ventilators. The design team must be aware of the new code changes and properly size, design, and control the systems. This would increase the size of the air handling units, so coordination with the architects for mechanical room space and structural engineers for loads is anticipated.
- **Permit Application Phase:** The changes to the compliance document NRCC-MCH-E reflect the code change requirements. The permit reviewer would need to know if a particular air handler would require an energy recovery device and check if the building is designing the air system in compliance with the new code based on the hours of operation of the building (to determine whether 1) the building falls above or below the 8,000 hours per year threshold or 2) the building falls below the 20 hours per week threshold and qualifies for an exception), climate zone, and characteristics of the air handler. Performance compliance applications that choose to use heat recovery would also need to have the system design checked.
- **Construction Phase:** The proposed changes require mechanical subcontractors to be able to properly install heat recovery ventilators and operate as required by code.
- **Inspection Phase:** The inspector must check if the exhaust air heat recovery device meets the minimum allowed energy recovery ratio for the net sensible energy recovery. During the acceptance testing, the inspector needs to make sure the heat recovery ventilator is working properly. The inspector must also make sure the heat recovery ventilator is not interfering with the economizer controls that would increase heating or cooling energy.

5.2 Market Analysis

The Statewide CASE Team proposed similar requirements in the 2019 code cycle and has built off research from the 2019 CASE Report. The Statewide CASE Team has confirmed it is still accurate with additional research and stakeholder outreach.

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry players who were invited to participate in utility-sponsored stakeholder meetings held on October 15, 2019 and April 14, 2020 (Statewide CASE Team: HVAC Controls 2020)

5.2.1 Market Structure

Principal manufacturers of heat recovery ventilators include RenewAire and Venmar. Greenheck, Trane, AAON, and Carrier offer heat recovery ventilators as an option on packaged systems. The products are distributed through manufacturer representatives or directly from the manufacturers. The products are a well-established technology as there have been requirements in ASHRAE 90.1 since the 2004 version of the standard. Products are readily available from multiple manufacturers.

5.2.2 Market Actors

Building Designers and Energy Consultants

This measure would require building designers to specify an energy recovery device under certain scenarios based on building-type, climate-zone, and system capacity. The primary impact in the design and consulting process would fall to equipment representatives who are closely connected to the differentiating capabilities of products and know what products can meet these new requirements. Overall, the impact would be minor since many manufacturers already contain these features for other regions.

Impact on Building Owners and Occupants

This measure would increase outdoor air rates during cold and hot weather conditions which would provide indoor air quality benefits to occupants. Additional documentation and inspections of the energy recovery device would now be required during permitting and construction. These changes are minor impacts as this would be an add on feature to an already existing unit which already requires documentation and inspection.

Controls Contractors and HVAC Manufacturers

Controls programming would need to be updated to include an energy recovery device into the logic. This should also be incorporated into the FDD systems to ensure the bypass is operating properly and able to notify operators when it is not. This impact would be minor since this is a simple change for controls contractors and already exist for national manufacturers to comply with ASHRAE's requirements in other regions.

Equipment Representatives

New requirements for energy recovery would lean on equipment representatives to be able to differentiate different options for clients. For example, because energy recovery devices save energy at the extremes, it would be an opportunity to downsize cooling capacities in certain situations. Designers would lean heavily on equipment reps for understanding of unit capabilities.

Building Inspectors and Plan Checkers

This would add a minor change for plan checkers which would verify that prescriptive units must utilize a qualified exhaust air heat recovery device should the air handling systems meet the hours-of-operation criteria along with the climate zone, outdoor air, and design CFM requirements. During inspection, air handling units would need to be verified during to ensure they meet this requirement.

5.2.3 Technical Feasibility, Market Availability, and Current Practices

Exhaust air heat recovery units are available from many different manufacturers and the Statewide CASE Team expects that all manufacturers are familiar with the technology because it is already a long-standing requirement in ASHRAE Standard 90.1 and IECC. In addition, with the increased familiarity with DOAS and decoupled systems generally, the California market is becoming more familiar with energy and heat recovery devices.

The Statewide CASE Team completed a market analysis to confirm market availability of the higher energy recovery requirements. The AHRI Directory of Certified Product Performance lists tested ratings for all certified energy recovery devices available in the market made by AHRI participating manufacturers. Table 84 shows the breakdown of products that would be able to meet the 60 percent sensible energy recovery ratio and found that over 75 percent of the current market can meet these requirements, with almost all wheel-type and the large majority of plate-type heat exchangers.

Table 84: Market Analysis of AHRI Directory of Energy Recovery Devices

Device Type	Number of Products in AHRI Database	Products with a 60%+ Sensible Cooling Recovery Ratio	Products with a 60%+ Sensible Heating Recovery Ratio
Heat Pipe	231	0	0
Plate-type	710	421	467
Wheel-type	1776	1707	1776

Technical feasibility for implementation of the heat recovery device must also be considered, including economizer bypass, increased fan size, and co-locating the intake and exhaust. The ASHRAE 90.1 standard addresses each of these issues:

- Section 6.5.6.1.2 addresses economizer bypass
- Section 6.5.3.1 addresses fan power increase
- Exception 6 to Section 6.5.6.1 addresses the feasibility of co-locating the intake and exhaust airstreams.

For projects with heat recovery devices, these criteria are all current practices. Heat recovery devices used in package units would need to include an economizer bypass, but most package units would size the bypass opening to match the pressure drop through the heat recovery ventilator. This is to maintain consistent fan operation. The proposed language also includes a requirement for the bypass controls to modulate to achieve a supply air setpoint or outdoor air temperature setpoint.

5.2.4 Market Impacts and Economic Assessments

5.2.4.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2022 code cycle. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California’s construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 85).[21] In 2018, total payroll was $80 billion. Nearly 17,000 establishments and 344,000 employees focus on the commercial sector.

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

Table 85: California Construction Industry, Establishments, Employment, and Payroll

Construction Sectors	Establishments	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 change to nonresidential HVAC controls would likely affect commercial builders and nonresidential electrical, HVAC, and plumbing contractors but would not significantly impact other building trades. The effects on the commercial building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 86 shows the commercial building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report as they are related directly related to the purchase and installation of HVAC equipment.

Table 86: Specific Subsectors of the California Commercial Building Industry Impacted by Proposed Change to Code

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	$4.8
Other Nonresidential equipment contractors	506	8,884	$0.9

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

5.2.4.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. 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 compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 87 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code changes would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for Nonresidential HVAC Controls to affect firms that focus on nonresidential construction.

There is not a North American Industry Classification System (NAICS)[22] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[23] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 87 provides an upper bound indication of the size of this sector in California.

Table 87: California Building Designer and Energy Consultant Sectors

Sector	Establishments	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 establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;

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[22] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of 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 Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

[23] Establishments in this sector include businesses primarily engaged in evaluating a building's structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily 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.

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

5.2.4.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

5.2.4.4 Impact on Building Owners and Occupants

Commercial Buildings

The commercial building sector includes a wide array of building types, including offices, restaurants and lodging, retail, and mixed-use establishments, and warehouses (including refrigerated) (California Energy Commission. 2019). Energy use by occupants of commercial buildings also varies considerably with electricity used primarily for lighting, space cooling and conditioning, and refrigeration. Natural gas consumed primarily for heating water and for space heating. According to information published in the 2019 California Energy Efficiency Action Plan, there is more than 7.5 billion square feet of commercial floor space in California and consumes 19 percent of California's total annual energy use (California Energy Commission. 2019). 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.

Estimating Impacts

Building owners and occupants would benefit from lower energy bills. As discussed in Section 5.2.5.1, 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 Statewide CASE Team does not expect the proposed code change for the 2022 code cycle to impact building owners or occupants adversely.

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

The Statewide CASE Team does not expect any significant impacts on manufacturers and distributors of these products.

5.2.4.6 *Impact on Building Inspectors*

Table 88 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 88: Employment in California State and Government Agencies with Building Inspectors

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs[a]	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

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

a. Administration of Housing Programs (NAICS 925110) comprises government establishments 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 establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

5.2.4.7 *Impact on Statewide Employment*

The Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 5.2.5, the Statewide CASE Team 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 Statewide CASE Team 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.

5.2.5 Economic Impacts

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the commercial building industry, architects, energy consultants, and building inspectors. The Statewide CASE

Team does not anticipate that money saved by commercial building owners or other organizations affected by the proposed 2022 code cycle regulations would result in additional spending by those businesses.

Table 89: Estimated Impact that Adoption of the Proposed Measure would have on the California Commercial Construction Sector

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Commercial Builders)	55	$3.63	$4.81	$7.95
Indirect Effect (Additional spending by firms supporting Commercial Builders)	12	$0.87	$1.38	$2.67
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	24	$1.34	$2.40	$3.93
Total Economic Impacts	**91**	**$5.84**	**$8.59**	**$14.54**

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

Table 90: Estimated Impact that Adoption of the Proposed Measure would have on the California Building Designers and Energy Consultants Sectors

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Building Designers & Energy Consultants)	0	$0.02	$0.02	$0.04
Indirect Effect (Additional spending by firms supporting Bldg. Designers & Energy Consult.)	0	$0.01	$0.01	$0.02
Induced Effect (Spending by employees of firms experiencing “direct” or “indirect” effects)	0	$0.01	$0.02	$0.03
Total Economic Impacts	**0**	**$0.04**	**$0.05**	**$0.09**

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

Table 91: Estimated Impact that Adoption of the Proposed Measure would have on California Building Inspectors

Type of Economic Impact	Employment (jobs)	Labor Income (millions $)	Total Value Added (millions $)	Output (millions $)
Direct Effects (Additional spending by Building Inspectors)	0	$0.02	$0.03	$0.03
Indirect Effect (Additional spending by firms supporting Building Inspectors)	0	$0.00	$0.00	$0.00
Induced Effect (Spending by employees of Building Inspection Bureaus and Departments)	0	$0.01	$0.01	$0.02
Total Economic Impacts	**0**	**$0.03**	**$0.04**	**$0.05**

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

5.2.5.1 Creation or Elimination of Jobs

The Statewide CASE Team 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. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 5.2.5.1 would lead to modest changes in employment of existing jobs.

5.2.5.2 Creation or Elimination of Businesses in California

As stated above, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to HVAC Controls which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes.

5.2.5.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is located inside or outside of the state.[24] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2022 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

5.2.5.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[25] As Table 92 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, with an average of 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 92: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
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.)

The Statewide CASE Team does not anticipate that the economic impacts associated with the proposed measure would lead to significant change (increase or decrease) in investment in any directly or indirectly affected sectors of California's economy.

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[24] 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.

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

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

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

5.2.5.5.1 Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government would be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs 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 Statewide CASE Team does not expect any appreciable change to the state.

5.2.5.5.2 Cost to Local Governments

All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this 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.

5.2.5.6 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed code change may result in unintended consequences. The Statewide CASE Team has not found any information showing that specific persons would be impacted by this proposal.

5.3 Energy Savings

5.3.1 Key Assumptions for Energy Savings Analysis

Energy savings calculations performed in support of this proposal are estimated using CBECC-Com prototype building models. The baseline model represents the Standard Design EnergyPlus model generated by CBECC-Com in accordance with the 2019 Nonresidential ACM Reference Manual. The proposed model is produced by modifying the baseline model to incorporate exhaust air heat recovery.

The following are the key assumptions used in the energy savings analysis:

- Energy recovery is available only during periods when the outside air economizer is not in operation (outside air temperatures above 75°F and below 55°F).
- Heating and cooling energy in the exhaust/relief air is transferred to the fresh air supply via fixed plate heat exchanger equipped with bypass dampers.
- Energy recovery performance is assumed at 60 percent sensible energy recovery ratio. This performance is consistent with the proposed requirement for ventilation systems and DOAS.
- The added static pressure to airstream is based on that specified for “Energy recovery device, other than coil runaround loop” located in Table 140.4B – Fan Power Limitations Pressure Drop Adjustment within Title 24, Part 6, Section 140.4 (ASHRAE Standard 90.1 Section 6.5.3.1 uses an equivalent table):

  *2.2 IWC * Energy Recovery Effectiveness – 0.5 IWC, per airstream (Equation 1)*

  (IWC stands for inches of water column, a unit of pressure)

  - EnergyPlus does not have the ability to dynamically adjust static pressures based on whether airstreams are bypassing the heat exchanger. As a result, this simulation assumes a constant pressure drop adjustment of +1.2 IWC throughout the simulation based on this equation from the fan drop table.
  - There is an adjacent effort by the Statewide CASE Team to update pressure credits and penalties for fan systems. The overall impact of that proposal would reduce the pressure drop adjustment from 1.2 IWC to 1.0 IWC. The Statewide CASE Team did not implement the lower pressure drop for this analysis.

5.3.2 Energy Savings Methodology

Initial Analysis: Cost Effectiveness of ASHRAE Requirements

The Energy Commission directed the Statewide CASE Team to estimate energy impacts using specific prototypical building models that represent typical building geometries and space functions for different types of buildings. The Statewide CASE Team looked to develop a similar format of recommendations to the standards in Section 6.5.6.1.2 of ASHRAE Standard 90.1 (ASHRAE, Standard 90.1 2019). These requirements are dependent on climate zones with additional criteria based on design supply fan airflow rate, percentage of outdoor air at design conditions, and annual operating hours. Table 93 and Table 94 show the specific ASHRAE requirements located in Section 6.5.1.2 and Figure 12 shows a map of the climate zones referenced (in this map, most of California is covered by 3B and 3C which are represented by El Paso, Texas and San Francisco, California respectively).

Table 93. Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Less than 8000 Hours per Year (ASHRAE 90.1-2019 Table 6.5.6.1.2-1)

ASHRAE Climate Zone	**% *Outdoor Air* at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	NR	NR	NR	NR
0B, 1B, 2B, 5C	NR	NR	NR	NR	≥26,000	≥12,000	≥5,000	≥4,000
6B	≥28,000	≥26,500	≥11,000	≥5,500	≥4,500	≥3,500	≥2,500	≥1,500
0A, 1A, 2A, 3A, 4A, 5A, 6A	≥2,600	≥16,000	≥5,500	≥4,500	≥3,500	≥2,000	≥1,000	≥120
7, 8	≥4,500	≥4,000	≥2,500	≥1,000	≥140	≥120	≥100	≥80

Table 94. Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year (ASHRAE 90.1-2019 Table 6.5.6.1.2-2)

ASHRAE Climate Zone	**% *Outdoor Air* at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
3C	NR	NR	NR	NR	NR	NR	NR	NR
0B, 1B, 2B, 3B, 4C 5C	NR	≥19,500	≥9,000	≥5,000	≥4,000	≥3,000	≥1,500	≥120
0A, 1A, 2A, 3A, 4B, 5B	≥2,500	≥2,000	≥1,000	≥500	≥140	≥120	≥100	≥80
4A, 5A, 6A, 6B, 7, 8	≥200	≥130	≥100	≥80	≥70	≥60	≥50	≥40

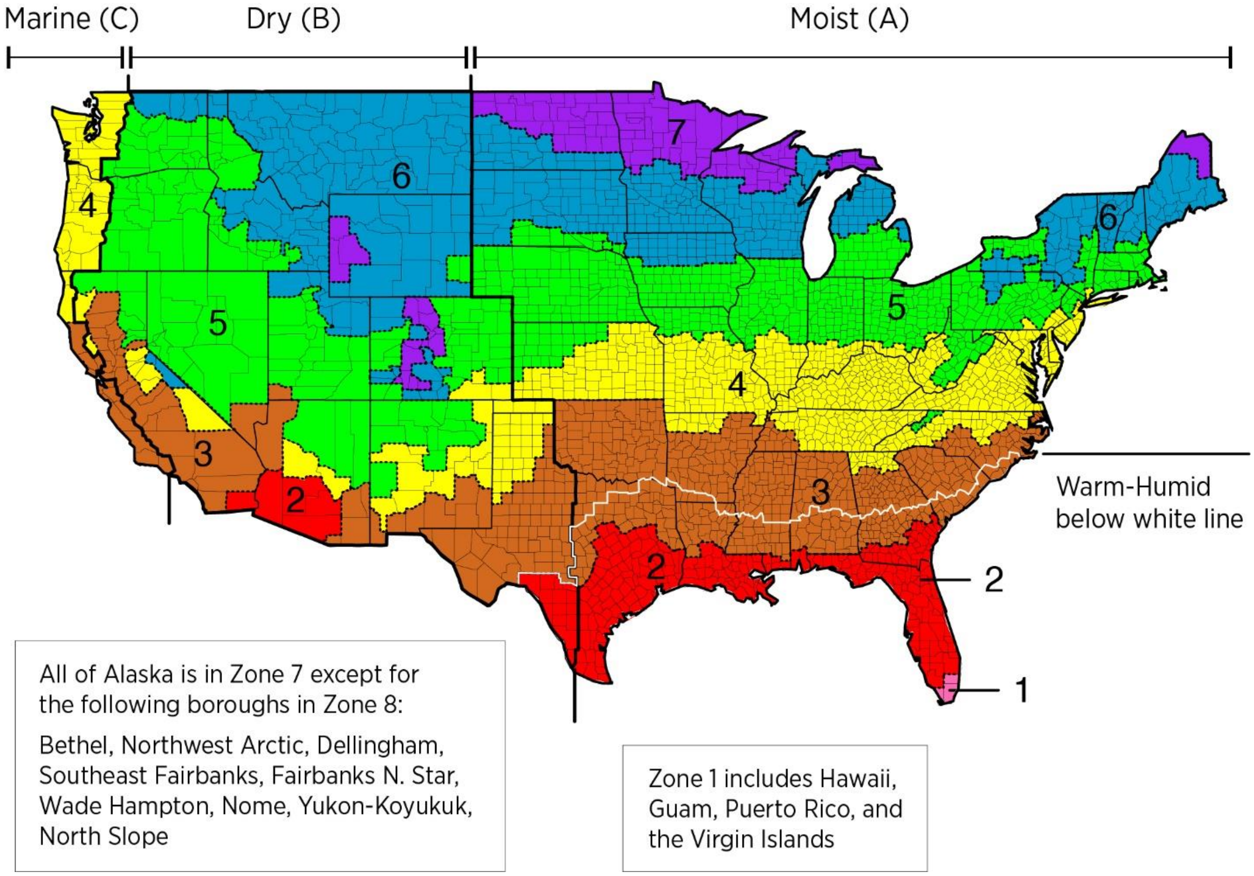

Figure 12. ASHRAE / IECC climate zone map.

The Statewide CASE Team conducted an initial modeling analysis of the criteria within the two tables above to confirm that the ASHRAE requirements were cost effective in California. The analysis utilized a 2016 California Energy Commission study to map ASHRAE/IECC zones to California's 16 Climate Zones (California Energy Commission 2016).The "Office Area (Open plan office)" space function was used as the basis of analysis because it represents moderate internal loads and is the single largest space function (in terms of forecasted building area) included in the Energy Commission's statewide construction forecast. This space function zone was then modified to each applicable scenario in the tables above by sizing the requirements to fit the criteria from Table 6.5.6.1.2-1 and Table 6.5.6.1.2-2 of Standard 90.1 of ASHRAE. Table 95 below summarizes the California climate zone mapping to the ASHRAE requirements and which climates were impacted.

Table 95: Applicability of California Climate Zones to ASHRAE / IECC Climate Zones

California Climate Zone	Reference City	ASHRAE / IECC Zone (Reference City)	90.1: Table 6.5.6.1-1 (below 8,000 h)	90.1: Table 6.5.6.1-2 (above 8,000 h)
1	Arcata	4c (Seattle)	No	Yes
2	Santa Rosa	3c (San Francisco)	No	No
3	Oakland	3c (San Francisco)	No	No
4	San Jose	3c (San Francisco)	No	No
5	Santa Maria	3c (San Francisco)	No	No
6	Torrance	3c (San Francisco)	No	No
7	San Diego	3b (El Paso)	No	Yes
8	Fullerton	3b (El Paso)	No	Yes
9	Burbank-Glendale	3b (El Paso)	No	Yes
10	Riverside	3b (El Paso)	No	Yes
11	Red Bluff	3b (El Paso)	No	Yes
12	Sacramento	3b (El Paso)	No	Yes
13	Fresno	4b (Albuquerque)	No	Yes
14	Palmdale	4b (Albuquerque)	No	Yes
15	Palm Springs	2b (Tucson)	Yes [a]	Yes
16	Blue Canyon	4b/5b/6b	Yes [b]	Yes

a. Only for >50% Outdoor Air at Full Design Airflow Rate.

b. Only ASHRAE/IECC climate zone 6B requires exhaust air heat recovery.

The modeling results showed that ASHRAE’s 90.1 requirements were cost effective and applied for 11 of 16 California climates and these results were presented in the April 14, 2020 stakeholder meeting. Several of the scenarios presented showed a high benefit-to-cost ratio indicating that significantly more cost-effective savings could be achieved with higher stringency. During the stakeholder meeting a majority of stakeholders responded positively to the Statewide CASE Team investigating additional savings through more stringent requirements than those listed in ASHRAE 90.1.

5.3.2.1.1 Final Analysis: California-Specific EAHR Requirements

The Statewide CASE Team assessed whether additional requirements may be appropriate and assessed the underlying question: for a given space type, what combinations of hours-of-operation, design CFM and OA percentage result in EAHR on an air handler being cost-effective in each of the California climate zones?

The Statewide CASE Team again selected the “Office Area (Open plan office)” space function as the basis of analysis, because it represents moderate internal loads and is the single largest space function (in terms of forecasted building area) included in the Energy Commission’s Statewide Construction forecast. The analysis involved varying zone size and ventilation requirements, such that the resulting design OA percentage of the air handler spanned the range of OA percentage bins in Table 93 and Table 94. Cost-effectiveness of EAHR, in terms of Benefit-to-Cost ratio (B/C) was then determined from the air handler's design CFM based on incremental costs presented in Section 5.4. Results in each climate zone were represented as separate surface plots to illustrate the thresholds at which EAHR is cost-effective (i.e., B/C ≥ 1). Two sets of these plots were generated: (1) an office building representing continuous operation (8,760 hours per year) and (2) an office building operating according to the ASHRAE 90.1's office schedule (4,644 hours per year). The surface plots below show the B/C ratio at different combinations of design flow and design outdoor air percentage for Climate Zone 2 (Santa Rosa) and Climate Zone 12 (Sacramento).

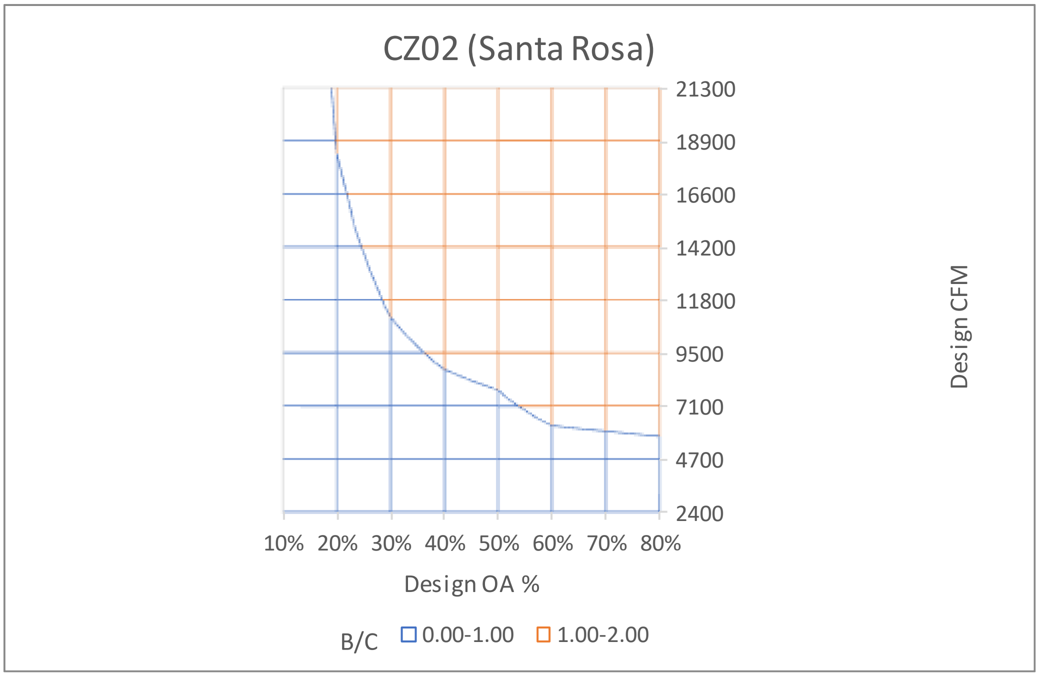

Figure 13: Cost effectiveness of EAHR in Climate Zone 2 with 4,644 hours of operation.

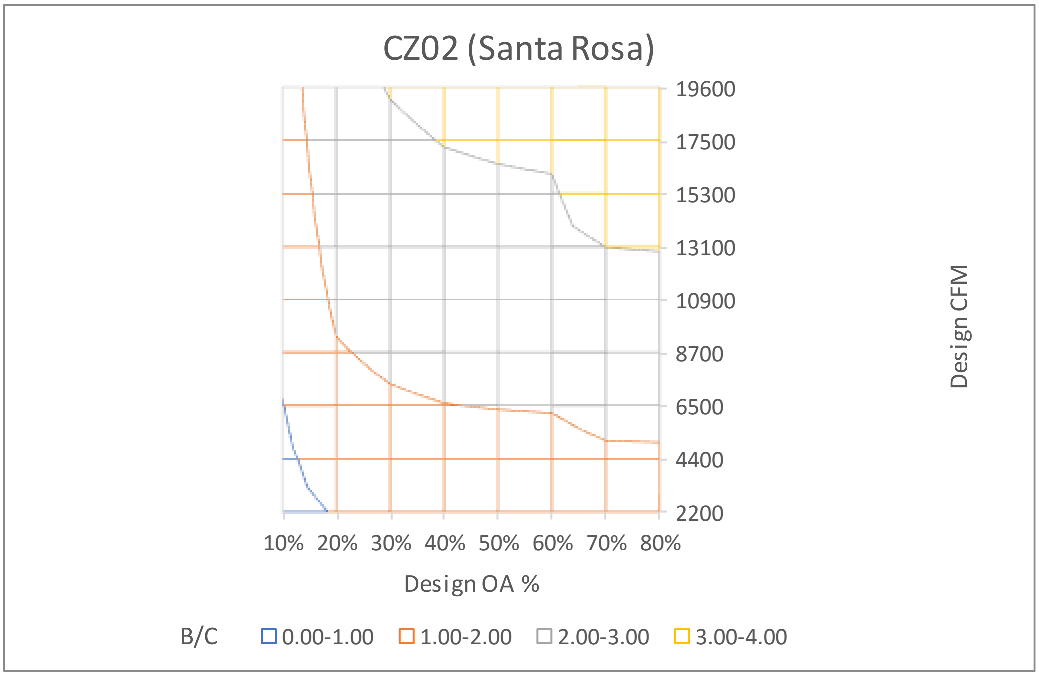

Figure 14: Cost effectiveness of EAHR in Climate Zone 2 with 8,760 hours of operation.

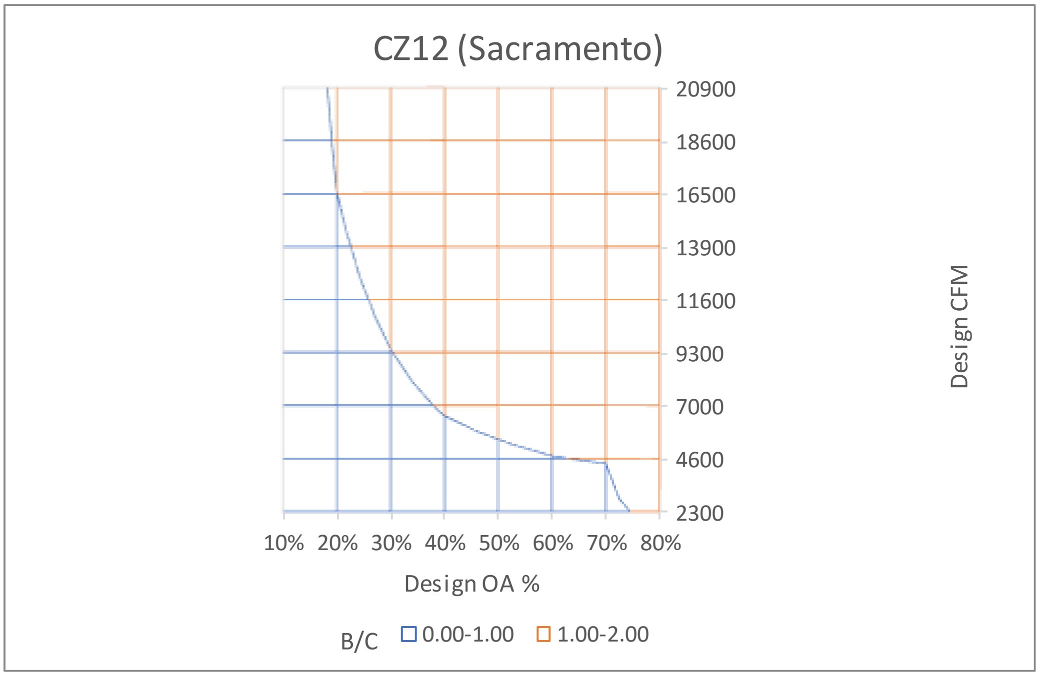

Figure 15: Cost effectiveness of EAHR in Climate Zone 12 with 4,644 hours of operation.

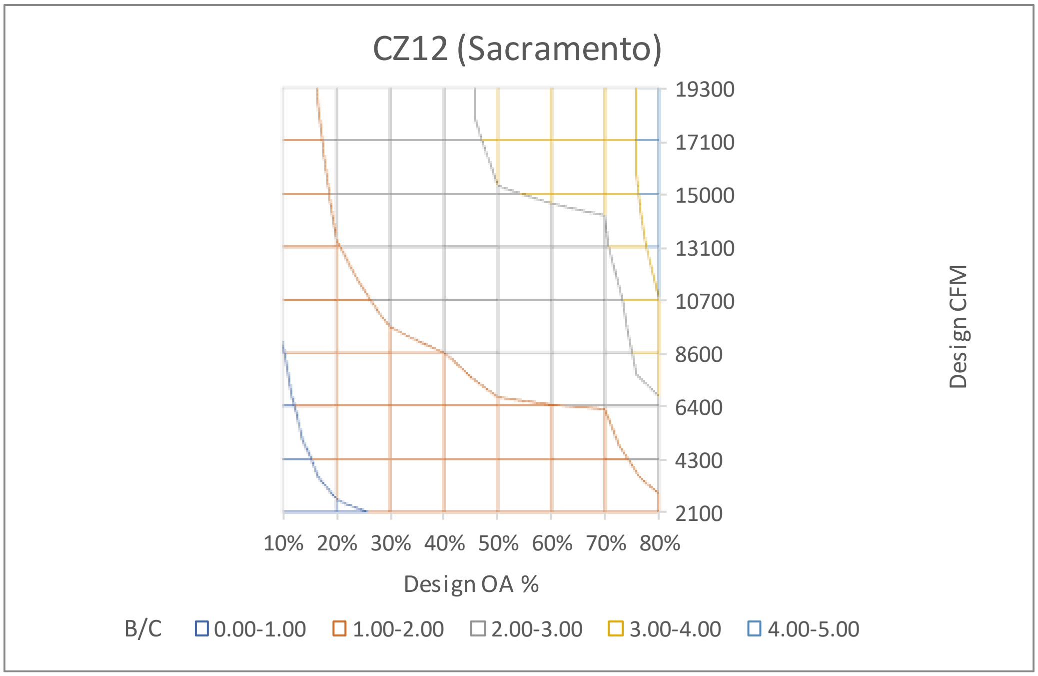

Figure 16: Cost effectiveness of EAHR in Climate Zone 12 with 8,760 hours of operation.

Surface plots similar to Figure 13 through Figure 16 were developed for each climate zone (Appendix M compiles all the applicable climate zone surface plots) to determine the thresholds at which EAHR is cost effective and create California-specific tables for above and below 8,000 hours similar to the ASHRAE Standard 90.1 tables presented above, which targets buildings with full time (24/7) operating schedules. Each of these surface plots was utilized to create the resulting requirements found in Table 96 and Table 97 below.

Table 96: Title 24 Proposed Requirements for Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Less than 8,000 Hours per Year

Climate Zone	% *Outdoor Air* at Full Design Airflow							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and <80%	≥80%
	Design Supply Fan Airflow Rate, cfm							
1	NR	≥15,000	≥13,000	≥10,000	≥9,000	≥7,000	≥6,500	≥4,500
2	NR	≥20,000	≥15,000	≥12,000	≥10,000	≥7,500	≥7,000	≥6,500
3, 5, 6, 7, 8	NR	NR	NR	NR	NR	NR	NR	NR
4	NR	NR	NR	NR	≥18,500	≥16,500	≥15,000	≥14,000
9	NR	NR	NR	NR	NR	≥20,000	≥17,000	≥15,000
10	NR	NR	NR	≥22,000	≥17,000	≥15,000	≥14,000	≥13,000
11 - 16	NR	≥18,500	≥15,000	≥10,000	≥8,000	≥7,000	≥5,000	≥2,000

Table 97: Title 24 Proposed Requirements for Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8,000 Hours per Year

Climate Zone	% Outdoor Air at Full Design Airflow							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and <80%	≥80%
	Design Supply Fan Airflow Rate, cfm							
1	≥10,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
2	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
3	NR	≥13,000	≥10,000	≥8,000	≥7,000	≥6,000	≥6,000	≥6,000
4, 5	NR	≥9,000	≥6,500	≥6,000	≥6,000	≥6,000	≥5,000	≥5,000
6, 7	NR	NR	NR	NR	NR	NR	NR	NR
8	NR	NR	NR	NR	≥20,000	≥18,000	≥15,000	≥12,000
9	NR	NR	≥15,000	≥12,000	≥10,000	≥9,000	≥8,000	≥7,000
10, 11	≥40,000	≥15,000	≥7,500	≥6,000	≥5,000	≥4,000	≥3,000	≥3,000
12	≥20,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
13 - 16	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000

The Statewide CASE Team applied these requirements to the CBECC-Com prototype buildings (note that in several cases, no prototype models applied despite establishing requirements). A summary of all the impacted prototypes used in the analysis are presented in Table 98. Statewide savings were estimated for New Construction and

Alteration floor area forecasts for the building types comprised of the prototypes listed below.

Table 98: Prototype Building Models Used for Energy, Demand, Cost, and Environmental Impact Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
OfficeLarge	12	498,589	12 story + 1 basement office building with 5 zones and a ceiling plenum on each floor. WWR-0.40
OfficeMedium	3	53,628	Office building with 5 zones and a ceiling plenum on each floor. WWR-0.33
RetailLarge	1	240,000	Big-box type Retail building with WWR -0.12
SchoolSecondary	2	210,866	High school with auditorium, fitness center, kitchen, library and support spaces. WWR-0.35

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of the CBECC software for nonresidential buildings (CBECC-Com). The prototype models, summarized in Table 98, were simulated in CBECC-Com for each climate zone. When CBECC-Com simulates a model, it first generates the baseline and proposed input files for EnergyPlus. The unmodified EnergyPlus input files representing the Standard Design generated by CBECC-Com serve as the baselines for each building type. Details regarding the Standard Design are described in the 2019 Nonresidential ACM Reference Manual. The proposed design reflects flat plate exhaust air heat recovery devices installed in the applicable air handlers. Because the requirements dictating applicability for this measure are based on four simultaneous criteria of design cooling airflow, climate zone, percentage of outdoor air, and hours of operation, the combination of impacted air handlers and climate zones vary significantly. Table 99 present precisely which parameters were changed in the Standard Design models to reflect exhaust air heat recovery capabilities in the Proposed Design models for all cases in which the air handler met the four criteria set through Table 96 and

Table 97. Comparing the energy impacts of the Standard Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2019 Title 24, Part 6 requirements.

Table 99: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Objects Modified	Parameter Names	Standard Design Parameter Value	Proposed Design Parameter Value
See below*	1,2 11–16	AirLoopHVAC:OutdoorAirSystem:EquipmentList	Component Object Type	N/A (added)	HeatExchanger:AirToAir:SensibleAndLatent
See below*	1,2 11–16	AirLoopHVAC	Component Object Name	N/A (added)	Energy Recovery Wheel
See below*	1,2 11–16	HeatExchanger:AirToAir:SensibleAndLatent	New Object	N/A (added)	Energy Recovery Wheel
See below*	1,2 11–16	NodeList	Node Name	N/A (added)	ER Supply Outlet Node
See below*	1,2 11–16	OutdoorAir:Mixer	Outdoor Air Stream Node Name	Outside Air Inlet Node	ER Supply Outlet Node
See below*	1,2 11–16	Fan:VariableVolume	Pressure Rise	Varies by model	Per Table 140.4-B: *2.2 IWC * Energy Recovery Effectiveness – 0.5 IWC, per airstream (Equation 1)*

*Only four prototype models were impacted based on the criteria in Table 96 and

Table 97: OfficeLarge, OfficeMedium, RetailLarge, SchoolSecondary.

The energy impacts of exhaust air heat recovery vary by climate zone due to differing outside air conditions. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the appropriate TDV factors when calculating TDV energy cost impacts.

Per-unit energy impacts for nonresidential buildings are presented in savings per square foot. Annual energy and peak demand impacts for each prototype building are translated into impacts per square foot by dividing by the floor area of the prototype building. This allows for easier comparison of savings across different building types and enables calculation of statewide savings using the published construction forecast in terms of floor area by building type.

5.3.3 Statewide Energy Savings Methodology

The per-unit energy impacts presented in this section represent the statewide savings potential that would result from exhaust air heat recovery being installed in the nonresidential building types represented by the prototype models summarized in Table 133. The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the Energy Commission provided. The Statewide Construction Forecasts estimate new construction that would occur in 2023, the first year that the 2022 Title 24, Part 6 requirements are in effect. It also estimates the size of the total existing building stock in 2023 that the Statewide CASE Team used to approximate savings from building alterations. The construction forecast provides construction (new construction and existing building stock) by building type and climate zone. The building types used in the construction forecast, Building Type ID, are not identical to the prototypical building types available in CBECC-Com, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. presents the prototypical buildings and weighting factors that the Energy Commission requested the Statewide CASE Team use for each Building Type ID in the Statewide Construction Forecast.

Appendix A presents additional information about the methodology and assumptions used to calculate statewide energy impacts.

Table 100: Nonresidential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Small Office	OfficeSmall	100%
Large Office	OfficeMedium	50%
" "	OfficeLarge	50%
Restaurant	RestaurantFastFood	100%
Retail	RetailStandAlone	10%
" "	RetailLarge	75%
" "	RetailStripMall	5%
" "	RetailMixedUse	10%
Grocery Store	Grocery	100%
Non-Refrigerated Warehouse	Warehouse	100%
Refrigerated Warehouse	RefrigWarehouse	N/A
Schools	SchoolPrimary	60%
" "	SchoolSecondary	40%
Colleges	OfficeSmall	5%
" "	OfficeMedium	15%
" "	OfficeMediumLab	20%
" "	PublicAssembly	5%
" "	SchoolSecondary	30%
" "	ApartmentHighRise	25%
Hospitals	Hospital	100%
Hotel/Motels	HotelSmall	100%

5.3.4 Per-Unit Energy Impacts Results

Energy savings per square foot are presented in Table 101 through Table 104. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. Per-unit savings for the first year are expected to range from 0.003 therms/yr to 0.105 therms/yr depending on building type and climate zone. The difference in energy savings between the prototype models is due to the different heating and cooling loads, ventilation and total airflow requirements in each model and climate zone. The instances of electricity and demand penalties are caused by the increased fan static pressure required to move air through the heat exchanger. In some cases, electrical savings is positive due to reduced need for cooling during peak conditions. Rows that have been grayed out were not impacted by the code requirements.

Table 101: First-Year Energy Impacts per Square Foot - OfficeLarge

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	(0.015)	6.62E-07	0.005	0.955
2	(0.009)	2.49E-06	0.003	0.828
3	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	(0.001)	3.35E-06	0.003	0.998
12	(0.007)	3.03E-06	0.003	0.777
13	(0.002)	7.52E-06	0.002	0.901
14	0.001	5.84E-06	0.002	0.943
15	0.013	2.23E-06	0.000	0.694
16	(0.016)	8.06E-06	0.005	1.100

Table 102: First-Year Energy Impacts per Square Foot – OfficeMedium

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	0.017	1.23E-05	0.035	14.706
12	N/A	N/A	N/A	N/A
13	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A
15	N/A	N/A	N/A	N/A
16	(0.148)	(3.73E-06)	0.065	14.113

Table 103: First-Year Energy Impacts per Square Foot - RetailLarge

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	(0.012)	(1.08E-06)	0.013	2.964
2	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A
13	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A
15	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A

Table 104: First-Year Energy Impacts per Square Foot - SchoolSecondary

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	(0.135)	(1.60E-05)	0.082	17.606
2	(0.105)	(9.86E-06)	0.049	13.878
3	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	0.018	2.04E-06	0.043	16.663
12	(0.062)	(3.51E-06)	0.042	13.336
13	0.016	5.74E-06	0.039	15.452
14	(0.000)	(2.47E-06)	0.040	14.520
15	0.261	2.04E-05	0.005	13.113
16	(0.164)	(1.80E-05)	0.105	23.473

5.4 Cost and Cost Effectiveness

5.4.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the TDV energy cost factors to the energy savings estimates that were derived using the methodology described in Section 5.3.2. TDV is a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the period of analysis (30 years for residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 15 years. The TDV cost impacts are presented in 2023 present value dollars and represent the energy cost savings realized over 15 years. The proposed measure applies only to new construction buildings and does not apply to additions or alterations.

5.4.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings that are realized over the 15-year period of analysis are presented in PV 2023 dollars in Table 105 through Table

108 (see Appendix N for similar tables in nominal dollar terms). The per-unit energy cost savings for additions and alterations are equivalent to the savings for newly constructed buildings.

The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 105: 2023 PV TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	($0.03)	$0.11	$0.09
2	($0.00)	$0.08	$0.07
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.02	$0.06	$0.09
12	$0.01	$0.06	$0.07
13	$0.03	$0.05	$0.08
14	$0.02	$0.06	$0.08
15	$0.05	$0.01	$0.06
16	($0.02)	$0.11	$0.10

Table 106: 2023 PV TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction – OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.46	$0.85	$1.31
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	($0.29)	$1.55	$1.26

Table 107: 2023 PV TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations - RetailLarge

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$)
1	($0.03)	$0.29	$0.26
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

Table 108: 2023 PV TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations – SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (2023 PV$)	15-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15-Year TDV Energy Cost Savings (2023 PV$))
1	($0.32)	$1.89	$1.57
2	$0.06	$1.17	$1.24
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.42	$1.06	$1.48
12	$0.17	$1.02	$1.19
13	$0.42	$0.95	$1.38
14	$0.31	$0.98	$1.29
15	$1.05	$0.11	$1.17
16	($0.38)	$2.47	$2.09

5.4.3 Incremental First Cost

Incremental first cost is the initial cost to adopt more efficient equipment or building practices when compared to the cost of an equivalent baseline project. Therefore, it was important that the Statewide CASE Team consider first costs in evaluating overall measure cost effectiveness. Incremental first costs are based on data available today and can change over time as markets evolve and professionals become familiar with new technology and building practices.

5.4.3.1 New Construction

Incremental first cost for the proposed measure was estimated from the 2019 CASE Report: Proposals Based on ASHRAE 90.1-2016 (CASE: Codes and Standards Enhancement 2017) . This included the incremental cost of adding a heat recovery device with bypass dampers and controls to an air handler. The reduced cost due to right-sizing the system was also included in the first cost analysis. The incremental costs of heating and cooling equipment were determined using RSMeans, and the peak load reduction was determined from each climate's design condition as well as each building's outdoor air percentage and supply air temperature. Boilers were estimated to cost $237 per ton; air-cooled chillers were estimated to cost $728 per ton; and water-cooled chiller systems were estimated to cost $715 per ton. The total cost includes the material and labor cost of installing each piece of equipment and are shown in Table 109, below.

Table 109: Incremental Cost for Heat Recovery Air Handlers

Air Handler Size (cfm)	Incremental Cost (Material, Labor, Controls)	Base Cost per Flow ($/cfm)
1,000	$6,775	$6.78
2,000	$7,925	$3.96
4,000	$9,175	$2.29
6,000	$10,700	$1.78
8,000	$11,800	$1.48
10,000	$14,200	$1.42
20,000	$25,700	$1.29
25,000	$31,400	$1.26
30,000	$34,800	$1.16
40,000	$48,000	$1.20
50,000	$56,000	$1.12

5.4.3.2 Additions and Alterations

The Statewide CASE Team’s current understanding is that there are no additional incremental costs for an additions or alterations scenario when compared to a new construction scenario.

5.4.4 Incremental Maintenance and Replacement Costs

Incremental maintenance cost 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 15-year period of analysis. The expected useful life of a flat plate heat recovery device is 30 years, which exceeds the lifecycle period. No additional maintenance is expected to be required during the lifecycle period.

5.4.5 Cost Effectiveness

The Energy Commission establishes the procedures for calculating cost effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. The incremental first cost and incremental maintenance costs over the 15-year period of analysis were included. The TDV energy cost savings from natural gas savings were also included in the evaluation. Neither the design costs nor the incremental costs of code compliance verification were included.

According to the Energy Commission's definitions, a measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 15 years by the total incremental costs, which includes maintenance costs for 15 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

The proposed measure was found to be cost effective in all climate zones they are being required in utilizing the surface-plot analysis described above. In applying the corresponding design airflow and outside air fractions of particular B/C ratios to the prototype models, results of the per-unit cost-effectiveness analyses are presented in Table 110 through Table 113. The B/C ratio ranges from 0.93 to 2.89. For all tables below, benefits and costs are defined as follows:

- **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2020). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs.
- **Costs: Total Incremental Present Valued Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation-adjusted) three percent rate and if PV of proposed maintenance costs is greater than PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

Table 110: 15-Year Cost-Effectiveness Summary Per Square Foot - New Construction - OfficeLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2023 PV$)	Costs Total Incremental PV Costs (2023 PV$)	Benefit-to-Cost Ratio
1	$0.09	$0.07	1.28
2	$0.07	$0.07	1.11
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.09	$0.07	1.34
12	$0.07	$0.07	1.04
13	$0.08	$0.07	1.21
14	$0.08	$0.07	1.26
15	$0.06	$0.07	0.93
16	$0.10	$0.07	1.47

Table 111: 15-Year Cost-Effectiveness Summary Per Square Foot - New Construction - OfficeMedium

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[a] (2023 PV$)	Costs Total Incremental PV Costs[b] (2023 PV$)	Benefit-to-Cost Ratio
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$1.31	$1.16161	1.13
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	$1.26	$1.16161	1.08

Table 112: 15-Year Cost-Effectiveness Summary Per Square Foot - New Construction - RetailLarge

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2023 PV$)	Costs Total Incremental PV Costs (2023 PV$)	Benefit-to-Cost Ratio
1	$0.26	$0.10095	2.77
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

Table 113: 15-Year Cost-Effectiveness Summary Per Square Foot - New Construction – SchoolSecondary

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings (2023 PV$)	Costs Total Incremental PV Costs (2023 PV$)	Benefit-to-Cost Ratio
1	$1.57	$0.72	2.16
2	$1.24	$0.72	1.71
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$1.48	$0.72	2.05
12	$1.19	$0.72	1.64
13	$1.38	$0.72	1.90
14	$1.29	$0.72	1.78
15	$1.17	$0.72	1.61
16	$2.09	$0.72	2.89

5.5 First-Year Statewide Impacts

5.5.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per-unit savings, which are presented in Section 5.3.4, by assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2023 is presented in Appendix A as are the Statewide CASE Team's assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2023. The 15-year energy cost savings represent the energy cost savings over the entire 15-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Table 114 and Table 115 present the first-year statewide energy and energy cost savings from newly constructed buildings and additions / alterations by climate zone (climate zones that did not have prototype models that were impacted by the new requirements were omitted).

Table 114: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.21	(0.01)	(0.00)	0.00	$0.09
2	0.64	(0.03)	(0.00)	0.01	$0.29
3	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A
11	0.64	0.01	0.00	0.02	$0.64
12	2.90	(0.07)	0.00	0.04	$1.23
13	0.78	0.01	0.01	0.02	$0.67
14	0.50	0.00	0.00	0.01	$0.25
15	0.21	0.03	0.00	0.00	$0.13
16	0.24	(0.03)	(0.00)	0.01	$0.26
TOTAL	6.1	**(0.08)**	**0.01**	**0.12**	**$3.55**

a. First-year savings from all buildings completed statewide in 2023.

Table 115: Statewide Energy and Energy Cost Impacts - Alterations

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (million square feet)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (million 2023 PV$)
1	0.48	(0.02)	(0.00)	0.01	$0.22
2	1.57	(0.07)	(0.00)	0.03	$0.75
3	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A
11	1.61	0.02	0.01	0.05	$1.61
12	6.94	(0.18)	0.01	0.11	$3.20
13	1.98	0.02	0.01	0.05	$1.80
14	1.31	0.00	0.00	0.02	$0.75
15	0.54	0.08	0.01	0.00	$0.36
16	0.61	(0.07)	(0.00)	0.04	$0.70
TOTAL	**15.0**	**(0.21)**	**0.03**	**0.31**	**$9.38**

a. First-year savings from all buildings completed statewide in 2023.

Table 116 presents first-year statewide savings from new construction, additions, and alterations.

Table 116: Statewide Energy and Energy Cost Impacts – New Construction, Alterations, and Additions

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (MMTherms)	15-Year Present Valued Energy Cost Savings (PV$ million)
New Construction	(0.1)	0.01	0.12	$3.55
Additions and Alterations	(0.2)	0.03	0.31	$9.38
TOTAL	(0.3)	0.04	0.43	$12.93

a. First-year savings from all alterations completed statewide in 2023.

5.5.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42). See Appendix C for additional details on the methodology used to calculate GHG emissions. In short, this analysis assumes an average electricity emission factor of 240.4 metric tons CO2e per GWh based on the average emission factors for the CACX EGRID subregion.

Table 117 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 2,259 metric tons of carbon dioxide equivalents (metric tons CO2e) would be avoided.

Table 117: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (MMTherms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
Exhaust Air Heat Recovery	(0.3)	(71.7)	0.43	2,331	2,259

a. First-year savings from all buildings completed statewide in 2023.

b. Assumes the following emission factors: 240.4 MTCO2e/GWh and 5,454 MTCO2e/MMTherms.

5.5.3 Statewide Water Use Impacts

EAHR can result in water savings in systems that are cooling dominated and are served by water-cooled chillers, caused by reduced cooling tower evaporation. However, water savings occur only when EAHR achieves net cooling energy savings. Net cooling energy savings are achieved only when cooling energy savings exceed the cooling energy penalty incurred due to increased fan heat gains. The OfficeLarge and SchoolSecondary prototype building models have air handlers that would be subject to the EAHR requirements in some climate zones and are served by water-cooled chillers. The per-unit and statewide water savings associated with EAHR for each prototype building are summarized in Table 118 and Table 119. Negative water savings are anticipated in Climate Zone 1 for both building types, and in Climate Zone 16 for OfficeLarge, due to net cooling penalties associated with EAHR in these climate zones.

Table 118: First-Year Water Impacts - OfficeLarge

Climate Zone	Water Savings Per Square Foot (gal/ft^2/yr)	Statewide Water Savings (gal)
1	(0.004)	(278)
2	0.005	2,206
3	N/A	N/A
4	N/A	N/A
5	N/A	N/A
6	N/A	N/A
7	N/A	N/A
8	N/A	N/A
9	N/A	N/A
10	N/A	N/A
11	0.023	4,515
12	0.009	17,074
13	0.023	7,118
14	0.030	9,898
15	0.066	6,487
16	(0.007)	(601)

Table 119: First-Year Water Impacts - SchoolSecondary

Climate Zone	Water Savings Per Square Foot (gal/ft^2/yr)	Statewide Water Savings (gal)
1	(0.020)	(707)
2	0.120	24,701
3	N/A	N/A
4	N/A	N/A
5	N/A	N/A
6	N/A	N/A
7	N/A	N/A
8	N/A	N/A
9	N/A	N/A
10	N/A	N/A
11	0.543	117,926
12	0.259	239,182
13	0.519	242,639
14	0.679	115,501
15	1.422	152,635
16	0.006	378

Embedded electricity savings associated with on-site water savings are presented in Table 120. The embedded electricity factor was assumed at 3,565 kWh/million gallons of water, and all water savings occur outdoors. The embedded electricity estimate was derived from a 2015 CPUC study that quantified the embedded electricity savings from IOU programs that save both water and energy (CPUC 2015). See in Appendix B additional information on the embedded electricity savings estimates.

Table 120: Impacts on Water Use and Embedded Electricity in Water

Impact	On-Site Indoor Water Savings (gallons/yr)	On-site Outdoor Water Savings (gallons/yr)	Embedded Electricity Savings[a] (kWh/yr)
First-Year[b] Statewide Impacts	0	938,672	3,346

a. Assumes embedded energy factor of 3,565 kWh per million gallons of water for outdoor use (CPUC 2015).

b. First-year savings from all buildings completed statewide in 2023.

5.5.4 Statewide Material Impacts

This measure would increase the amount of steel needed to provide exhaust air heat recovery for climate zones and designs impacted by this measure. In order to calculate statewide impacts, the Statewide CASE Team determined the number of air handler units impacted for each prototype and climate zone combination. A value of 400 lbs was used for a wheel-type heat exchanger and that weight was added to each air handler.

Table 121: First-Year Statewide Impacts on Material Use

Material	Impact (I, D, of NC)[a]	Impact on Material Use (per year)	
		Per-Unit Impacts (lbs/ft2)	First Year[b] Statewide Impacts (pounds)
Steel	i	0.006849	144,807

a. Material Increase (I), Decrease (D), or No Change (NC) compared to base case (lbs/yr).

b. First-year savings from all buildings completed statewide in 2023.

5.5.5 Other Non-Energy Impacts

This measure would have a positive impact on indoor air quality because the exhaust air heat recovery would increase ventilation air during very hot and very cold conditions which would improve indoor air quality.

5.6 Proposed Revisions to Code Language

5.6.1 Guide to Markup 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 red underlining (new language) and ~~strikethroughs~~ (deletions).

5.6.2 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

(b) – Definitions

SENSIBLE ENERGY RECOVERY RATIO: change in the dry-bulb temperature of the outdoor air supply divided by the difference between the outdoor air and entering exhaust air dry-bulb temperature, expressed as a percentage.

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 (p) ~~(o)~~.

(sections omitted)

(p) – Exhaust Air Heat Recovery.

1. Fan systems designed to operate to the criteria listed in either Table 140.4-G or Table 140.4-H shall include an exhaust air heat recovery system and the ability to bypass both outdoor air and exhaust air or control the energy recovery system to permit air economizer operation as required by Section 140.4(e).

2. Heat recovery systems required by this section shall result in a sensible energy recovery ratio of at least 60 percent for both heating and cooling design conditions.

TABLE 140.4-G: ENERGY RECOVERY REQUIREMENTS (VENTILATING SYSTEMS OPERATING LESS THAN 8,000 HOURS PER YEAR)

Climate Zone	***% Outdoor Air* at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
1	NR	≥15,000	≥13,000	≥10,000	≥9,000	≥7,000	≥6,500	≥4,500
2	NR	≥20,000	≥15,000	≥12,000	≥10,000	≥7,500	≥7,000	≥6,500
3, 5, 6, 7, 8	NR	NR	NR	NR	NR	NR	NR	NR
4	NR	NR	NR	NR	≥18,500	≥16,500	≥15,000	≥14,000
9	NR	NR	NR	NR	NR	≥20,000	≥17,000	≥15,000
10	NR	NR	NR	≥22,000	≥17,000	≥15,000	≥14,000	≥13,000
11 - 16	NR	≥18,500	≥15,000	≥10,000	≥8,000	≥7,000	≥5,000	≥2,000

TABLE 140.4-H: ENERGY RECOVERY REQUIREMENTS (VENTILATING SYSTEMS OPERATING GREATER THAN 8,000 HOURS OR MORE PER YEAR)

Climate Zone	***% Outdoor Air* at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
1	≥10,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
2	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
3	NR	≥13,000	≥10,000	≥8,000	≥7,000	≥6,000	≥6,000	≥6,000
4, 5	NR	≥9,000	≥6,500	≥6,000	≥6,000	≥6,000	≥5,000	≥5,000
6, 7	NR	NR	NR	NR	NR	NR	NR	NR

8	NR	NR	NR	NR	≥20,000	≥18,000	≥15,000	≥12,000
9	NR	NR	≥15,000	≥12,000	≥10,000	≥9,000	≥8,000	≥7,000
10, 11	≥40,000	≥15,000	≥7,500	≥6,000	≥5,000	≥4,000	≥3,000	≥3,000
12	≥20,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
13 - 16	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000

EXCEPTION 1 to Section 140.4(p): Systems meeting Section 140.9(c) Prescriptive Requirements for Laboratory and Factory Exhaust Systems

EXCEPTION 2 to Section 140.4(p): Systems serving spaces that are not cooled and that are heated to less than 60°F.

EXCEPTION 3 to Section 140.4(p): Where more than 60 percent of the outdoor air heating energy is provided from site-recovered energy in Climate Zone 16.

EXCEPTION 4 to Section 140.4(p): Sensible recovery ratio requirements at heating design conditions are exempted for Climate Zone 15.

EXCEPTION 5 to Section 140.4(p): Sensible recovery ratio requirements at cooling design conditions are exempted for Climate Zone 01.

EXCEPTION 6 to Section 140.4(p): Where the sum of the airflow rates exhausted and relieved within 20 feet of each other is less than 75 percent of the design outdoor airflow rate, excluding exhaust air that is either:

1. used for another energy recovery system,
2. not allowed by California Mechanical Code (Title 24, Part 4) for use in energy recovery systems with leakage potential, or
3. of Class 4 as specified in Section 120.1(g).

EXCEPTION 7 to Section 140.4(p): Systems expected to operate less than 20 hours per week.

5.6.3 Reference Appendices

NA7.5 Mechanical Systems Acceptance Tests

NA7.5.4 Air Economizer Controls and Exhaust Air Heat Recovery

NA7.5.4.1 Construction Inspection

Prior to Functional Testing, verify and document the following:

(a) Economizer (or heat recovery bypass) high limit shutoff control complies with Table 140.4-E of Section140.4(e)2.

(b) If the high-limit control is fixed dry-bulb or fixed enthalpy + fixed dry-bulb, it shall have an adjustable setpoint.

(c) Economizer (or heat recovery bypass) lockout control sensor is located to prevent false readings.

(d) Sensor performance curve is provided by factory with economizer (or heat recovery bypass) instruction material.

(e) Sensor output value measured during sensor calibration is plotted on the performance curve.

(f) Economizer (or heat recovery bypass) damper moves freely without binding.

  1. Indicate if bypass control is achieved through heat/energy recovery wheel rotation speed modulation as means other than air dampers,

(g) Economizer (or heat recovery bypass) has control systems, including two-stage or electronic thermostats, that cycle compressors off when economizers (or heat recovery bypass) can provide partial cooling.

(h) Economizer (or heat recovery bypass) reliability features are present as specified by Standards Section 140.4(e)2D.

  1. Indicate N/A for heat recovery bypass.

(i) Economizer inlet damper is designed to modulate up to 100 percent open, and return air damper to 100 percent closed, without over-pressurizing the building.

  1. Indicate N/A for heat recovery bypass.

(j) For systems with DDC controls lockout sensor(s) are either factory calibrated or field calibrated.

(k) For systems with non-DDC controls, manufacturer’s startup and testing procedures have been applied.

(l) The economizer has been certified to the Energy Commission as specified by Section 140.4(e)2Diii.

  1. Indicate N/A for heat recovery bypass.

NA7.5.4.2 Functional Testing

Step 1: Disable demand control ventilation systems (if applicable).

Step 2: Enable the economizer and simulate a cooling demand large enough to drive system into full economizer cooling mode (e.g., the economizer is fully open). Verify and document the following:

(a) Economizer (or heat recovery bypass) damper is 100 percent open and return air damper is 100 percent closed.

  1. If bypass is achieved through heat/energy recovery wheel rotation speed modulation, wheel speed is fully stopped.

(b) All applicable fans and dampers operate as intended to maintain building pressure.

(c) The unit heating is disabled (if unit has heating capability).

Step 3: Disable the economizer and simulate a cooling demand. Verify and document the following:

(d) Economizer damper closes to its minimum position.

(e) All applicable fans and dampers operate as intended to maintain building pressure.

(f) The unit heating is disabled (if unit has heating capability).

(g) Indicate N/A for this step for heat recovery bypass.

Step 4: If unit has heating capability, simulate a heating demand and set the economizer so that it is capable of operating (i.e. actual outdoor air conditions are below lockout setpoint). Verify the following:

For economizer systems

(h) The economizer is at minimum position.

(i) Return air damper opens.

For HRV/ERV or DOAS systems:

(j) Heat recovery bypass control modulates bypass damper/wheel speed to control to temperature setpoint.

Step 5: Turn off the unit. Verify and document the following:

(k) Economizer damper closes completely.

(l) Indicate N/A for this step for heat recovery bypass.

Step 6: Restore demand control ventilation systems (if applicable) and remove all system overrides initiated during the test.

5.6.4 ACM Reference Manual

Specific redline changes are in progress would be made to define the “Standard Design” of Section 5.7.6.5 Heat Recovery of the Nonresidential ACM Reference Manual, including the following subsections:

- Recovery Type
- Exhaust Air Sensible Heat Recovery Effectiveness
- Exhaust Air Sensible Part-Load Effectiveness
- Exhaust Air Latent Heat Recovery Effectiveness

- Economizer Enabled during Heat Recovery

5.6.5 Compliance Manuals

An additional section would need to be added to Section 4.5.2 of the Nonresidential Compliance Manual to detail the new additions made from Section 140.4(p) of Title 24, Part 6 related to Exhaust Air Heat Recovery. In addition, a small change would be needed to Section 4.5.2.2 of the Nonresidential Compliance Manual to define and detail economizer bypass controls.

5.6.6 Compliance Documents

Changes to compliance documents are still in development and would modify NRCC-MCH-E and NRCA-MCH-05.

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Appendix A: Statewide Savings Methodology

To calculate first-year statewide savings, the Statewide CASE Team multiplied the per-unit savings by statewide construction estimates for the first year the standards would be in effect (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 122 through Table 129.

The Energy Commission Building Standards Office provided the nonresidential construction forecast, which is available for public review on the Energy Commission's website: https://www.energy.ca.gov/title24/participation.html.

The construction forecast presents total floorspace of newly constructed buildings in 2023 by building type and climate zone. The building types included in the Energy Commissions' forecast are summarized by measure in Table 10, Table 37, Table 69, and Table 98. These tables also identifies the prototypical buildings that were used to model the energy use of the proposed code changes. This mapping was required because the building types the Energy Commission defined in the construction forecast are not identical to the prototypical building types that the Energy Commission requested that the Statewide CASE Team use to model energy use. This mapping is consistent with the mapping that the Energy Commission used in the Final Impacts Analysis for the 2019 code cycle (California Energy Commission 2018).

The Energy Commission's forecast allocated 19 percent of the total square footage of new construction in 2023 to the miscellaneous building type, which is a category for all space types that do not fit well into another building category. It is likely that the Title 24, Part 6 requirements apply to the miscellaneous building types, and savings would be realized from this floorspace. The new construction forecast does not provide sufficient information to distribute the miscellaneous square footage into the most likely building type, so the Statewide CASE Team redistributed the miscellaneous square footage into the remaining building types so that the percentage of building floorspace in each climate zone, net of the miscellaneous square footage, would remain constant. See Table 130 for a sample calculation for redistributing the miscellaneous square footage among the other building types.

After the miscellaneous floorspace was redistributed, the Statewide CASE Team made assumptions about the percentage of newly constructed floorspace that would be impacted by the proposed code change. As mentioned previously, the measures proposed have varying impacts across the different space types and climate zones. As a result, individual impact tables were developed.

Table 131 and Table 132 present a summary of the assumed percentage of floorspace that would be impacted by the proposed code change by building type. If a proposed code change does not apply to a specific building type, it is assumed that zero percent of the floorspace would be impacted by the proposal. If the assumed percentage is non-zero, but less than 100 percent, it is an indication that a portion of all buildings constructed statewide would be impacted by the proposal. Several of the code change proposals had criteria that simultaneously involved impacts based on climate zone. For example, exhaust air heat recovery had criteria based on outside air fraction, design airflow rate, and climate zone. Based on the combination of these criteria, the Statewide CASE Team determined which air handlers amongst all the prototype models and climate zones would be impacted. A summary of each measure's assumptions can be found in the notes below.

Table 133 presents percentage of floorspace assumed to be impacted by the proposed change by climate zone.

VAV Deadband Airflow – Statewide Extrapolation Assumptions

Analysis assumed that among the nonresidential prototype models, any HVAC systems defined as a VAV-type systems would be impacted by this measure. Five prototype models included at least one air handler with a VAV HVAC system (OfficeLarge, OfficeMedium, OfficeMediumLab, SchoolSecondary, and ApartmentHighRise). The extrapolation to statewide savings includes all VAV boxes within the impacted air handlers use the higher of the 20 percent design airflow requirement and the ventilation minimum flow requirement for each zone as is set in the prototype models.

Expand Economizer Requirements – Statewide Extrapolation Assumptions

Analysis examined all prototype models and climate zone combinations for nonresidential HVAC systems between 33,000 Btu/h and 54,000 Btu/h. Any HVAC systems identified with these criteria were included for the analysis. This impacted a total of four prototype models[26] (RestaurantFastFood, RetailMixedUse, RetailStripMall,and SchoolPrimary). The extrapolation to statewide savings includes all impacted air handlers do not contain an economizer as is set in the applicable prototype models.

Exhaust Air Heat Recovery – Statewide Extrapolation Assumptions

Analysis examined all prototype models and climate zone combinations for nonresidential HVAC systems which met the design air flow, outdoor air fraction, operating hours, and climate zone. Any HVAC systems identified with these criteria were included for the analysis. This impacted a total of four prototype models

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[26] Note: HotelSmall prototype model was excluded from this analysis because the HVAC units that were impacted served corridors more consistent with a DOAS-type unit.

(OfficeLarge, OfficeMedium, RetailLarge,and SchoolSecondary). The extrapolation to statewide savings includes all impacted air handlers do not contain heat recovery capabilities as is set in the applicable prototype models.

Dedicated Outdoor Air Systems – Statewide Extrapolation Assumptions

The percentage of floorspace for DOAS was estimated from a construction database tracking building projects across the US with granularity for each state. The Statewide CASE Team analyzed an online database of construction projects called ConstructConnect Insight for projects in California between 2012 and 2019. Data for 2012 for the first 4 months was extrapolated to make a complete year estimate. The database was searched using the following key terms: DOAS, DX-DOAS, ERV, HRV, Energy Recovery Ventilator, Heat Recovery Ventilator, Decoupled.

The database was filtered to only include projects where this information was referenced in Section 23 of specifications, referring to the HVAC system. The database was also filter for all projects greater than $0.5 million in overall cost to focus on whole building projects or whole system renovations.

The database provided a number of projects built each year. The data was sorted by new construction and alterations to align with the CASE construction forecasts for buildings. Each dataset provided a count of projects by a specific type, based on building types, for the period of time searched (2012-2019). These project types were re-classified based on reviewing the building types in each and used as the basis for estimating specific market size for specific building classifications.

New Construction Data

Project Type	Project Count	DOAS Count	Prototype Re-Classification
CIVIL	1,122	104	Office & Assembly
COMMERCIAL	585	110	Office
COMMUNITY	308	62	Assembly
EDUCATIONAL	1,181	210	Schools
GOVERNMENT	596	104	Office
INDUSTRIAL	230	30	Non-Refrigerated Warehouse
MEDICAL	259	41	OfficeMediumLab
MILITARY	49	15	Office
RESIDENTIAL	774	128	HotelSmall
RETAIL	1,820	251	Retail

Alterations Data

Project Type	Count	DOAS Count	Prototype Re-Classification
CIVIL	24940	538	Office & Assembly
COMMERCIAL	1575	93	Office
COMMUNITY	1556	65	Assembly
EDUCATIONAL	9816	579	Schools
GOVERNMENT	5301	290	Office
INDUSTRIAL	349	18	Non-Refrigerated Warehouse
MEDICAL	1241	114	OfficeMediumLab
MILITARY	594	46	Office
RESIDENTIAL	878	54	HotelSmall
RETAIL	6995	263	Retail

	Project Count	DOAS Count	Percent of New Construction	Project Count	DOAS Count	Percent of New Alteration
ApartmentHighRise	N/A	N/A	N/A	N/A	N/A	N/A
Assembly	1430	166	12%	26496	603	2%
Grocery	N/A	N/A	N/A	N/A	N/A	N/A
Hospital	N/A	N/A	N/A	N/A	N/A	N/A
HotelSmall	774	128	17%	878	54	6%
OfficeLarge	2352	333	14%	32410	967	3%
OfficeMedium	2352	333	14%	32410	967	3%
OfficeMediumLab	259	41	16%	1241	114	9%
OfficeSmall	2352	333	14%	32410	967	3%
RestaurantFastFood	N/A	N/A	N/A	N/A	N/A	N/A
RetailLarge	1820	251	14%	6995	263	4%
RetailMixedUse	1820	251	14%	6995	263	4%
RetailStandAlone	1820	251	14%	6995	263	4%
RetailStripMall	1820	251	14%	6995	263	4%
SchoolPrimary	1181	210	18%	9816	579	6%
SchoolSecondary	1181	210	18%	9816	579	6%
Warehouse	N/A	N/A	N/A	N/A	N/A	N/A

Total historical trends were also recorded to show the market growth in DOAS and are included in the report as a historical reference. Only the direct building type market percentages were used in estimating the statewide impact.

For alterations a 5 percent value was applied to the overall existing building stock to estimate the annual renovations. The amount of buildings then considering DOAS was applied by each building prototype. For example, 5 percent of the market of offices was assumed to be renovated and only 3 percent of those would then implement a DOAS system.

Table 122: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023, by Climate Zone and Building Type (Million Square Feet) – VAV Deadband Airflow

Climate Zone	Apartment HighRise	Assembly	Grocery	Hospital	Hotel Small	Office Large	Office Medium	Office MediumLab	Office Small	Restaurant FastFood	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
2	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	1.2
3	0.2	0.0	0.0	0.0	0.0	2.4	2.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	6.2
4	0.1	0.0	0.0	0.0	0.0	1.3	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	3.2
5	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.6
6	0.1	0.0	0.0	0.0	0.0	1.7	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	4.1
7	0.1	0.0	0.0	0.0	0.0	0.9	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.6
8	0.2	0.0	0.0	0.0	0.0	2.5	2.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	6.0
9	0.3	0.0	0.0	0.0	0.0	4.6	4.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	11.0
10	0.2	0.0	0.0	0.0	0.0	1.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	3.1
11	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.7
12	0.2	0.0	0.0	0.0	0.0	2.0	2.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	5.3
13	0.1	0.0	0.0	0.0	0.0	0.3	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.3
14	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.9
15	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3
16	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3
TOTAL	**1.6**	**0.0**	**0.0**	**0.0**	**0.0**	**18.1**	**19.1**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**6.9**	**0.0**	**47.1**

Table 123: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet) – VAV Deadband Airflow

Climate Zone	**Apartment HighRise**	**Assembly**	**Grocery**	**Hospital**	**Hotel Small**	**Office Large**	**Office Medium**	**Office MediumLab**	**Office Small**	**Restaurant FastFood**	**Retail Large**	**Retail Mixed Use**	**Retail Stand Alone**	**Retail Strip Mall**	**SchoolPrimary**	**SchoolSecondary**	**Warehouse**	**Total NR**
1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5
2	0.1	0.0	0.0	0.0	0.0	1.0	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.9
3	0.6	0.0	0.0	0.0	0.0	5.6	6.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	14.9
4	0.3	0.0	0.0	0.0	0.0	2.9	3.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	7.8
5	0.1	0.0	0.0	0.0	0.0	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	1.5
6	0.4	0.0	0.0	0.0	0.0	3.8	4.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	10.0
7	0.3	0.0	0.0	0.0	0.0	2.5	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	6.9
8	0.5	0.0	0.0	0.0	0.0	5.6	6.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	14.7
9	0.9	0.0	0.0	0.0	0.0	9.9	10.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	25.5
10	0.5	0.0	0.0	0.0	0.0	2.6	2.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	8.6
11	0.1	0.0	0.0	0.0	0.0	0.5	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	1.8
12	0.5	0.0	0.0	0.0	0.0	4.5	4.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	12.7
13	0.2	0.0	0.0	0.0	0.0	0.7	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	3.2
14	0.1	0.0	0.0	0.0	0.0	0.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.3
15	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.9
16	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.7
TOTAL	**4.7**	**0.0**	**0.0**	**0.0**	**0.0**	**41.6**	**44.5**	**3.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**20.2**	**0.0**	**114.9**

Table 124: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023, by Climate Zone and Building Type (Million Square Feet) – Expanded Economizer Requirements

Climate Zone	Apartment HighRise	Assembly	Grocery	Hospital	Hotel Small	Office Large	Office Medium	Office MediumLab	Office Small	Restaurant FastFood	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.5
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.2	0.9	0.0	0.0	1.9
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.1	0.5	0.0	0.0	1.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.3	0.0	0.1	0.5	0.0	0.0	1.3
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.1	0.5	0.0	0.0	1.1
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4	0.0	0.2	0.7	0.0	0.0	1.9
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.6	0.0	0.3	0.9	0.0	0.0	2.9
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.2	0.9	0.0	0.0	2.3
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.5
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.2	1.0	0.0	0.0	2.1
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.1	0.5	0.0	0.0	1.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5.4**	**0.0**	**3.2**	**0.0**	**1.6**	**7.4**	**0.0**	**0.0**	**17.6**

Table 125: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet) – Expanded Economizer Requirements

Climate Zone	Apartment HighRise	Assembly	Grocery	Hospital	Hotel Small	Office Large	Office Medium	Office MediumLab	Office Small	Restaurant FastFood	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3
2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.1	0.6	0.0	0.0	1.7
3	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.9	0.0	0.8	0.0	0.4	2.4	0.0	0.0	7.3
4	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.2	1.2	0.0	0.0	3.7
5	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.8
6	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	1.0	0.0	0.6	0.0	0.3	1.6	0.0	0.0	5.4
7	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4	0.0	0.2	1.3	0.0	0.0	4.6
8	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	1.5	0.0	0.9	0.0	0.4	2.3	0.0	0.0	7.6
9	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	2.5	0.0	1.3	0.0	0.7	3.4	0.0	0.0	11.8
10	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	0.5	2.7	0.0	0.0	8.4
11	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.1	0.6	0.0	0.0	1.5
12	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	1.1	0.0	0.9	0.0	0.4	2.7	0.0	0.0	7.4
13	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.2	1.5	0.0	0.0	3.3
14	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.1	0.6	0.0	0.0	1.9
15	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.1	0.4	0.0	0.0	1.1
16	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.6
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**22.6**	**0.0**	**0.0**	**0.0**	**0.0**	**11.9**	**0.0**	**7.5**	**0.0**	**3.7**	**21.7**	**0.0**	**0.0**	**67.5**

Table 126: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023, by Climate Zone and Building Type (Million Square Feet) – DOAS

Climate Zone	Apartment HighRise	Assembly	Grocery	Hospital	Hotel Small	Office Large	Office Medium	Office MediumLab	Office Small	Restaurant FastFood	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.1
2	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.4
3	N/A	0.0	N/A	N/A	0.2	0.3	0.4	0.0	0.1	N/A	0.4	0.1	0.1	0.0	0.2	0.2	N/A	1.9
4	N/A	0.0	N/A	N/A	0.1	0.2	0.2	0.0	0.1	N/A	0.2	0.0	0.0	0.0	0.1	0.1	N/A	1.0
5	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.2
6	N/A	0.0	N/A	N/A	0.1	0.2	0.2	0.0	0.1	N/A	0.3	0.0	0.0	0.0	0.1	0.1	N/A	1.3
7	N/A	0.0	N/A	N/A	0.2	0.1	0.1	0.0	0.1	N/A	0.2	0.0	0.0	0.0	0.1	0.1	N/A	1.0
8	N/A	0.0	N/A	N/A	0.2	0.4	0.4	0.0	0.1	N/A	0.4	0.1	0.1	0.0	0.1	0.1	N/A	1.8
9	N/A	0.0	N/A	N/A	0.3	0.7	0.7	0.0	0.2	N/A	0.6	0.1	0.1	0.0	0.2	0.2	N/A	3.0
10	N/A	0.0	N/A	N/A	0.2	0.1	0.1	0.0	0.2	N/A	0.4	0.0	0.0	0.0	0.2	0.1	N/A	1.5
11	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.3
12	N/A	0.0	N/A	N/A	0.2	0.3	0.3	0.0	0.2	N/A	0.4	0.1	0.1	0.0	0.2	0.2	N/A	1.9
13	N/A	0.0	N/A	N/A	0.1	0.0	0.1	0.0	0.1	N/A	0.2	0.0	0.0	0.0	0.1	0.1	N/A	0.7
14	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.4
15	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.2
16	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.1
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**1.8**	**2.5**	**2.7**	**0.2**	**1.5**	**0.0**	**3.3**	**0.4**	**0.4**	**0.2**	**1.3**	**1.2**	**0.0**	**15.8**

Table 127: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet) – DOAS

Climate Zone	Apartment HighRise	Assembly	Grocery	Hospital	Hotel Small	Office Large	Office Medium	Office MediumLab	Office Small	Restaurant FastFood	Retail Large	Retail Mixed Use	Retail Stand Alone	Retail Strip Mall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.0
2	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.3
3	N/A	0.0	N/A	N/A	0.2	0.2	0.2	0.0	0.1	N/A	0.2	0.0	0.0	0.0	0.1	0.1	N/A	1.2
4	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.1	0.1	N/A	0.6
5	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.1
6	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.1	N/A	0.2	0.0	0.0	0.0	0.1	0.1	N/A	0.9
7	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.1	N/A	0.1	0.0	0.0	0.0	0.1	0.1	N/A	0.7
8	N/A	0.0	N/A	N/A	0.2	0.2	0.2	0.0	0.1	N/A	0.3	0.0	0.0	0.0	0.1	0.1	N/A	1.2
9	N/A	0.0	N/A	N/A	0.2	0.3	0.3	0.1	0.1	N/A	0.4	0.1	0.1	0.0	0.2	0.2	N/A	2.0
10	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.1	N/A	0.3	0.0	0.0	0.0	0.2	0.1	N/A	1.1
11	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.2
12	N/A	0.0	N/A	N/A	0.1	0.1	0.1	0.0	0.1	N/A	0.3	0.0	0.0	0.0	0.2	0.1	N/A	1.2
13	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.1	N/A	0.1	0.0	0.0	0.0	0.1	0.1	N/A	0.5
14	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.1	0.0	0.0	0.0	0.0	0.0	N/A	0.3
15	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.1
16	N/A	0.0	N/A	N/A	0.0	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0	N/A	0.1
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**1.4**	**1.2**	**1.3**	**0.3**	**0.7**	**0.0**	**2.2**	**0.3**	**0.3**	**0.1**	**1.3**	**1.2**	**0.0**	**10.5**

Table 128: Estimated New Nonresidential Construction Impacted by Proposed Code Change in 2023, by Climate Zone and Building Type (Million Square Feet) – Exhaust Air Heat Recovery

Climate Zone	ApartmentHighRise	Assembly	Grocery	Hospital	HotelSmall	OfficeLarge	OfficeMedium	OfficeMediumLab	OfficeSmall	RestaurantFastFood	RetailLarge	RetailMixedUse	RetailStandAlone	RetailStripMall	SchoolPrimary	SchoolSecondary	Warehouse	Total NR
1	N/A	N/A	N/A	N/A	N/A	0.07	N/A	N/A	N/A	N/A	0.10	N/A	N/A	N/A	N/A	0.03	N/A	0.21
2	N/A	N/A	N/A	N/A	N/A	0.43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21	N/A	0.64
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
11	N/A	N/A	N/A	N/A	N/A	0.20	0.23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.22	N/A	0.64
12	N/A	N/A	N/A	N/A	N/A	1.97	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.92	N/A	2.90
13	N/A	N/A	N/A	N/A	N/A	0.31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47	N/A	0.78
14	N/A	N/A	N/A	N/A	N/A	0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.17	N/A	0.50
15	N/A	N/A	N/A	N/A	N/A	0.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.11	N/A	0.21
16	N/A	N/A	N/A	N/A	N/A	0.08	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.06	N/A	0.24
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.5**	**0.3**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**2.2**	**0.0**	**6.1**

Table 129: Estimated Existing Nonresidential Floorspace Impacted by Proposed Code Change in 2023 (Alterations), by Climate Zone and Building Type (Million Square Feet) – Exhaust Air Heat Recovery

Climate Zone	**ApartmentHighRise**	**Assembly**	**Grocery**	**Hospital**	**HotelSmall**	**OfficeLarge**	**OfficeMedium**	**OfficeMediumLab**	**OfficeSmall**	**RestaurantFastFood**	**RetailLarge**	**RetailMixedUse**	**RetailStandAlone**	**RetailStripMall**	**SchoolPrimary**	**SchoolSecondary**	**Warehouse**	**Total NR**
1	N/A	N/A	N/A	N/A	N/A	0.17	N/A	N/A	N/A	N/A	0.21	N/A	N/A	N/A	N/A	0.09	N/A	0.48
2	N/A	N/A	N/A	N/A	N/A	1.03	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.55	N/A	1.57
3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00
11	N/A	N/A	N/A	N/A	N/A	0.49	0.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.57	N/A	1.61
12	N/A	N/A	N/A	N/A	N/A	4.51	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	N/A	6.94
13	N/A	N/A	N/A	N/A	N/A	0.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.27	N/A	1.98
14	N/A	N/A	N/A	N/A	N/A	0.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.53	N/A	1.31
15	N/A	N/A	N/A	N/A	N/A	0.24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.30	N/A	0.54
16	N/A	N/A	N/A	N/A	N/A	0.20	0.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19	N/A	0.61
TOTAL	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**8.1**	**0.8**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**5.9**	**0.0**	**15.0**

Table 130: Example of Redistribution of Miscellaneous Category - 2023 New Construction in Climate Zone 1

Building Type	**2020 Forecast (Million Square Feet) [A]**	**Distribution Excluding Miscellaneous Category [B]**	**Redistribution of Miscellaneous Category (Million Square Feet) [C] = B × [D = 0.145]**	**Revised 2020 Forecast (Million Square Feet) [E] = A + C**
Small Office	0.036	7%	0.010	0.046
Large Office	0.114	21%	0.031	0.144
Restaurant	0.015	3%	0.004	0.020
Retail	0.107	20%	0.029	0.136
Grocery Store	0.029	5%	0.008	0.036
Non-Refrigerated Warehouse	0.079	15%	0.021	0.101
Refrigerated Warehouse	0.006	1%	0.002	0.008
Schools	0.049	9%	0.013	0.062
Colleges	0.027	5%	0.007	0.034
Hospitals	0.036	7%	0.010	0.046
Hotel/Motels	0.043	8%	0.012	0.055
Miscellaneous **[D]**	0.145	N/A	0.000	0.145
TOTAL	0.686	100%	0.147	0.83370

Table 131: Percent of Impacted Floorspace by Building Type (New Construction)

Building Type Building sub-type	**Prototype Model**	**Composition of Building Type by Subtypes**[a/b]	**Percentage of Impacted Area by Proposed Measure**[c]			
			VAV Deadband	**Expand Economizer**	**EAHR**	**DOAS**
Small Office	OfficeSmall	N/A	0%	0%	0%	15%
Large Offices	N/A	N/A	100%	0%	100%	N/A
Large Office	OfficeMedium	50%	100%	0%	100%	15%
Large Office	OfficeLarge	50%	100%	0%	100%	0%
Restaurant	RestaurantFastFood	N/A	0%	100%	0%	0%
Retail	RETAIL	N/A	0%	15%	75%	1%
Retail	*RetailStandAlone*	*10%*	0%	0%	0%	14%
Retail	*RetailLarge*	*75%*	0%	0%	100%	14%
Retail	*RetailStripMall*	*5%*	0%	100%	0%	(not included for draft)
Retail	*RetailMixedUse*	*10%*	0%	100%	0%	(not included for draft)
Grocery	FOOD	N/A	0%	0%	0%	0%
Non-Refrigerated Warehouse	NWHSE	N/A	0%	0%	0%	(not included for draft)
Refrigerated Warehouse	RWHSE	N/A	0%	0%	0%	(not included for draft)
Schools	SCHOOL	N/A	40%	60%	40%	18%
School	*SchoolPrimary*	*60%*	0%	100%	0%	18%
School	*SchoolSecondary*	*40%*	100%	0%	100%	18%
College	COLLEGE		90%	0%	45%	13%
College	*OfficeSmall*	*5%*	0%	0%	0%	15%
College	*OfficeMedium*	*15%*	100%	0%	100%	15%
College	*OfficeMediumLab*	*20%*	100%	0%	0%	(not included for draft)
College	*PublicAssembly*	*5%*	0%	0%	0%	(not included for draft)
College	*SchoolSecondary*	*30%*	100%	0%	100%	18%
College	*ApartmentHighRise*	*25%*	100%	0%	0%	(not included for draft)
Hospital	HOSP		0%	0%	0%	0%
Hotel/motel	HotelSmall		0%	0%	0%	17%

a. Presents the assumed composition of the main building type category by the building subtypes. All 2022 CASE Reports assumed the same percentages of building subtypes.

b. When the building type is composed of multiple subtypes, the overall percentage for the main building category was calculated by weighing the contribution of each subtype.

c. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 132: Percent of Impacted Floorspace by Building Type (Alterations)

Building Type Building sub-type	**Prototype Model**	**Composition of Building Type by Subtypes**$^{a/b}$	**Percentage of Impacted Area by Proposed Measure**^{c}			
			VAV Deadband	**Expand Economizer**	**EAHR**	**DOAS**
Small Office	OfficeSmall	0%	0%	0%	0%	3%
Large Offices	N/A	5%	0%	5%	5%	2%
Large Office	OfficeMedium	5%	0%	5%	5%	3%
Large Office	OfficeLarge	5%	0%	5%	5%	0%
Restaurant	RestaurantFastFood	0%	5%	0%	0%	0%
Retail	RETAIL	0%	1%	4%	0%	0.4%
Retail	*RetailStandAlone*	0%	0%	0%	0%	4%
Retail	*RetailLarge*	0%	0%	5%	0%	4%
Retail	*RetailStripMall*	0%	5%	0%	0%	(not included for draft)
Retail	*RetailMixedUse*	0%	5%	0%	0%	(not included for draft)
Grocery	FOOD	0%	0%	0%	0%	0%
Non-Refrigerated Warehouse	NWHSE	0%	0%	0%	0%	(not included for draft)
Refrigerated warehouse	RWHSE	0%	0%	0%	0%	0%
Schools	SCHOOL	2%	3%	2%	2%	6%
School	*SchoolPrimary*	0%	5%	0%	0%	6%
School	*SchoolSecondary*	5%	0%	5%	5%	6%
College	COLLEGE	5%	0%	2%	5%	4%
College	*OfficeSmall*	0%	0%	0%	0%	3%
College	*OfficeMedium*	5%	0%	5%	5%	3%
College	*OfficeMediumLab*	5%	0%	0%	5%	(not included for draft)
College	*PublicAssembly*	0%	0%	0%	0%	(not included for draft)
College	*SchoolSecondary*	5%	0%	5%	5%	6%
College	*ApartmentHighRise*	5%	0%	0%	5%	(not included for draft)
Hospital	HOSP	0%	0%	0%	0%	0%
Hotel/motel	HotelSmall	0%	0%	0%	0%	6%

a. Presents the assumed composition of the main building type category by the building subtypes. All 2022 CASE Reports assumed the same percentages of building subtypes.

b. When the building type is composed of multiple subtypes, the overall percentage for the main building category was calculated by weighing the contribution of each subtype.

c. Percent of existing floorspace that would be altered during the first year the 2022 standards are in effect.

Table 133: Percent of Floorspace Impacted by Proposed Measure, by Climate Zone

Climate Zone	Percent of Square Footage Impacted (New Construction)				Percent of Square Footage Impacted (Alterations & Additions)			
	VAV Deadband	Expand Economizer	EAHR	DOAS	VAV Deadband	Expand Economizer	EAHR	DOAS
1	29%	11%	31%	100%	1.6%	0.6%	1.6%	5%
2	29%	11%	16%	100%	1.6%	0.6%	0.9%	5%
3	33%	10%	0%	100%	1.8%	0.5%	0.0%	5%
4	33%	10%	0%	100%	1.8%	0.5%	0.0%	5%
5	31%	11%	0%	100%	1.7%	0.5%	0.0%	5%
6	32%	10%	0%	100%	1.6%	0.6%	0.0%	5%
7	27%	11%	0%	100%	1.5%	0.5%	0.0%	5%
8	33%	10%	0%	100%	1.6%	0.6%	0.0%	5%
9	36%	9%	0%	100%	1.7%	0.5%	0.0%	5%
10	18%	13%	0%	100%	1.0%	0.7%	0.0%	5%
11	19%	12%	17%	100%	1.0%	0.6%	0.9%	5%
12	26%	10%	14%	100%	1.4%	0.6%	0.8%	5%
13	17%	14%	10%	100%	0.9%	0.7%	0.6%	5%
14	23%	13%	12%	100%	1.1%	0.7%	0.6%	5%
15	14%	12%	9%	100%	0.7%	0.6%	0.4%	5%
16	20%	13%	19%	100%	1.0%	0.7%	0.9%	5%
TOTAL	29%	11%	4%	100%	1.5%	0.6%	0.2%	5%

Appendix B: Embedded Electricity in Water Methodology

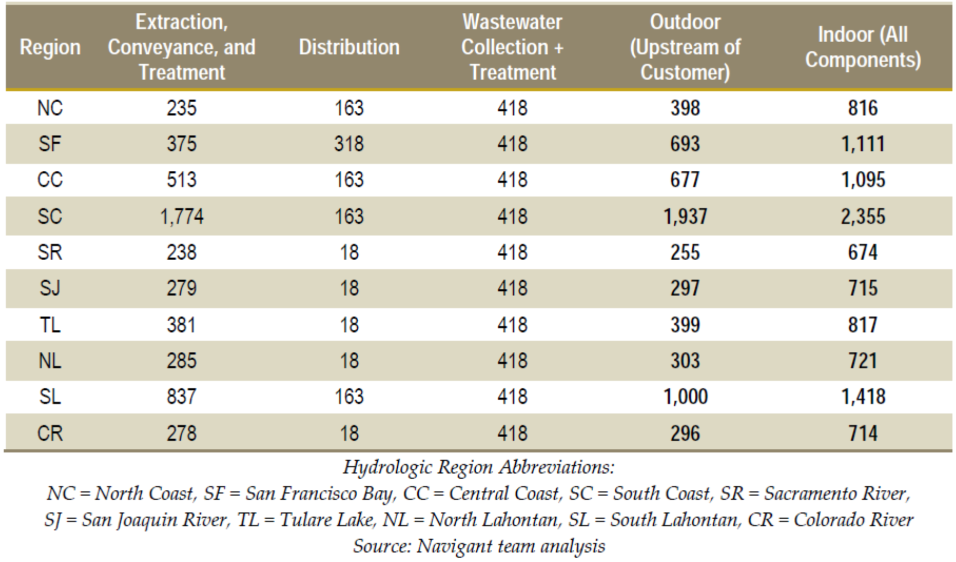
The following methodology is specific to the EAHR proposed code change because it is the only measure with water savings.

The Statewide CASE Team assumed the following embedded electricity in water values: 4,848 kWh/million gallons of water for indoor water use and 3,565 kWh/million gallons for outdoor water use. Embedded electricity use for indoor water use includes electricity used for water extraction, conveyance, treatment to potable quality, water distribution, wastewater collection, and wastewater treatment. Embedded electricity for outdoor water use includes all energy uses upstream of the customer; it does not include wastewater collection or wastewater treatment. The embedded electricity values do not include on-site energy uses for water, such as water heating and on-site pumping. On-site energy impacts are accounted for in the energy savings estimates presented in Section 5.3 of this report.

These embedded electricity values were derived from research conducted for CPUC Rulemaking 13-12-011. The CPUC study aimed to quantify the embedded electricity savings associated with IOU incentive programs that result in water savings, and the findings represent the most up-to-date research by the CPUC on embedded energy in water throughout California (California Public Utilities Commission 2015a, California Public Utilities Commission (CPUC) 2015b). The CPUC analysis was limited to evaluating the embedded electricity in water and does not include embedded natural gas in water. For this reason, this CASE Report does not include estimates of embedded natural gas savings associated with water reductions, though the embedded electricity values can be assumed to have the same associated emissions factors as grid-demanded electricity in general.

The specific CPUC embedded electricity values used in the CASE analysis are shown in Table 134. These values represent the average energy intensity by hydrologic region, which are based on the historical supply mix for each region regardless of who supplied the electricity (IOU-supplied and non-IOU- supplied electricity). The CPUC calculated the energy intensity of marginal supply but recommended using the average IOU and non-IOU energy intensity to estimate total statewide average embedded electricity of water use in California.

Table 134: Embedded Electricity in Water by California Department of Water Resources Hydrologic Region (kWh Per Acre Foot (AF))



Region	Extraction, Conveyance, and Treatment	Distribution	Wastewater Collection + Treatment	Outdoor (Upstream of Customer)	Indoor (All Components)
NC	235	163	418	398	816
SF	375	318	418	693	1,111
CC	513	163	418	677	1,095
SC	1,774	163	418	1,937	2,355
SR	238	18	418	255	674
SJ	279	18	418	297	715
TL	381	18	418	399	817
NL	285	18	418	303	721
SL	837	163	418	1,000	1,418
CR	278	18	418	296	714

Hydrologic Region Abbreviations:
NC = North Coast, SF = San Francisco Bay, CC = Central Coast, SC = South Coast, SR = Sacramento River, SJ = San Joaquin River, TL = Tulare Lake, NL = North Lahontan, SL = South Lahontan, CR = Colorado River
Source: Navigant team analysis

Source: (California Public Utilities Commission (CPUC) 2015b).

The Statewide CASE Team used CPUC’s indoor and outdoor embedded electricity estimates by hydrologic region (presented in Table 135) and population data by hydrologic region from the U.S. Census Bureau (U.S. Census Bureau, Population Division 2014) to calculate the statewide population-weighted average indoor and outdoor embedded electricity values that were used in the CASE analysis (see Table 135). The energy intensity values presented in Table 135 were converted from kWh per acre foot to kWh per million gallons to harmonize with the units used in the CASE analysis. There are 3.07 acre feet per million gallons.

Table 135: Statewide Population-Weighted Average Embedded Electricity in Water

Hydrologic Region	Indoor Water Use (kWh/million gallons)	Outdoor Water Use (kWh/million gallons)	Percent of California Population
North Coast	2,504	1,221	2.1%
San Francisco	3,410	2,127	18.2%
Central Coast	3,360	2,078	3.8%
South Coast	7,227	5,944	44.8%
Sacramento River	2,068	783	8.1%
San Joaquin River	2,194	911	4.7%
Tulare Lake	2,507	1,224	6.3%
North Lahontan	2,213	930	0.1%
South Lahontan	4,352	3,069	5.5%
Colorado River	2,191	908	6.5%
Statewide Population-Weighted Average	**4,848**	**3,565**	

Sources: (U.S. Census Bureau, Population Division 2014) and (California Department of Water Resources 2016).

Appendix C: Environmental Impacts Methodology

Greenhouse Gas (GHG) Emissions Factors

As directed by Energy Commission staff, GHG emissions were calculated making use of the average emissions factors specified in the United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion (United States Environmental Protection Agency 2018). This ensures consistency between state and federal estimations of potential environmental impacts. The electricity emissions factor calculated from the eGRID data is 240.4 metric tons CO2e per GWh. The Summary Table from eGrid 2016 reports an average emission rate of 529.9 pounds CO2e/MWh for the WECC CAMX subregion. This value was converted to metric tons/GWh.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in Chapter 1.4 of the U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (United States Environmental Protection Agency 1995). The U.S. EPA's estimates of GHG pollutants that are emitted during combustion of one million standard cubic feet of natural gas are: 120,000 pounds of CO_2 (Carbon Dioxide), 0.64 pounds of N_2O (Nitrous Oxide) and 2.3 pounds of CH_4 (Methane). The emission value for N_2O assumed that low NOx burners are used in accordance with California air pollution control requirements. The carbon equivalent values of N_2O and CH_4 were calculated by multiplying by the global warming potentials (GWP) that the California Air Resources Board used for the 2000-2016 GHG emission inventory, which are consistent with the 100-year GWPs that the Intergovernmental Panel on Climate Change used in the fourth assessment report (AR4). The GWP for N_2O and CH_4 are 298 and 25, respectively. Using a nominal value of 1,000 Btu per standard cubic foot of natural gas, the carbon equivalent emission factor for natural gas consumption is 5,454.4 metric tons per MMTherms.

GHG Emissions Monetization Methodology

The 2022 TDV energy cost factors used in the lifecycle cost-effectiveness analysis include the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs). To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the other economic impacts. The authors used the same monetary values that are used in the TDV factors – $106.20 per metric ton CO2e.

Water Use and Water Quality Impacts Methodology

Of the four measures presenting in the report, only the Exhaust Air Heat Recovery measure has significant impacts on water use. For HVAC measures, water savings are obtained when reducing cooling demand for water-cooled systems. Under the Exhaust Air Heat Recovery Measure, only the OfficeLarge and SchoolSecondary prototype models had both significant cooling reductions and a utilized water-cooled systems. Due to the climatic specificity of this measure, only eight of the sixteen climate zones were impacted.

The Statewide CASE Team utilized CBECC-Com outputs to determine the annual reduction in water usage on the cooling tower for each impacted climate zone and then normalized those savings to square footage as shown in Table 118 and

Table 119. In order to extend this to statewide impacts, this value was multiplied by the estimated statewide impacted square footage.

To calculate the embedded energy savings, the Statewide CASE Team utilized the “Statewide Population-Weighted Average” in Table 135 to estimate the energy savings resulting from this water reduction.

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

Introduction

The purpose of this appendix is to present proposed revisions to CBECC-Com along with the supporting documentation that the Energy Commission staff and the technical support contractors would need to approve and implement the software revisions. The software changes are organized by measure

Appendix D1: VAV Deadband Airflow

Technical Basis for Software Change

VAV deadband airflow control is a mature technology in commercial settings as addressed in Section 2.2. The current Standard Design specifies the larger of 20 percent of peak primary airflow or the design minimum outdoor airflow rate. The new prescriptive criteria for VAV deadband airflow established in Section 2.3 eliminates the requirement to consider 20 percent of peak primary airflow and specifies it to be equal to the design minimum outdoor airflow rate, and outlines other key variables needed to simulate the performance of these systems in energy modeling software.

Description of Software Change

Background Information for Software Change

This report describes how the design minimum outdoor airflow rate can be implemented in CBECC-Com for VAV deadband airflow.

Existing CBECC-Com Modeling Capabilities

CBECC-Com currently models the Standard Design VAV deadband airflow to be the larger of 20 percent of peak primary airflow or the design minimum outdoor airflow rate.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 2 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 VAV deadband airflow to be equal to the design minimum outdoor airflow rate.

User Inputs to CBECC-Com

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

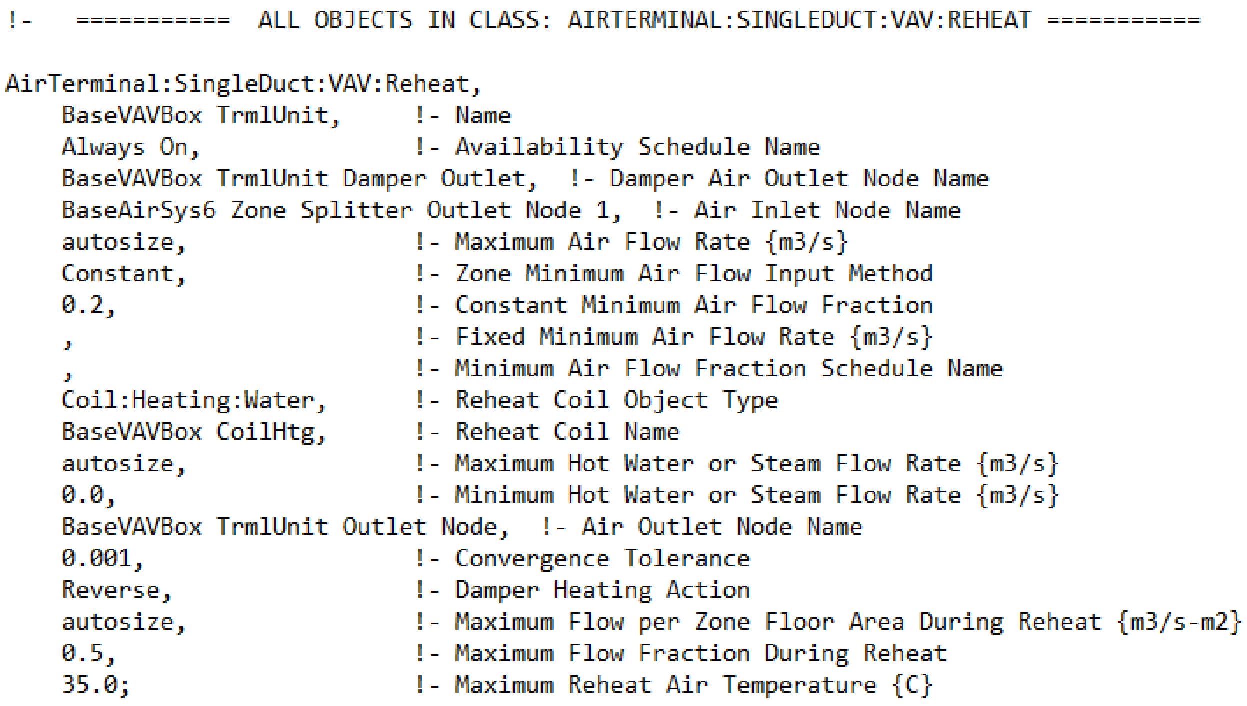
Simulation Engine Inputs

EnergyPlus/California Simulation Engine Inputs

Table 136 summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the BaseVAVBox TrmlUnit object (Figure 17).

Table 136: EnergyPlus Input Variables Relevant to VAV deadband Airflow

Target EnergyPlus Class = AirTerminal:SingleDuct:VAV:Reheat			
EnergyPlus Field	**CBECC-Com user input/specified value (if applicable)**	**Units**	**Notes**
Name	**Name**		
Constant Minimum Air Flow Fraction	Min. Primary Flow	None	



```
!-   ===========  ALL OBJECTS IN CLASS: AIRTERMINAL:SINGLEDUCT:VAV:REHEAT ===========

AirTerminal:SingleDuct:VAV:Reheat,
    BaseVAVBox TrmlUnit,     !- Name
    Always On,               !- Availability Schedule Name
    BaseVAVBox TrmlUnit Damper Outlet,  !- Damper Air Outlet Node Name
    BaseAirSys6 Zone Splitter Outlet Node 1,  !- Air Inlet Node Name
    autosize,                !- Maximum Air Flow Rate {m3/s}
    Constant,                !- Zone Minimum Air Flow Input Method
    0.2,                     !- Constant Minimum Air Flow Fraction
    ,                        !- Fixed Minimum Air Flow Rate {m3/s}
    ,                        !- Minimum Air Flow Fraction Schedule Name
    Coil:Heating:Water,      !- Reheat Coil Object Type
    BaseVAVBox CoilHtg,      !- Reheat Coil Name
    autosize,                !- Maximum Hot Water or Steam Flow Rate {m3/s}
    0.0,                     !- Minimum Hot Water or Steam Flow Rate {m3/s}
    BaseVAVBox TrmlUnit Outlet Node,  !- Air Outlet Node Name
    0.001,                   !- Convergence Tolerance
    Reverse,                 !- Damper Heating Action
    autosize,                !- Maximum Flow per Zone Floor Area During Reheat {m3/s-m2}
    0.5,                     !- Maximum Flow Fraction During Reheat
    35.0;                    !- Maximum Reheat Air Temperature {C}
```

Figure 17: EnergyPlus object BaseVAVBox TrmlUnit

Simulation Engine Output Variables

CBECC-Com generates hourly EnergyPlus simulation results to CSV files during analysis. These hourly simulation results can be used by the analyst to debug a building energy model. Variables of particular interest in this case would include:

- Zone Air Terminal VAV Damper Position,hourly; !- HVAC Average []
- Zone Air Terminal Minimum Air Flow Fraction,hourly; !- HVAC Average []
- Zone Air Terminal Outdoor Air Volume Flow Rate,hourly; !- HVAC Average [m3/s]

The existing algorithms for calculations, fixed values and limitations are sufficient for the proposed measure. No changes are needed.

Compliance Report

No change needs to be made for the compliance report for this CASE measure.

Compliance Verification

The existing compliance reports are sufficient for the proposed measure. No changes are needed.

Testing and Confirming CBECC-Com Modeling

The existing testing and confirmation process are sufficient for the proposed measure. No changes are needed.

Description of Changes to ACM Reference Manual

This information is available in Section 2.6.

Appendix D2: Expand Economizer Requirements

Technical Basis for Software Change

An air-side economizer is a mature technology in commercial settings as addressed 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 33,000 Btu/hr, and outlines other key variables needed to simulate the performance of these systems in energy modeling software.

Description of Software Change

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 33,000 Btu/h.

User Inputs to CBECC-Com

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

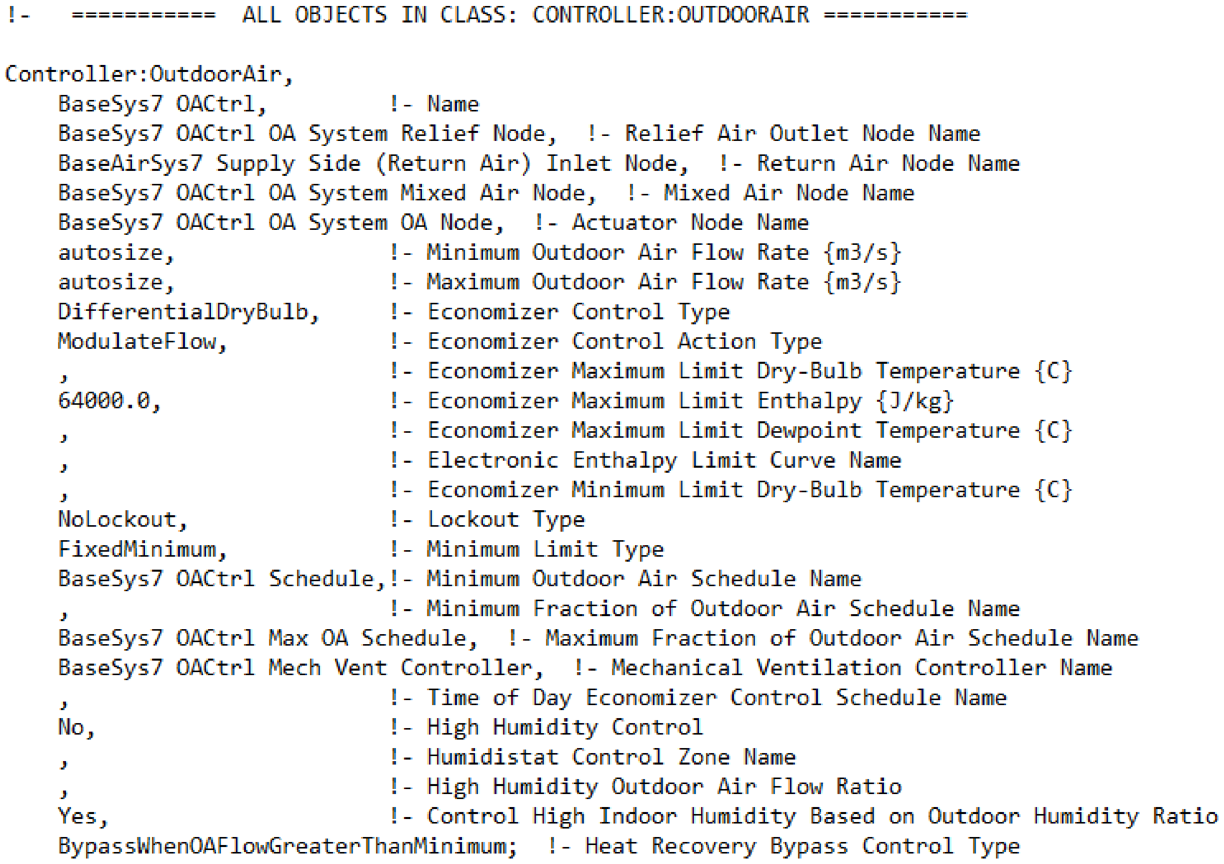
Simulation Engine Inputs

EnergyPlus/California Simulation Engine Inputs

Table 137 summarizes the relevant EnergyPlus input variable and corresponding variable name in CBECC-Com. In EnergyPlus, this variable is located in the BaseSys7 OACtrl-2 object (Figure 17).

Table 137: EnergyPlus Input Variables Relevant to Air-side Economizer

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



```
!-   ===========  ALL OBJECTS IN CLASS: CONTROLLER:OUTDOORAIR ===========

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
    autosize,                !- Minimum Outdoor Air Flow Rate {m3/s}
    autosize,                !- Maximum Outdoor Air Flow Rate {m3/s}
    DifferentialDryBulb,     !- Economizer Control Type
    ModulateFlow,            !- Economizer Control Action Type
    ,                        !- Economizer Maximum Limit Dry-Bulb Temperature {C}
    64000.0,                 !- 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
    ,                        !- Minimum Fraction of Outdoor Air Schedule Name
    BaseSys7 OACtrl Max OA 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
    BypassWhenOAFlowGreaterThanMinimum;  !- Heat Recovery Bypass Control Type
```

Figure 18: EnergyPlus object BaseSys7 OACtrl-2

Simulation Engine Output Variables

CBECC-Com generates hourly EnergyPlus simulation results to CSV files during analysis. These hourly simulation results can be used by the analyst to debug a building energy model. Variables of particular interest in this case would include:

- Air System Outdoor Air Economizer Status,hourly; !- HVAC Average []
- Air System Outdoor Air Flow Fraction,hourly; !- HVAC Average []

- Air System Outdoor Air Minimum Flow Fraction,hourly; !- HVAC Average

The existing algorithms for calculations, fixed values and limitations are sufficient for the proposed measure. No changes are needed.

Compliance Report

No change needs to be made for the compliance report for this CASE measure.

Compliance Verification

The existing compliance reports are sufficient for the proposed measure. No changes are needed.

Testing and Confirming CBECC-Com Modeling

The existing testing and confirmation process are sufficient for the proposed measure. No changes are needed.

Description of Changes to ACM Reference Manual

This information is available in Section 3.6.

Appendix D3: Dedicated Outside Air Systems (DOAS)

Technical Basis for Software Change

Current functionality in CBECC-Com does exist for DOAS unit and space heating and cooling component configurations. Additional modifications are anticipated and not currently drafted for this Draft CASE Report. A short list of the items is included here for context and would be further developed for the Final CASE Report:

1. Heat recovery default effectiveness values
2. Bypass control capabilities and defaults
3. HRV/ERV supply air temperature control to a constant or to a scheduled value or based on outdoor air reset.
4. DX-DOAS control defaults for the supply air temperature off a cooling coil and from the unit itself.
5. Space conditioning fan control defaults. Primarily adjustments to the labeling in the software of when zone fans can cycle based on a designs duct work configuration.
6. Multiple speed zone fan controls for fan coils.

Many of these enhancements would be based on the control functionality defined in Appendix L and would be described here in detail in the Final CASE Report.

Appendix D4: Exhaust Air Heat Recovery

Technical Basis for Software Change

Exhaust air heat recovery (EAHR) is a mature technology used to conserve heating and cooling energy by tempering incoming outside air with energy from outgoing exhaust air. The measure proposed in Section 5.1 would add prescriptive requirements for EAHR in air handling systems meeting specific criteria in climate zones that were found to be cost effective.

Description of Software Change

Background Information for Software Change

Exhaust air heat recovery is already implemented in CBECC-Com as a compliance option for the proposed design. This proposal would change the Standard Design air handling systems to include EAHR where required.

Existing CBECC-Com Modeling Capabilities

CBECC-Com already supports EAHR systems as a compliance option for the proposed design model.

Summary of Proposed Revisions to CBECC-Com

The proposed change is described in Section 5.6.2 including air handler criteria and climate zones where EAHR would be a prescriptive requirement. CBECC-Com would need to implement EAHR in Standard Design air handlers that meet the criteria the Table 138 and Table 139 below (copied from Section 5.3.2).

Table 138. Proposed Requirements for EAHR for Ventilation Systems Operating Less than 8000 Hours per Year

ASHRAE Climate Zone	**% *Outdoor Air* at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
01	NR	≥15,000	≥13,000	≥10,000	≥9,000	≥7,000	≥6,500	≥4,500
02	NR	≥20,000	≥15,000	≥12,000	≥10,000	≥7,500	≥7,000	≥6,500
03, 5, 6, 7, 8	NR	NR	NR	NR	NR	NR	NR	NR
04	NR	NR	NR	NR	≥18,500	≥16,500	≥15,000	≥14,000
09	NR	NR	NR	NR	NR	≥20,000	≥17,000	≥15,000
10	NR	NR	NR	≥22,000	≥17,000	≥15,000	≥14,000	≥13,000
11 - 16	NR	≥18,500	≥15,000	≥10,000	≥8,000	≥7,000	≥5,000	≥2,000

Table 139. Proposed Requirements for EAHR for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year

California Climate Zone	**% Outdoor Air at Full Design Airflow**							
	≥10% and <20%	**≥20% and <30%**	**≥30% and <40%**	**≥40% and <50%**	**≥50% and <60%**	**≥60% and <70%**	**≥70% and <80%**	**≥80%**
	Design Supply Fan Airflow Rate, cfm							
01	≥10,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
02	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
03	NR	≥13,000	≥10,000	≥8,000	≥7,000	≥6,000	≥6,000	≥6,000
04, 5	NR	≥9,000	≥6,500	≥6,000	≥6,000	≥6,000	≥5,000	≥5,000
06, 7	NR	NR	NR	NR	NR	NR	NR	NR
08	NR	NR	NR	NR	≥20,000	≥18,000	≥15,000	≥12,000
09	NR	NR	≥15,000	≥12,000	≥10,000	≥9,000	≥8,000	≥7,000
10, 11	≥40,000	≥15,000	≥7,500	≥6,000	≥5,000	≥4,000	≥3,000	≥3,000
12	≥20,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000
13 - 16	≥10,000	≥5,000	≥3,000	≥2,000	≥2,000	≥2,000	≥2,000	≥2,000

User Inputs to CBECC-Com

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

Simulation Engine Inputs

EnergyPlus Inputs

The following bullets describe the changes to the Standard Design needed to implement the prescriptive requirement for EAHR. Table 140 summarizes the relevant EnergyPlus input variables needed to simulate EAHR in the Standard Design.

- Energy recovery is available only during periods when the outside air economizer is not in operation (outside air temperatures above 75°F and below 55°F).
- Heating and cooling energy in the exhaust/relief air is transferred to the fresh air supply via fixed plate heat exchanger equipped with bypass dampers.
- Energy recovery performance is assumed at 60 percent sensible energy recovery ratio. This performance is consistent with the proposed requirement for ventilation systems and Dedicated Outside Air Systems.
- The added static pressure to airstream is based on that specified for “Energy recovery device, other than coil runaround loop” located in Table 140.4B – Fan Power Limitations Pressure Drop Adjustment within Title 24, Part 6, Section 140.4 (ASHRAE Standard 90.1 Section 6.5.3.1 uses an equivalent table):

  *2.2 IWC * Energy Recovery Effectiveness – 0.5 IWC, per airstream (Equation 1)*

  (IWC stands for inches of water column, a unit of pressure)

  - EnergyPlus does not have the ability to dynamically adjust static pressures based on whether airstreams are bypassing the heat exchanger. As a result, this simulation assumes a constant pressure drop adjustment of +1.2 IWC throughout the simulation based on this equation.
  - There is an adjacent effort by the Statewide CASE Team to update pressure credits and penalties for fan systems. The overall impact of that proposal would reduce the pressure drop adjustment from 1.2 IWC to 1.0 IWC. The Statewide CASE Team did not implement the lower pressure drop for this analysis.

Table 140. Modifications Made to Standard Design to Simulate EAHR

Objects Modified	Parameter Names	Standard Design Parameter Value	Proposed Design Parameter Value
AirLoopHVAC:OutdoorAirSystem:EquipmentList	Component Object Type	N/A (added)	HeatExchanger:AirToAir:SensibleAndLatent
AirLoopHVAC	Component Object Name	N/A (added)	Energy Recovery Wheel
HeatExchanger:AirToAir:SensibleAndLatent	New Object	N/A (added)	Energy Recovery Wheel
NodeList	Node Name	N/A (added)	ER Supply Outlet Node
OutdoorAir:Mixer	Outdoor Air Stream Node Name	Outside Air Inlet Node	ER Supply Outlet Node
Fan:VariableVolume	Pressure Rise	Varies by model	Per Table 140.4-B: *2.2 IWC * Energy Recovery Effectiveness – 0.5 IWC, per airstream (Equation 1)*

Simulation Engine Output Variables

No change needs to be made for the compliance report for this CASE measure.

Compliance Report

No change needs to be made for the compliance report for this CASE measure.

Compliance Verification

The existing compliance reports are sufficient for the proposed measure. No changes are needed.

Testing and Confirming CBECC-Com Modeling

The existing testing and confirmation process are sufficient for the proposed measure. No changes are needed.

Description of Changes to ACM Reference Manual

This information is available in Section 5.6.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.1.5/3.1.5/4.1.6/5.1.5, could impact various market actors. Table 141 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing workflow, and ways negative impacts could be mitigated. The information contained in Table 141 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes. Appendix F summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the code change proposal, including gathering information on the compliance process.

Below is a summary of proposed changes to the current compliance and enforcement process as a result of the measures presented in this CASE Report.

- VAV Deadband Airflow requires different information to be specified in the mechanical drawings related to the deadband airflow. However, this change would fit within the current compliance workflow and would not lead to any changes or new tasks.
- Expand Economizer Requirement would expand the existing economizer compliance framework into a smaller capacity range. This change would fit within the current compliance workflow and would not lead to significant changes. However, changes to an existing exception may cause some alterations.
- DOAS would add prescriptive requirements for DOAS systems. This change would fit within the current compliance workflow with significant modifications as DOAS systems the scope would be expanded to include more than just ventilation.
- Exhaust Air Heat Recovery: would require exhaust air heat recovery devices to be installed under specific conditions. However, this change would fit within the current compliance workflow and would not lead to significant changes.

Table 141: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
HVAC Designer	• VAV Deadband: Ensuring that the volume of primary air does not exceed code requirements • Expand Economizer Requirements: Coordinate with supplier to ensure economizer installation. Coordinate with controls contractor for FDD • DOAS: N/A • EAHR: N/A	• VAV Deadband: Easy to identify the threshold of airflow to comply. Would utilize same documentation as previous code cycle. • Expand Economizer Requirements: Easy to identify compliance, would use same documentation as previous code cycle with minor modifications. • DOAS: Ensure ventilation requirements are met • EAHR: Ensure heat recovery requirements are met and optimize heat recovery to reduce cooling and heating capacity requirements to reduce costs.	• VAV Deadband: Acknowledge deadband airflow change, make sure to update mechanical schedules, sequence of operation, and other related documents. • Expand Economizer Requirements: Acknowledge new capacity requirement for economizers, make sure to indicate how new criteria is met in design. • DOAS: Ensure specified DOAS systems meets the new criteria. • EAHR: Ensure system meet new requirements. Would need to coordinate with controls team for economizer bypass controls.	ALL: • Training to understand CBECC-Com Modeling software changes. • Need to understand changes to the following forms: ○ NRCA-MCH-02 ○ NRCA-MCH-05 ○ NRCA-MCH-06 ○ NRCC-MCH-E ○ NRCC-PRF-E

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
HVAC Controls Contractor	• VAV Deadband: Match minimum airflow to plans • Expand Economizer Requirements: Ensure Economizer controls are implemented • DOAS: N/A • EAHR: N/A	• VAV Deadband: Quickly and easily determine requirements based on design documents • Expand Economizer Requirements: Quickly and easily determine requirements based on scope • DOAS: N/A • EAHR: N/A	• VAV Deadband: Mechanical schedules would need to be changed • Expand Economizer Requirements: Need to be aware of • DOAS: Ensuring heat recovery bypass control is configured. Ensure system supply air control meets minimum criteria for 60F or less with active cooling. • EAHR: Ensure economizer bypass controls are incorporated properly	• VAV Deadband: Clearly defined airflow rates on mechanical schedule. • DOAS: Changes in scope from previous projects are clearly outlined to controls subcontractor. • EAHR: Bypass damper controls or recovery wheel controls are clearly outlined for controls subcontractors
Acceptance Test Technician (MCH)	• VAV Deadband: N/A • Expand Economizer Requirements: Test Economizer controls • DOAS: N/A • EAHR: N/A	• VAV Deadband: N/A • Expand Economizer Requirements: Quickly complete compliance documents • DOAS: Quickly complete compliance documents. • EAHR: N/A	• Expand Economizer Requirements: Perform HVAC AT Tests, noting new economizer requirements • DOAS: Perform HVAC AT Test, noting new language requirements • EAHR: Perform HVAC AT Tests, noting new requirements for Heat Recovery	ALL: • ATT Training on changes to NRCA documents

Market Actor	**Task(s) In Compliance Process**	**Objective(s) in Completing Compliance Tasks**	**How Proposed Code Change Could Impact Work Flow**	**Opportunities to Minimize Negative Impacts of Compliance Requirement**
Plans Examiner	ALL: • Identify relevant requirements • Confirm data on documents is compliant • Confirm plans/ specifications match data on documents • Provide correction comments if necessary	ALL: • Quickly and easily determine requirements based on scope • Quickly and easily determine if data in documents meets requirements • Quickly and easily determine if plans/ specs match documents • Quickly and easily provide correction comments that would resolve issue	• VAV Deadband: Needs to review VAV Box Schedule to confirm lower airflow is easily found for implementation • Expand Economizer Requirements: Needs to review Mechanical Schedule to confirm presence of economizer • DOAS: Needs to review Mechanical Schedule to confirm DOAS systems meet criteria • EAHR: Needs to review Mechanical Schedule to confirm certified heat recovery device installed in applicable fan systems. Needs to review controls capabilities to ensure bypass damper	ALL: • Compliance document could auto-verify data is compliant with standards. • Record compliance on documents in a way easily compared to plans.

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Cx Agent	• VAV Deadband Airflow: Verify VAV box operation • Expand Economizer Requirements: Verify Economizer Controls and FDD • DOAS: Verify ventilation requirements are met • EAHR: N/A	ALL: • Quickly and easily validate requirements • Quickly and easily determine if data in documents meets requirements • Quickly and easily determine if plans/ specs match documents • Quickly and easily provide correction comments that would resolve issues • Quickly and easily observe verify proper controls	• VAV Deadband: Would need to be aware of the lower deadband airflow • Expand Economizer Requirements: Would need to verify operation of economizers on smaller units • DOAS: would need to verify proper SAT and Fan controls • DOAS and EAHR: Would need to verify presence and proper control of bypass damper or recovery wheel controls into both Economizer testing and Fault Detection and Diagnostics	ALL: • Attending training of code changes • Work with professional Cx orgs to develop fact sheets on code changes
Energy Commission	N/A	N/A	N/A	ALL: • Need to incorporate changes to CBECC-Com Modeling • Need to conduct CBECC-Com software training updates. • Create selection guide for compliant equipment • Need to conduct industry trainings • Need to make changes to the relevant forms

Market Actor	**Task(s) In Compliance Process**	**Objective(s) in Completing Compliance Tasks**	**How Proposed Code Change Could Impact Work Flow**	**Opportunities to Minimize Negative Impacts of Compliance Requirement**
Mfr Equipment reps/ vendors	• VAV Deadband Airflow: Specify equipment operating ranges • Expand Economizer Requirements: Verify that HVAC units meet minimum requirements • DOAS: Specify equipment per ventilation requirements • EAHR: N/A	• VAV Deadband Airflow: Provide easily read specification sheets on equipment • Expand Economizer Requirements: Provide easily read specification sheets on equipment. • DOAS: Industry standard requirements for easy equipment selection • EAHR: Provide easily read specification sheets on equipment.	• VAV Deadband Airflow: Verify that equipment would meet new lower flow deadband requirements • Expand Economizer Requirements: Ensure that equipment can be installed with an economizer at lower capacity units. • DOAS: Need to be aware of requirements to adjust products, marketing materials, and product specifications • EAHR: Ensure that products would be able to meet new EAHR requirements	• VAV Deadband Airflow: modify sales literature • Expand Economizer Requirements: Notify and train sales representatives and edit product selection software with lower threshold economizer criteria • DOAS: Create selection guide for compliant equipment • EAHR: Incorporate into marketing literature. Notify distributors and sales reps in climate zones most impacted by measure. Train sales staff on how to specify EAHR to reduce unit capacity.

Appendix F: Summary of Stakeholder Engagement

Collaborating with stakeholders that might be impacted by proposed changes is a critical aspect of the Statewide CASE Team's efforts. The Statewide CASE Team aims to work with interested parties to identify and address issues associated with the proposed code changes so that the proposals presented to the Energy Commission in this Final CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including: cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

This appendix summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the recommendations presented in this report.

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2022 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

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

The Statewide CASE Team hosted three stakeholder meetings for HVAC Controls via webinar. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting. Such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography section of this report.

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
First Round: Nonresidential HVAC Part 1: Boilers, Data Center Efficiency, Dedicated Outside Air Systems, and VAV Minimum Airflow Utility-Sponsored Stakeholder Meeting	Tuesday, October 15, 2019	https://title24stakeholders.com/event/nonresidential-hvac-utility-sponsored-stakeholder-meeting/
First Round: Nonresidential HVAC and Envelope Part 2: Air Distribution, Air Efficiency, Guest Room Controls, and Reduced Infiltration Utility-Sponsored Stakeholder Meeting	Tuesday, November 5, 2019	https://title24stakeholders.com/event/nonresidential-hvac-air-distribution-controls-reduced-infiltration-utility-sponsored-stakeholder-meeting/
Second Round: Nonresidential HVAC and Envelope Part 2: Reduced Infiltration, HVAC Controls Utility-Sponsored Stakeholder Meeting	Tuesday, April 14, 2020	https://title24stakeholders.com/event/nonresidential-hvac-and-envelope-part-2-reduced-infiltration-hvac-controls-air-efficiency-doas/

The first round of utility-sponsored stakeholder meetings occurred from September to November 2019 and were important for providing transparency and an early forum for stakeholders to offer feedback on measures being pursued by the Statewide CASE Team. The objectives of the first round of stakeholder meetings were to solicit input on the scope of the 2022 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for the energy impacts and cost-effectiveness analyses; and understand potential technical and market barriers. The Statewide CASE Team also presented initial draft code language for stakeholders to review.

The second round of utility-sponsored stakeholder meetings occurred from March to April 2020 and provided updated details on proposed code changes. The second round of meetings introduced early results of energy, cost-effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

Utility-sponsored stakeholder meetings were open to the public. For each stakeholder meeting, two promotional emails were distributed from info@title24stakeholders.com One email was sent to the entire Title 24 Stakeholders listserv, totaling over 1,900 individuals, and a second email was sent to a targeted list of individuals on the listserv depending on their subscription preferences. The Title 24 Stakeholders' website listserv is an opt-in service and includes individuals from a wide variety of industries and trades, including manufacturers, advocacy groups, local government, and building and energy professionals. Each meeting was posted on the Title 24 Stakeholders' LinkedIn page[27] (and cross-promoted on the Energy Commission LinkedIn page) two weeks before each meeting to reach out to individuals and larger organizations and channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted in to the listserv. Exported webinar meeting data captured attendance numbers and individual comments, and recorded outcomes of live attendee polls to evaluate stakeholder participation and support.

Statewide CASE Team Communications

The Statewide CASE Team held personal communications over email, phone, and web-based conference with numerous stakeholders when developing this report. Some of the stakeholders engaged to date are listed below; this is not an exhaustive list of all keyholders engaged.

- Air-Conditioning, Heating, and Refrigeration Institute (AHRI)
- New Buildings Institute (NBI)
- TRANE
- Aaon
- Johnson Controls
- Daikin
- Carrier
- GreenHeck
- NRDC
- Mitsubishi
- Samsung
- Emerson
- EBTron
- Morrison Products

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[27] Title 24 Stakeholders' LinkedIn page can be found here: https://www.linkedin.com/showcase/title-24-stakeholders/.

Appendix G: DOAS Per Building Energy Impact Complete Results

This appendix includes the energy savings results of the Market Reference DOAS building configurations to the Proposed code enhancement DOAS for the following building types:

Small Office, Medium Office, Primary School, Secondary School, Small Hotel, Retail Stand Alone.

The results are organized into five sections in this appendix:

1. First-Year Energy Impacts Per Square Foot
2. Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot
3. 2023 PV TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot
4. 15-Year Cost-effectiveness Summary Per Square Foot – New Construction

Other appendices include additional energy equivalency for DOAS to a reference set of prototypes with airside economizers.

Office Small

Table 142: First-Year Energy Impacts Per Square Foot, Office Small

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	1.244	0.000	(0.009)	29.0
2	1.602	0.000	(0.006)	39.0
3	1.660	0.000	(0.005)	43.0
4	1.678	0.000	(0.004)	42.0
5	1.563	0.000	(0.005)	41.0
6	1.818	0.000	(0.002)	48.0
7	1.814	0.000	(0.002)	49.0
8	1.773	0.000	(0.003)	46.0
9	1.792	0.000	(0.003)	44.0
10	1.779	0.000	(0.003)	44.0
11	1.656	0.000	(0.006)	41.0
12	1.614	0.000	(0.005)	39.0
13	1.603	0.000	(0.005)	37.0
14	1.758	0.000	(0.005)	42.0
15	1.772	0.000	(0.001)	47.0
16	1.810	0.000	(0.010)	43.0

Office Small continued

Table 143: Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Small

Climate Zone	15 Year TDV Electricity Cost Savings (Nominal $)	15 Year TDV Natural Gas Cost Savings (Nominal $)	Total 15 Year TDV Energy Cost Savings (Nominal $)
1	$45.12	($4.26)	$40.86
2	$56.40	($1.42)	$54.98
3	$63.45	($2.84)	$60.61
4	$60.63	($1.42)	$59.21
5	$60.63	($2.84)	$57.79
6	$69.09	($1.42)	$67.67
7	$69.09	$0.00	$69.09
8	$64.86	$0.00	$64.86
9	$63.45	($1.42)	$62.03
10	$63.45	($1.42)	$62.03
11	$59.22	($1.42)	$57.80
12	$57.81	($2.84)	$54.97
13	$54.99	($2.84)	$52.15
14	$62.04	($2.84)	$59.20
15	$66.27	$0.00	$66.27
16	$64.86	($4.26)	$60.60

Table 144: 2023 PV TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Small

Climate Zone	15 Year TDV Electricity Cost Savings (2023 PV $)	15 Year TDV Natural Gas Cost Savings (2023 PV $)	Total 15 Year TDV Energy Cost Savings (2023 PV $)
1	$2.85	($0.27)	$2.58
2	$3.56	($0.09)	$3.47
3	$4.01	($0.18)	$3.83
4	$3.83	($0.09)	$3.74
5	$3.83	($0.18)	$3.65
6	$4.36	($0.09)	$4.27
7	$4.36	$0.00	$4.36
8	$4.09	$0.00	$4.09
9	$4.01	($0.09)	$3.92
10	$4.01	($0.09)	$3.92
11	$3.74	($0.09)	$3.65
12	$3.65	($0.18)	$3.47
13	$3.47	($0.18)	$3.29
14	$3.92	($0.18)	$3.74
15	$4.18	$0.00	$4.18
16	$4.09	($0.27)	$3.83

Table 145: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - OfficeSmall

Climate Zone	Benefits 2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Costs Total Incremental PV Costs	Benefit-to-Cost Ratio
1	$2.58	$0.88	2.95
2	$3.47	$0.88	3.96
3	$3.83	$0.88	4.37
4	$3.74	$0.88	4.27
5	$3.65	$0.88	4.17
6	$4.27	$0.88	4.88
7	$4.36	$0.88	4.98
8	$4.09	$0.88	4.67
9	$3.92	$0.88	4.47
10	$3.92	$0.88	4.47
11	$3.65	$0.88	4.17
12	$3.47	$0.88	3.96
13	$3.29	$0.88	3.76
14	$3.74	$0.88	4.27
15	$4.18	$0.88	4.78
16	$3.83	$0.88	4.37

Office Medium

Table 146: First-Year Energy Impacts Per Square Foot, Office Medium

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	2.250	0.000	0.000	62.0
2	2.473	0.000	0.000	68.0
3	2.420	0.000	0.000	69.0
4	2.521	0.000	0.000	71.0
5	2.405	0.000	0.000	68.0
6	2.555	0.000	0.000	73.0
7	2.518	0.000	0.000	72.0
8	2.597	0.000	0.000	72.0
9	2.673	0.000	0.000	74.0
10	2.660	0.000	0.000	74.0
11	2.672	0.000	0.000	73.0
12	2.529	0.000	0.000	69.0
13	2.628	0.000	0.000	70.0
14	2.834	0.000	0.000	78.0
15	2.835	0.000	0.000	79.0
16	2.983	0.000	0.000	83.0

Table 147:Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Medium

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$87.42	$0.00	$87.42
2	$95.88	$0.00	$95.88
3	$97.29	$0.00	$97.29
4	$100.11	$0.00	$100.11
5	$95.88	$0.00	$95.88
6	$102.93	$0.00	$102.93
7	$101.52	$0.00	$101.52
8	$101.52	$0.00	$101.52
9	$104.34	$0.00	$104.34
10	$104.34	$0.00	$104.34
11	$102.93	$0.00	$102.93
12	$97.29	$0.00	$97.29
13	$98.70	$0.00	$98.70
14	$109.98	$0.00	$109.98
15	$111.39	$0.00	$111.39
16	$117.03	$0.00	$117.03

Table 148: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Medium

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$5.52	$0.00	$5.52
2	$6.05	$0.00	$6.05
3	$6.14	$0.00	$6.14
4	$6.32	$0.00	$6.32
5	$6.05	$0.00	$6.05
6	$6.50	$0.00	$6.50
7	$6.41	$0.00	$6.41
8	$6.41	$0.00	$6.41
9	$6.59	$0.00	$6.59
10	$6.59	$0.00	$6.59
11	$6.50	$0.00	$6.50
12	$6.14	$0.00	$6.14
13	$6.23	$0.00	$6.23
14	$6.94	$0.00	$6.94
15	$7.03	$0.00	$7.03
16	$7.39	$0.00	$7.39

Table 149: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - OfficeMedium

Climate Zone	Benefits 2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Costs Total Incremental PV Costs	Benefit-to-Cost Ratio
	$5.52	$0.88	6.30
2	$6.05	$0.88	6.91
3	$6.14	$0.88	7.01
4	$6.32	$0.88	7.21
5	$6.05	$0.88	6.91
6	$6.50	$0.88	7.42
7	$6.41	$0.88	7.32
8	$6.41	$0.88	7.32
9	$6.59	$0.88	7.52
10	$6.59	$0.88	7.52
11	$6.50	$0.88	7.42
12	$6.14	$0.88	7.01
13	$6.23	$0.88	7.11
14	$6.94	$0.88	7.92
15	$7.03	$0.88	8.03
16	$7.39	$0.88	8.43

Office Large

Table 150: First-Year Energy Impacts Per Square Foot, Office Large

Climate Zone	Electricity Savings (kWh/ft²)	Peak Electricity Demand Reductions (kW/ft²)	Natural Gas Savings (therms/ft²)	TDV Energy Savings (TDV kBtu/ft²)
1	2.578	0.000	(0.025)	67.0
2	2.717	0.000	(0.018)	70.0
3	2.667	0.000	(0.018)	69.0
4	2.715	0.000	(0.013)	72.0
5	2.665	0.000	(0.016)	72.0
6	2.678	0.000	(0.010)	73.0
7	2.637	0.000	(0.008)	72.0
8	2.737	0.000	(0.009)	73.0
9	2.808	0.000	(0.009)	75.0
10	2.804	0.000	(0.010)	73.0
11	2.855	0.000	(0.016)	74.0
12	2.726	0.000	(0.016)	71.0
13	2.797	0.000	(0.012)	74.0
14	3.023	0.000	(0.014)	79.0
15	2.918	0.000	(0.006)	79.0
16	3.260	0.000	(0.021)	87.0

Table 151:Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Large

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$104.34	($9.94)	$94.40
2	$105.75	($7.10)	$98.65
3	$104.34	($7.10)	$97.24
4	$107.16	($5.68)	$101.48
5	$107.16	($5.68)	$101.48
6	$105.75	($2.84)	$102.91
7	$104.34	($2.84)	$101.50
8	$107.16	($4.26)	$102.90
9	$109.98	($4.26)	$105.72
10	$108.57	($5.68)	$102.89
11	$111.39	($7.10)	$104.29
12	$107.16	($7.10)	$100.06
13	$108.57	($4.26)	$104.31
14	$117.03	($5.68)	$111.35
15	$114.21	($2.84)	$111.37
16	$131.13	($8.52)	$122.61

Table 152: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Office Large

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$6.59	($0.62)	$5.96
2	$6.68	($0.45)	$6.23
3	$6.59	($0.45)	$6.14
4	$6.76	($0.36)	$6.41
5	$6.76	($0.36)	$6.41
6	$6.68	($0.18)	$6.50
7	$6.59	($0.18)	$6.41
8	$6.76	($0.27)	$6.50
9	$6.94	($0.27)	$6.68
10	$6.85	($0.36)	$6.50
11	$7.03	($0.45)	$6.59
12	$6.76	($0.45)	$6.32
13	$6.85	($0.27)	$6.59
14	$7.39	($0.36)	$7.03
15	$7.21	($0.18)	$7.03
16	$8.28	($0.53)	$7.74

Table 153: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction – Office Large

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Total Incremental PV Costs	
1	$5.96	$0.88	6.81
2	$6.23	$0.88	7.11
3	$6.14	$0.88	7.01
4	$6.41	$0.88	7.32
5	$6.41	$0.88	7.32
6	$6.50	$0.88	7.42
7	$6.41	$0.88	7.32
8	$6.50	$0.88	7.42
9	$6.68	$0.88	7.62
10	$6.50	$0.88	7.42
11	$6.59	$0.88	7.52
12	$6.32	$0.88	7.21
13	$6.59	$0.88	7.52
14	$7.03	$0.88	8.03
15	$7.03	$0.88	8.03
16	$7.74	$0.88	8.84

Retail Stand Alone

Table 154: First-Year Energy Impacts Per Square Foot, Retail Stand Alone

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	1.14	0.000	0.000	29.0
2	1.17	0.000	0.000	26.0
3	1.38	0.000	0.000	35.0
4	1.19	0.000	0.000	25.0
5	1.32	0.000	0.000	36.0
6	1.31	0.000	0.000	32.0
7	1.35	0.000	0.000	36.0
8	1.11	0.000	0.000	24.0
9	1.16	0.000	0.000	25.0
10	1.04	0.000	0.000	22.0
11	1.00	0.000	0.000	23.0
12	1.03	0.000	0.000	21.0
13	0.87	0.000	0.000	17.0
14	1.08	0.000	0.000	24.0
15	0.83	0.000	0.000	19.0
16	1.24	0.000	0.000	32.0

Table 155: Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Retail Stand Alone

Climate Zone	15 Year TDV Electricity Cost Savings (Nominal $)	15 Year TDV Natural Gas Cost Savings (Nominal $)	Total 15 Year TDV Energy Cost Savings (Nominal $)
1	$40.89	$0.00	$40.89
2	$36.66	$0.00	$36.66
3	$49.35	$0.00	$49.35
4	$35.25	$0.00	$35.25
5	$50.76	$0.00	$50.76
6	$45.12	$0.00	$45.12
7	$50.76	$0.00	$50.76
8	$33.84	$0.00	$33.84
9	$35.25	$0.00	$35.25
10	$31.02	$0.00	$31.02
11	$32.43	$0.00	$32.43
12	$29.61	$0.00	$29.61
13	$23.97	$0.00	$23.97
14	$33.84	$0.00	$33.84
15	$26.79	$0.00	$26.79
16	$45.12	$0.00	$45.12

Table 156: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Retail Stand Alone

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$2.58	$0.00	$2.58
2	$2.31	$0.00	$2.31
3	$3.12	$0.00	$3.12
4	$2.23	$0.00	$2.23
5	$3.20	$0.00	$3.20
6	$2.85	$0.00	$2.85
7	$3.20	$0.00	$3.20
8	$2.14	$0.00	$2.14
9	$2.23	$0.00	$2.23
10	$1.96	$0.00	$1.96
11	$2.05	$0.00	$2.05
12	$1.87	$0.00	$1.87
13	$1.51	$0.00	$1.51
14	$2.14	$0.00	$2.14
15	$1.69	$0.00	$1.69
16	$2.85	$0.00	$2.85

Table 157: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - RetailStandAlone

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Total Incremental PV Costs	
1	$2.58	$0.88	2.94
2	$2.31	$0.88	2.63
3	$3.12	$0.88	3.54
4	$2.23	$0.88	2.53
5	$3.20	$0.88	3.65
6	$2.85	$0.88	3.24
7	$3.20	$0.88	3.65
8	$2.14	$0.88	2.43
9	$2.23	$0.88	2.53
10	$1.96	$0.88	2.23
11	$2.05	$0.88	2.33
12	$1.87	$0.88	2.13
13	$1.51	$0.88	1.72
14	$2.14	$0.88	2.43
15	$1.69	$0.88	1.92
16	$2.85	$0.88	3.24

School Primary

Table 158: First-Year Energy Impacts Per Square Foot, School Primary

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.64	0.000	0.042	33.0
2	0.50	0.000	0.028	24.0
3	0.52	0.000	0.034	27.0
4	0.39	0.000	0.024	19.0
5	0.49	0.000	0.032	24.0
6	0.27	0.000	0.019	17.0
7	0.28	0.000	0.021	16.0
8	0.22	0.000	0.017	13.0
9	0.30	0.000	0.017	14.0
10	0.30	0.000	0.017	15.0
11	0.38	0.000	0.020	19.0
12	0.39	0.000	0.023	18.0
13	0.31	0.000	0.017	15.0
14	0.41	0.000	0.018	18.0
15	0.22	0.000	0.009	10.0
16	0.61	0.000	0.024	27.0

Table 159: Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, School Primary

Climate Zone	15 Year TDV Electricity Cost Savings (Nominal $)	15 Year TDV Natural Gas Cost Savings (Nominal $)	Total 15 Year TDV Energy Cost Savings (Nominal $)
1	$31.02	$15.62	$46.64
2	$22.56	$11.36	$33.92
3	$23.97	$14.20	$38.17
4	$16.92	$9.94	$26.86
5	$22.56	$11.36	$33.92
6	$15.51	$8.52	$24.03
7	$14.10	$8.52	$22.62
8	$11.28	$7.10	$18.38
9	$12.69	$7.10	$19.79
10	$14.10	$7.10	$21.20
11	$18.33	$8.52	$26.85
12	$16.92	$8.52	$25.44
13	$14.10	$7.10	$21.20
14	$18.33	$7.10	$25.43
15	$11.28	$2.84	$14.12
16	$28.20	$9.94	$38.14

Table 160: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, School Primary

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$1.96	$0.98	$2.94
2	$1.42	$0.71	$2.14
3	$1.51	$0.89	$2.40
4	$1.07	$0.62	$1.69
5	$1.42	$0.71	$2.14
6	$0.98	$0.53	$1.51
7	$0.89	$0.53	$1.42
8	$0.71	$0.45	$1.16
9	$0.80	$0.45	$1.25
10	$0.89	$0.45	$1.34
11	$1.16	$0.53	$1.69
12	$1.07	$0.53	$1.60
13	$0.89	$0.45	$1.34
14	$1.16	$0.45	$1.60
15	$0.71	$0.18	$0.89
16	$1.78	$0.62	$2.40

Table 161: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - SchoolPrimary

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Total Incremental PV Costs	
1	$2.94	$0.88	3.32
2	$2.14	$0.88	2.42
3	$2.40	$0.88	2.72
4	$1.69	$0.88	1.91
5	$2.14	$0.88	2.42
6	$1.51	$0.88	1.71
7	$1.42	$0.88	1.61
8	$1.16	$0.88	1.31
9	$1.25	$0.88	1.41
10	$1.34	$0.88	1.51
11	$1.69	$0.88	1.91
12	$1.60	$0.88	1.81
13	$1.34	$0.88	1.51
14	$1.60	$0.88	1.81
15	$0.89	$0.88	1.01
16	$2.40	$0.88	2.72

School Secondary

Table 162: First-Year Energy Impacts Per Square Foot, School Secondary

Climate Zone	Electricity Savings (kWh/ft²)	Peak Electricity Demand Reductions (kW/ft²)	Natural Gas Savings (therms/ft²)	TDV Energy Savings (TDV kBtu/ft²)
1	1.86	0.000	0.004	49.0
2	1.81	0.000	0.002	52.0
3	1.94	0.000	0.010	58.0
4	1.83	0.000	0.006	53.0
5	1.86	0.000	0.009	54.0
6	1.74	0.000	0.008	52.0
7	1.79	0.000	0.010	53.0
8	1.72	0.000	0.006	50.0
9	1.82	0.000	0.006	51.0
10	1.76	0.000	0.004	52.0
11	1.74	0.000	(0.002)	47.0
12	1.75	0.000	0.000	50.0
13	1.73	0.000	(0.001)	46.0
14	1.78	0.000	(0.002)	47.0
15	1.74	0.000	0.003	52.0
16	1.82	0.000	(0.011)	47.0

Table 163: Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, School Secondary

Climate Zone	15 Year TDV Electricity Cost Savings (Nominal $)	15 Year TDV Natural Gas Cost Savings (Nominal $)	Total 15 Year TDV Energy Cost Savings (Nominal $)
1	$69.09	$0.00	$69.09
2	$71.91	$1.42	$73.33
3	$77.55	$4.26	$81.81
4	$71.91	$2.84	$74.75
5	$73.32	$2.84	$76.16
6	$70.50	$2.84	$73.34
7	$71.91	$2.84	$74.75
8	$67.68	$2.84	$70.52
9	$70.50	$1.42	$71.92
10	$71.91	$1.42	$73.33
11	$67.68	($1.42)	$66.26
12	$70.50	$0.00	$70.50
13	$66.27	($1.42)	$64.85
14	$67.68	($1.42)	$66.26
15	$71.91	$1.42	$73.33
16	$70.50	($4.26)	$66.24

Table 164: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, School Secondary

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$4.36	$0.00	$4.36
2	$4.54	$0.09	$4.63
3	$4.90	$0.27	$5.16
4	$4.54	$0.18	$4.72
5	$4.63	$0.18	$4.81
6	$4.45	$0.18	$4.63
7	$4.54	$0.18	$4.72
8	$4.27	$0.18	$4.45
9	$4.45	$0.09	$4.54
10	$4.54	$0.09	$4.63
11	$4.27	($0.09)	$4.18
12	$4.45	$0.00	$4.45
13	$4.18	($0.09)	$4.09
14	$4.27	($0.09)	$4.18
15	$4.54	$0.09	$4.63
16	$4.45	($0.27)	$4.18

Table 165: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - SchoolSecondary

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per ft2	Total Incremental PV Costs	
1	$4.36	$0.88	4.93
2	$4.63	$0.88	5.24
3	$5.16	$0.88	5.84
4	$4.72	$0.88	5.34
5	$4.81	$0.88	5.44
6	$4.63	$0.88	5.24
7	$4.72	$0.88	5.34
8	$4.45	$0.88	5.03
9	$4.54	$0.88	5.13
10	$4.63	$0.88	5.24
11	$4.18	$0.88	4.73
12	$4.45	$0.88	5.03
13	$4.09	$0.88	4.63
14	$4.18	$0.88	4.73
15	$4.63	$0.88	5.24
16	$4.18	$0.88	4.73

Hotel Small

Table 166: First-Year Energy Impacts Per Home / Dwelling Unit / Square Foot, Hotel Small

Climate Zone	Electricity Savings (kWh/ft^2)	Peak Electricity Demand Reductions (kW/ft^2)	Natural Gas Savings (therms/ft^2)	TDV Energy Savings (TDV kBtu/ft^2)
1	0.54	0.000	(0.007)	13.0
2	0.67	0.000	(0.004)	17.0
3	0.70	0.000	(0.003)	18.0
4	0.71	0.000	(0.003)	18.0
5	0.67	0.000	(0.003)	18.0
6	0.77	0.000	(0.001)	21.0
7	0.76	0.000	(0.001)	20.0
8	0.78	0.000	(0.001)	21.0
9	0.78	0.000	(0.002)	20.0
10	0.76	0.000	(0.002)	18.0
11	0.73	0.000	(0.004)	18.0
12	0.68	0.000	(0.004)	16.0
13	0.72	0.000	(0.004)	17.0
14	0.80	0.000	(0.004)	19.0
15	0.81	0.000	(0.001)	22.0
16	0.79	0.000	(0.007)	20.0

Table 167: Nominal TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Hotel Small

Climate Zone	15 Year TDV Electricity Cost Savings (Nominal $)	15 Year TDV Natural Gas Cost Savings (Nominal $)	Total 15 Year TDV Energy Cost Savings (Nominal $)
1	$21.15	($2.84)	$18.31
2	$25.38	($1.42)	$23.96
3	$26.79	($1.42)	$25.37
4	$26.79	($1.42)	$25.37
5	$26.79	($1.42)	$25.37
6	$29.61	$0.00	$29.61
7	$29.61	($1.42)	$28.19
8	$29.61	$0.00	$29.61
9	$29.61	($1.42)	$28.19
10	$26.79	($1.42)	$25.37
11	$26.79	($1.42)	$25.37
12	$25.38	($2.84)	$22.54
13	$25.38	($1.42)	$23.96
14	$29.61	($2.84)	$26.77
15	$31.02	$0.00	$31.02
16	$31.02	($2.84)	$28.18

Table 168: 2023 TDV Energy Cost Savings Over 15 Year Period of Analysis – Per Square Foot – New Construction, Hotel Small

Climate Zone	15 Year TDV Electricity Cost Savings (2023 $)	15 Year TDV Natural Gas Cost Savings (2023 $)	Total 15 Year TDV Energy Cost Savings (2023 $)
1	$1.34	($0.18)	$1.16
2	$1.60	($0.09)	$1.51
3	$1.69	($0.09)	$1.60
4	$1.69	($0.09)	$1.60
5	$1.69	($0.09)	$1.60
6	$1.87	$0.00	$1.87
7	$1.87	($0.09)	$1.78
8	$1.87	$0.00	$1.87
9	$1.87	($0.09)	$1.78
10	$1.69	($0.09)	$1.60
11	$1.69	($0.09)	$1.60
12	$1.60	($0.18)	$1.42
13	$1.60	($0.09)	$1.51
14	$1.87	($0.18)	$1.69
15	$1.96	$0.00	$1.96
16	$1.96	($0.18)	$1.78

Table 169: 15-Year Cost-effectiveness Summary Per Square Foot – New Construction - HotelSmall

Climate Zone	Benefits	Costs	Benefit-to-Cost Ratio
	2023 PV $ Energy Cost Savings + Other PV Savings per ft^2	Total Incremental PV Costs	
1	$1.16	$0.88	1.32
2	$1.51	$0.88	1.73
3	$1.60	$0.88	1.83
4	$1.60	$0.88	1.83
5	$1.60	$0.88	1.83
6	$1.87	$0.88	2.13
7	$1.78	$0.88	2.03
8	$1.87	$0.88	2.13
9	$1.78	$0.88	2.03
10	$1.60	$0.88	1.83
11	$1.60	$0.88	1.83
12	$1.42	$0.88	1.63
13	$1.51	$0.88	1.73
14	$1.69	$0.88	1.93
15	$1.96	$0.88	2.24
16	$1.78	$0.88	2.03

Appendix H: DOAS Manufacturers Technical Capabilities

24 manufacturers products were reviewed to understand the product availability for different DOAS units and the energy efficiency components. Of the commercial units reviewed, all 24 manufactures had a system which could meet the minimum prescriptive requirements proposed by the code change proposal. 13 of the 24 manufactures offered products which would also meet the requirements of item 1 with regards to ventilation heat recovery and bypass or free cooling control capabilities.

	DOAS Types			**DOAS Criteria for Code Proposal**				
	HRV	**ERV**	**DX-DOAS**	**Free Cooling or Bypass**	**Meet or Exceed Heat Recovery**	**Modulating Fan Option**	**Meets Minimum Criteria**	**Meets Criteria for item 1**
Manufacturer 1	Yes			Yes	Yes	Yes	Yes	Yes
Manufacturer 2	Yes	Yes	Yes	Optional	Yes	Optional	Yes	Yes
Manufacturer 3	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Manufacturer 4	Yes	Yes		No	Yes	Optional	Yes	No
Manufacturer 5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Manufacturer 6	Yes			Optional	Yes	Optional	Yes	Yes
Manufacturer 7		Yes		Yes	Yes	Yes	Yes	Yes
Manufacturer 8	Yes			No	Yes	Optional	Yes	No
Manufacturer 9	Yes	Yes		No	Yes	Optional	Yes	No
Manufacturer 10		Yes		Yes	Yes	Yes	Yes	Yes
Manufacturer 11	Yes	Yes		No	Yes	Optional	Yes	No
Manufacturer 12	Yes			No	Yes	Optional	Yes	No
Manufacturer 13	Yes	Yes		No	Yes	Optional	Yes	No
Manufacturer 14	Yes	Yes		No	Yes	Optional	Yes	No
Manufacturer 15			Yes	n/a	No	Yes	Yes	No
Manufacturer 16			Yes	Optional	Optional	Optional	Yes	Yes
Manufacturer 17			Yes	n/a	No	Yes	Yes	No
Manufacturer 18			Yes	Optional	Optional	Optional	Yes	Yes
Manufacturer 19			Yes	Optional	Optional	Optional	Yes	Yes
Manufacturer 20			Yes	Optional	Optional	Optional	Yes	Yes
Manufacturer 21	Yes		Yes	Optional	Yes	Optional	Yes	Yes
Manufacturer 22			Yes	n/a	No	Yes	Yes	No
Manufacturer 23	Yes	Yes	Yes	Optional	Yes	Optional	Yes	Yes
Manufacturer 24			Yes	n/a	No	Yes	Yes	No

Appendix I: DOAS Incremental Cost References

Incremental costs were estimated for the proposed DOAS efficiency components. This included:

- Incremental costs for item 1, including bypass or free cooling controls with energy recovery DOAS units.
- Incremental cost for item 2, DOAS units with modulating fan speed controls.
- Incremental cost for item 4, additional duct work or duct configurations to enable terminal unit fans to have separate supply pathways for terminal unit fans to cycle off.

Item 3 stipulates meeting or exceeding the fan power requirement already set in code for larger systems and now for smaller fan systems and is considered to not have any incremental cost.

Item 5 sets reheat requirements on DOAS units with active cooling and is considered a controls configuration which can be done as part of a typical installation and not increase the cost of a system.

Cost Sources

Item 1

For estimating the incremental cost for item 1 several DOAS unit costs were gathered from equipment representatives in California and construction projects of nonresidential buildings. Costs were normalized to a cost per airflow (cfm) using the DOAS unit's nominal airflow rating.

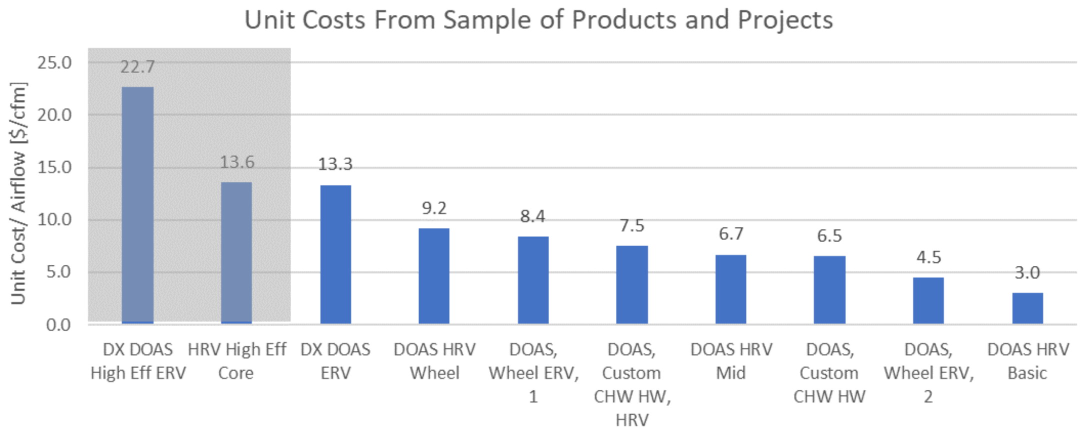


Figure 19: Comparison of DOASu capabilities and relative costs per cfm

Two products were selected with higher efficiency components and were not included in the incremental cost estimate. The majority of DOAS products come standard with an energy or heat recovery device. To estimate the cost of including bypass or free cooling controls the 8 product costs were averaged and an additional 15 percent was assumed to be a conservative assumption for the cost of including this capability. This equates to an average of $1.11/cfm and is applied as a flat cost assuming 0.15 cfm/sf to be $0.17/sf incremental costs.

Item 2

Item 2 was estimated from an incremental cost study of ECM vs conventional motors for fans from Excel Energy. This data estimated an incremental cost of a 5 hp system to be $918 or $184/hp. On larger sized systems this cost ratio decreased. To make a conservative assumption $184/hp was assumed as the highest cost. Motor size was converted to airflow based on using an assumption of a DOAS fan operating at 4" and 60 percent fan efficiency. This resulted in a fan size of 4,767 cfm which equates to an incremental cost of $0.039/cfm. This cost was then applied to each prototype model based on the ventilation per building floor area.

Item 4

The duct work for DOAS and terminal unit supply and return was obtained from an itemized medium office with DOAS and VRF with a mix of VRF air handling units and wall mounted cassettes. The cost of the DOAS ventilation duct work and heating and cooling duct work was normalized using the projects floor area. This equated to the ventilation duct work being $0.70/sf and the zone distribution duct work $7.0/sf. To estimate the incremental cost of requiring terminal units to cycle to off when there is no active call for heating and cooling the cost of ducting ventilation to a room independent of the heating and cooling was assumed to be the primary cost requirement.

The distribution duct work was assumed to require an increase in cost by 10 percent. Because this would only apply to some projects as DOAS configurations today may already have separate duct configurations the cost is conservative.

Ventilation Only Duct Work	$0.70	$/SF
Zone Distribution Duct Work	$7.00	$/SF
Site Cost for Duct Work	$7.70	$/SF
Additional Ducting Routing, assume 10% of Zone Distribution	$0.70	$/SF

Combined Incremental Costs

The incremental costs of each component were applied to the individual prototype buildings to estimate the total incremental cost per square foot.

Building Prototype	Ventilation cfm/ft^2	Item 1 Cost [\$/ft^2]	Item 2 Cost [\$/ft^2]	Item 4 Cost [\$/ft^2]	Total Incremental Cost per Building [\$/ft^2]
OfficeSmall	0.15	$0.17	$0.01	$0.70	$0.876
OfficeLarge	0.15	$0.17	$0.01	$0.70	$0.876
OfficeMedium	0.15	$0.17	$0.01	$0.70	$0.876
RetailStandAlone	0.23	$0.17	$0.01	$0.70	$0.879
RetailLarge	0.23	$0.17	$0.01	$0.70	$0.879
SchoolPrimary	0.35	$0.17	$0.01	$0.70	$0.884
SchoolSecondary	0.35	$0.17	$0.01	$0.70	$0.884
HotelSmall	0.15	$0.17	$0.01	$0.70	$0.876

Appendix J: DOAS Heat Recovery Ventilation Data Source

Ventilation Energy Recovery

Product data from AHRI test 1060 provides both full energy recovery and by components, sensible and latent. In California, the primary benefits of ventilation energy recovery considered focus on dry heat due to the relatively low humidity levels. The sensible data was reviewed to assess the number of products able to achieve different levels of sensible energy recovery. Heat recovery ventilation devices are split primarily into three types of systems in the market, core devices (referred to as plates), wheel devices, and heat pipes. Wheels tend to be selected as a space saving opportunity though tend to move air at higher velocities and have different performance characteristics than core energy recovery components.

Based on reviewing this data, most wheel energy recovery products achieve 60 percent or higher net sensible energy recovery. Plate packages and components tend to reach 60 percent or higher in 2/3 of products. Exact counts by effectiveness level and count are shown below:

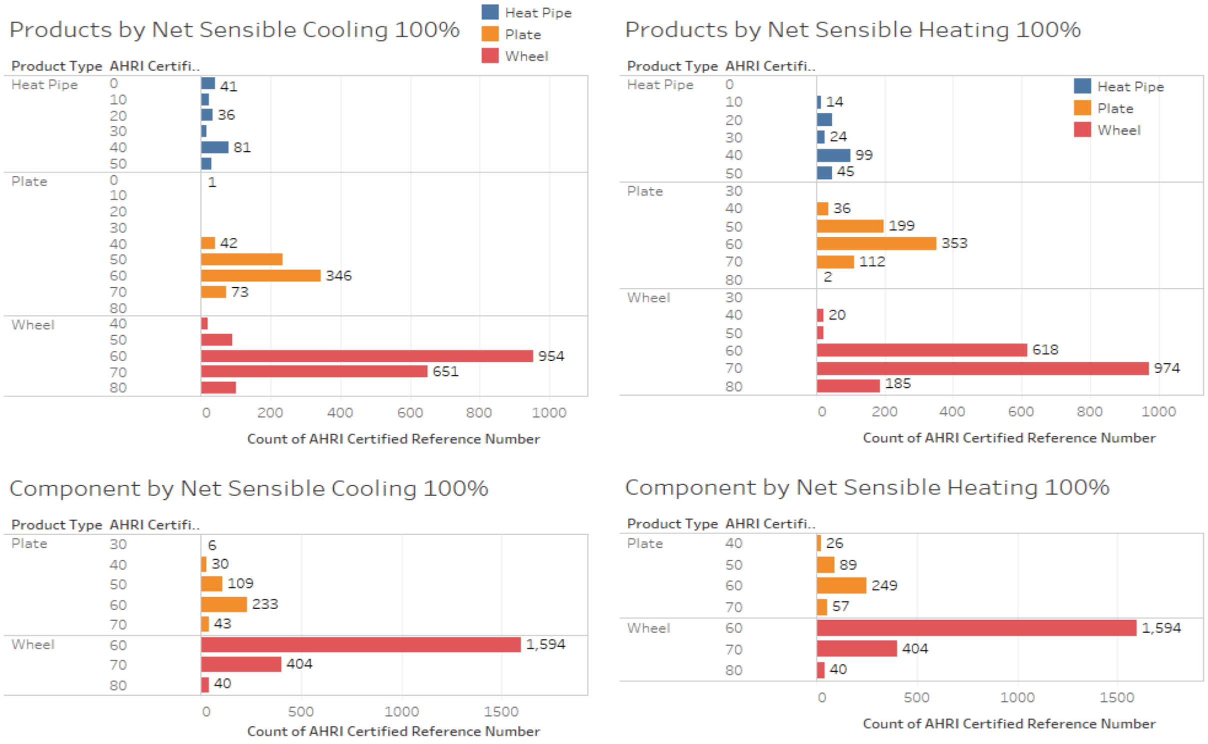
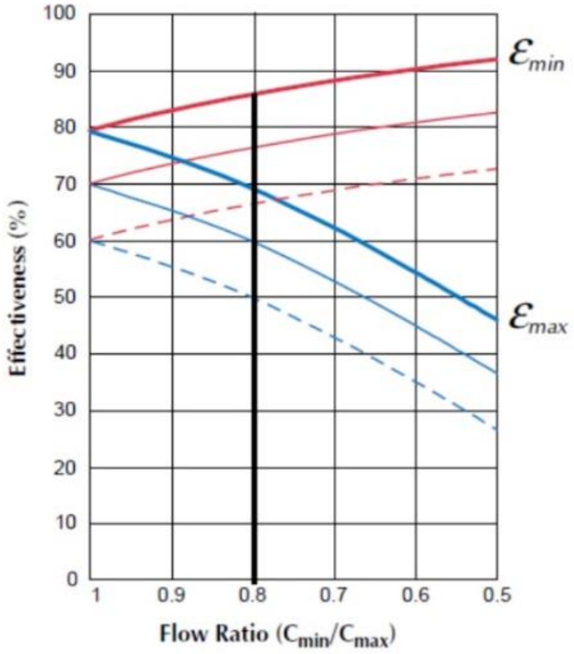


Figure 20: AHRI data on ventilation air to air recovery units.

In DOAS units, the actual energy recovery opportunity depends on this effectiveness level and on the airstreams of incoming air and relief air. If these streams are unbalanced due to, for example bathroom exhaust leaving through another location, the overall amount of energy recovery would be reduced as there is less air to recovery energy from. ASHRAE fundamentals developed this chart to relate the impacts of unequal flows on overall system effectiveness. Highlighted is systems at 80 percent unbalanced flow. A unit normally able to recover 70 percent effectiveness now would be the equivalent of 60 percent effective if 80 percent unbalanced.

This information was used to establish a threshold for product availability at different effectiveness levels.



Impact of Unequal Flows on Effectiveness

Figure 21: Effectiveness to flow ratio of supply and return, ASHRAE.

Appendix K: DOAS Energy Modeling Analysis for DOAS Proposed Verses Market Reference DOAS

The following energy modeling process was utilized to develop the energy use and differences between the DOAS Proposed configuration and the Market Reference DOAS configurations. The CASE Report includes more detail as to the different reference configurations used. This appendix documents the steps taken to build each model. A separate set of analysis was done for the DOAS economizer exception and included in a different appendix. The following key energy modeling elements were modeled for all DOAS using EnergyPlus 9.0.1:

1. Ventilation was provided by separate air terminal units, either constant volume or variable air volume controlled to constant volume depending on the prototype.
2. Ventilation was configured to provide any source of heating or cooling first. This is a configuration criterion in EnergyPlus to ensure the thermal loads are correctly captured.
3. All VRF, Fan Coil, Mini Split, or RTU systems used in combination with a DOAS were configured to not directly bring in outside air, which is the default for all zone system types like this in CBECC-Com.
4. DOAS fans were controlled to be constant volume systems.
5. Zone terminal fan pressure drop was set to the fan coil pressure drop per the ACM for all VRF fan coils and four pipe fan coils.
6. All ventilation heat recovery was assumed to operate at 60 percent sensible energy recovery at 100 percent airflow and 65 percent sensible energy recovery at 75 percent flow. Only sensible energy recovery was simulated to maintain conservative estimates.
7. In DX-DOAS units the supply air was set to a reset based on outside air temperature.
8. In HRV-DOAS the supply air setpoint was fixed.
9. In all DOAS with bypass controls the supply air setpoint bypass control was used as the only means of controlling the bypass. This control best reflects how these would operate with real loads.
10. Ducted terminal unit fans were simulated with multi-speed fans in select VRF systems and some with constant volume fans. The primary field configuration is multi-speed fans which continuously ventilate at lower volumes based on sites surveyed.
11. All DOAS were sized to ventilation only. Default DOAS in CBECC-Com are sized for full sensible cooling and over ventilate, over cool, and utilize more fan energy.
12. Fan pressure drops were calculated based on the current fan credit allowance with a deduction for any HRV without heating or cooling coils and an increase for all DOAS with a heat recovery ventilation unit.

Appendix L: Supplemental Report of DOAS Energy Equivalency with Mixed Air Systems with Airside Economizers

Document Summary and Intent

This document is a support document to the nonresidential HVAC controls for Title 24, Part 6 2022 Codes and Standards Enhancement (CASE) Report. The CASE Report covers several HVAC enhancements, one of which is Dedicated Outdoor Air Systems (DOAS).

The CASE Report on DOAS provides statewide context for why DOAS should be added as a new prescriptive section to Title 24, Part 6 2022 and what minimum energy efficiency criteria should be included. The CASE Report primarily evaluates the impact of adding regulation to any DOAS installation verses market research of how DOAS is installed today. The report also includes a recommendation to add an exception for specific DOAS configurations to not require an airside economizer as a means of expanding the prescriptive HVAC options the market. While performance compliance offers a means for more whole building trade-offs the economics of utilizing the performance pathway in project costs and project teams is often limited and not utilized, particularly in small nonresidential construction. This exception creates a mechanism by which operational energy cost is maintained or improved and simplifies the compliance documentation hurtle necessary. Further, this exception is anticipated to enhance access for small nonresidential buildings to all-electric, low-energy operational cost HVAC with many DOAS configurations being available with all-electric heating sources.

This document provides supplemental information on how DOAS was evaluated for energy cost equivalency with minimally code compliant buildings that include airside economizers. The report provides information based on the energy models, the metrics for statewide energy cost compliance and source energy, and the results of this analysis.

Separate energy analysis was done for statewide DOAS energy savings of the proposed code enhancements vs the market typical DOAS installed today. The basis for those energy models and results are included in the CASE Report itself.

Code language enhancements for DOAS are included in a CASE Report outside this document and in a stand-alone memo if requested.

Basis of DOAS Energy & Carbon Savings

DOAS provide a means to reduce building carbon emissions and reduce or maintain a level of operational cost equivalences with code compliant mixed-air HVAC systems. In mild and dry climates such as California, DOAS configurations with only sensible heat recovery ventilation (HRV) perform the best by relying on outdoor air to remove indoor moisture build-up. While there are many configurations of DOAS, core fundamentals do exist for how to make all configurations minimally energy efficient, including:

1. In small buildings, DOAS fans with modulating fan speed control can be properly balanced even if operating in a constant volume mode. The ability to balance a unit by adjusting the fan speed verses increasing the systems static pressure is critical when matching a DOAS units rated airflow capacity with a building designs specified airflow.
2. In larger buildings, controlling the DOAS fan to respond to duct static pressure or equivalent signal for demand control ventilation at specific zones required by code is a way to reduce overall fan energy in the system.
3. Separate ventilation pathway to supply each space from the cooling and heating system to allow a cooling and heating fan unit to cycle on and off.
4. Ventilation energy recovery, using a wheel, fixed plate, or other means, can reduce ventilation peak demand in winter and summer.
5. Ventilation inlet bypass control to stop energy recovery during mild outdoor air conditions provides a level of ventilation airside economizing.
6. An increased level of ventilation airflow, even when operated at full flow during occupied hours, can provide an increased level of ventilation airside economizing as well as provide future flexibility for building renovation or changes in use.

In California, a DOAS HVAC configuration can save energy in two ways:

3. DOAS would save on heating energy from ventilation heat recovery. Compared to mixed air systems with multi-zone reheat, a DOAS HVAC configuration would also eliminating space conditioning reheat with an HRV-DOAS or, minimizing system reheat with a DX-DOAS.
4. DOAS saves cooling peak demand by reducing the thermal cooling load with ventilation heat recovery. Compared to a mixed air system with multi-zone reheat, a DOAS HVAC configuration provides zone level cooling and can further reduce peak cooling loads by eliminating over-cooling of spaces during peak times.

Fundamentally, the largest challenges for DOAS to be as efficient as a mixed-air system is driven by two criteria:

1. Maintaining a level of fan energy with fan speed control of the DOAS unit and of space terminal units and
2. How ventilation supply air temperature is controlled and how dehumidification is managed.

In large buildings, DOAS with zone cooling can utilize waterside economizing if built around a chilled water plant and hydronic solution. In smaller buildings, DOAS with zone cooling loses the ability to airside economize but gains the ability to utilize sensible-only cooling which can have greater thermal efficiency than a cooling system which must also dehumidify. Multi-speed compression or variable refrigerant flow systems utilizing active refrigerant controls can adjust refrigerant pressures and temperatures to best match thermal loads and reduce compressor power. Air to water heat pumps can be selected and designed to always provide low ambient water temperatures and use less power. Secondarily, DOAS with zone systems are often able to utilize low lift heat pumps for heating, increasing the thermal efficiency by 300 percent to 500 percent compared with a natural gas furnace or electric boiler.

While the lack of full airside economizing is impactful in site energy, overall, it is a small difference in terms of source energy and carbon emissions. The increases in cooling energy when a mixed air system would otherwise be economizing coincide with the mid-day, when renewable energy is peaking. Based on the long term life cycle cost metric, represented by the Time Dependent Value metric, this time of day has a lower cost than morning and late afternoon periods.

Based on the items outlined, energy estimates of common DOAS configurations and an equivalent mixed-air system with an economizer were evaluated in each California climate to assess the overall energy use differences. The evaluation was completed using the life-cycle operational cost metrics developed and maintained by the Energy Commission known as Time-Dependent-Values (TDV) which are in draft form for 2022. Source energy was also included and is being considered as a secondary metric by the Energy Commission for energy compliance along with TDV. A section on metrics is included with additional detail.

Common Definition of DOAS

This definition is repeated from the CASE Report for completeness.

Dedicated Outdoor Air Systems (DOAS) as it relates to energy codes refers to an HVAC system and not just individual products or components. A common definition has been developed as part of the CASE 2022 HVAC controls measure as follows:

> **Dedicated Outdoor Air Systems (DOAS)** – An HVAC system which uses separate equipment to condition, temper, or filter all the outdoor air brought into a building for ventilation and delivers it to each space, either directly or in conjunction with local or central HVAC units serving those same spaces used to maintain space temperature.

Based on this definition, a DOAS unit would include products such as energy recovery ventilators (ERV), heat recovery ventilators (HRV), packaged DOAS or DX-DOAS units, etc. ASHRAE 90.1, 2018, provides a definition of a DX-DOAS unit as follows:

DX-Dedicated Outdoor Air System units (DX-DOAS units)- a type of air-cooled, water-cooled, or water-source factory assembled product that dehumidifies 100 percent outdoor air to a low dew point and includes reheat that is capable of controlling the supply dry-bulb temperature of the dehumidified air to the designed supply air temperature. This conditioned outdoor air is then delivered directly or indirectly to the conditioned spaces. It may precondition outdoor air by containing an enthalpy wheel, sensible wheel, desiccant wheel, plate heat exchanger, heat pipes, or other heat or mass transfer apparatus.

The intent of the proposed code enhancement would be to set minimum efficiency criteria which could be meet by all DOAS configurations through different means of built-in controls or additional control and configurations in design and construction.

Parameters of DOAS Included in Analysis

As part of the Statewide CASE Team's Title 24, Part 6 2022 HVAC controls measure, several parameters of DOAS were considered in the energy analysis and the proposed code language. Below is a list of the parameters considered and the assumptions made for each:

DOAS Parameters	Basis for Parameter Specified
DOAS Unit Fan Power	System pressure determined by component, based on CASE 2022 Fan Power tables. Provided a means for adjusting the TSP based on system size and detailed components. Same tables used to define mixed-air TSP for system comparison.
DOAS Unit Fan Speed Control	For units above 1,000 cfm, variable volume to 20% minimum based on zone airflow signals for outdoor air if DCV or occupancy shut-off is required.
Zone Cooling System Fan Power	Title 24 Alternate Compliance Manual assumption of 1.3 inches (317 PA) assumed for FPFC used for all terminal unit fans.
Zone Cooling System Fan Control	Cycling fans for all terminal units, set to off by default, activated with thermostat request.
System sequencing for cooling and heating	Ventilation set to provide cooling and heating first. Required to ensure all thermal loads are satisfied each timestep. Provides an accurate way to account for ventilation economizing if available.
Ventilation Air Delivery to Zone	Ventilation delivered separate from heating and cooling. Use of variable volume control in zones requiring DCV or occupancy shut-off. Use of fixed airflow to outdoor air in all other zones.
DOAS Supply Air Temperature Control	Fixed SAT setpoint in HRV and ERV systems. SAT reset in DOAS with active cooling based on Outdoor Air.
DOAS Heat Recovery Efficiency	Minimum sensible energy recovery for heating and cooling.

DOAS Parameters	**Basis for Parameter Specified**
DOAS Heat Recovery bypass control	Bypass control based on OA between economizer lower and upper limits and based on supply air temperature. Both controls necessary only in energy modeling to represent how systems operate where thermal loads are more gradual verses simulated thermal loads with step changes.
DOAS Heat Recovery economizer limits	Upper limit set based on economizer upper limit of 75F dry bulb. Lower limit included for proper representation of how DOAS are configured of 55F.
DOAS Reheat Limit for DX-DOAS	Supply air temperature reset controls on cooling coil discharge temperature and on heating coil discharge temperature. This allowed for reheat to be included when the unit was in cooling mode.
Cooling and Heating Equipment Efficiencies	Title 24 rated minimum efficiencies were used for all equipment, removing fan energy from any EER or COP number for proper inclusion in energy models.
Zone Ventilation Airflow Control	Zones with DCV or occupancy shut-off requirements included a schedule for the time of use to adjust ventilation airflow to match occupancy.
Zone Ventilation Airflow Quantities	Ventilation was increased at design conditions by 1.5 in DOAS configurations for each zone.

Philosophy of Energy Modeling for This Analysis

This analysis uses energy modeling to represent the HVAC systems as they would be designed and installed if multi-speed or variable speed airflow was required and airside economizing was required with the limits of control and capabilities set by the energy 2019 Title 24, Part 6 Standard. Prototypes were used to be representative of small or medium buildings to capture single zone or multi-zone systems. The models themselves are assumed to be relative examples of buildings, and not finite in their attributes of floor area or resulting system thermal capacity. In small buildings with small zones, systems were modeled with multi-speed fans and airside economizers, regardless of the capacity calculated by the energy model being above a threshold of a Btu limit. This is a different approach than traditional prototype modeling, where the finite attributes of the prototype result in the selection and limits of the HVAC system based on capacities.

Energy Modeling and Analysis Process

Energy models were built to estimate the energy use and savings from a market standard DOAS to the proposed standard code change DOAS and, models were compared with the current mixed-air standard design system for each building type to evaluate the economizer exception option.

Comparison of Building & Systems Process

1. Selected representative prototypes already built for nonresidential sectors.
2. Gathered market intelligence on how DOAS-HVAC is configured most-commonly in California nonresidential buildings.
3. Develop multiple cooling and heating configurations with DOAS to develop a conservative configuration for energy use which represents common and potentially, worst case scenarios.

Energy Model Creation Process

DOAS Models

This diagram is an example work-flow. Specific detail for each building type and HVAC system followed similar steps.

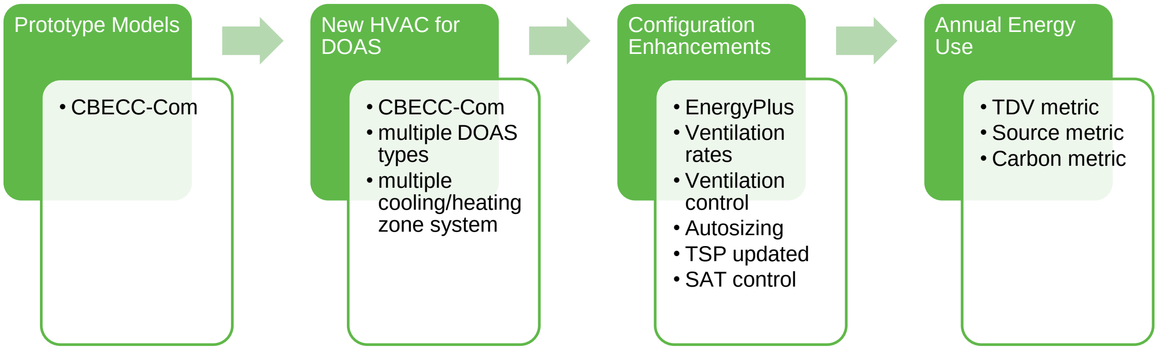


Figure 22: Diagram illustrating work-flow DOAS systems

Mixed-Air Models

This diagram is an example work-flow. Specific detail for each building type and HVAC system followed similar steps.

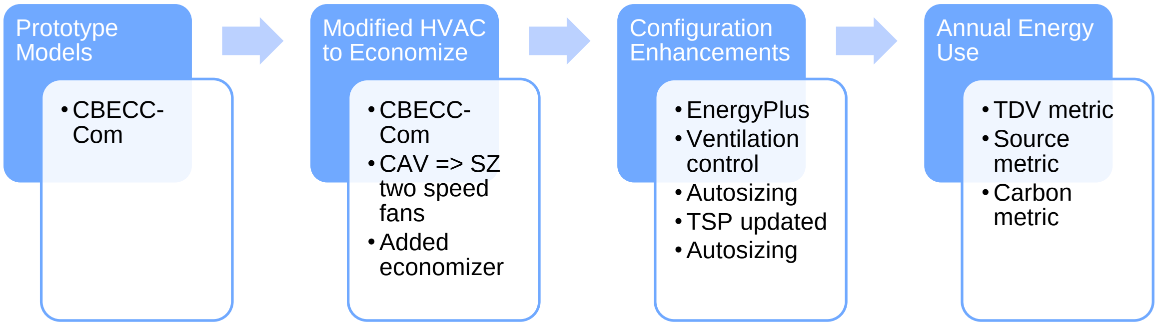


Figure 23: Diagram illustrating work-flow mixed-air systems

The method used to evaluate this comparison is presented as a recommendation to the Energy Commission as there is no formal method for this type comparison. An exception to the economizer requirement is recommended for Dedicated Outdoor Air Systems (DOAS) that meet the following criteria:

1. Ventilation heat recovery with bypass capabilities.
2. Increased design ventilation to 150 percent of the sum of ventilation and exhaust needs for the space(s) served.

To evaluate the energy use, two system types were applied to nonresidential prototype energy models:

1. Mixed air system with economizers.
2. DOAS with separate heating and cooling systems and no economizers.

In addition, demand-controlled ventilation (DCV) and occupancy-based controls were applied to models that contain spaces where these controls are required by code.

Each prototype was modified to include a system with an economizer which also matched the building size and scale. For instance, the small office building utilized

SZVAV with modulating fans and economizers as described by the ACM. Economizers were included on all SZVAV, regardless of size, since the purpose of the analysis is to compare mixed air systems with economizers to DOAS without economizers.

Each model was configured with several types of DOAS and several types of separate heating and cooling systems. Both items were configured to capture a conservative case and, where possible, only represent higher energy configurations to make a comparison.

The following models have been developed for this comparison. Additional detail is included in the next table for primary systems of this report. Detailed tables of inputs are in the appendix.

HVAC Configuration	Office Small	Office Medium	School Primary	School Secondary	Retail Stand Alone	Hotel Small
Mixed-Air Economizer						
SZPU RTU with Economizers	x		x			
SZPU HP with Economizers	x					
VAV Reheat, DX, Economizers		x		x		x
VAV Reheat, CHW, Economizers				x		
Reduced Equipment, VAV Reheat, DX, Economizers		x				
DOAS Systems						
HRV-DOAS with VRF	x	x				x
DX-DOAS with VRF	x	x	x	x		x
HP-DOAS with VRF		x		x		x
HRV-DOAS with Mini Splits	x					
HRV-DOAS with RTUs	x					
HRV-DOAS with FPFC		x				
Reduced Equipment, DX-DOAS with VRF		x				

These configurations of DOAS were assumed to be the highest energy intensive uses of DOAS and separate space heating and cooling as well as the most predominant in construction throughout CA. Other types using more hydronic systems are utilized though primarily in medium offices and larger buildings. A representative four pipe fan coil configuration was built and found to be one of the most efficient configurations of DOAS compared with other configurations. Based on this test, additional hydronic DOAS models were not assessed.

Energy Modeling Key Inputs and Assumptions

Below are the system configurations for major features for the economizer mixed air systems and the DOAS systems. Additional information provided in appendix tables including fan rated power, heating and cooling nominal efficiencies, and other key information.

Where DCV or occupancy based sensors are required per Title 24 they were included in both the DOAS and mixed air systems as this would be required regardless of the primary HVAC configuration.

		HVAC System Components	Ventilation Conditioning		Fan Type	Fan Airflow Control	Ventilation Amount	Supply Air Setpoint	Ventilation Heat Recovery System	Zone Fan Airflow Control
			Heat	Cool						
Medium Office Building	Mixed Air Economizer	VAV with Reheat and DX Cooling	n/a	DX-Coil	Variable Speed	DCV & Pressure Setpoint Reset	Code Min	SAT Reset based on Zone, 5 deg F	none	n/a
	DOAS Design	HRV (DOAS) with FPFC, Chiller, Boiler	none	none	Variable Speed	DCV & Pressure Setpoint Reset	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		HRV (DOAS) with Air-Source VRF	none	none	Variable Speed	DCV & Pressure Setpoint Reset	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		DX-DOAS with Air-Source VRF	Furnace	DX-Coil	Variable Speed	DCV & Pressure Setpoint Reset	1.5 x Code	DX-DOAS SAT Reset, Cooling and Reheat	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		DX-DOAS heat pump with Air-Source VRF	Heat Pump	DX-Coil	Variable Speed	DCV & Pressure Setpoint Reset	1.5 x Code	DX-DOAS SAT Reset, Cooling and Reheat	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
Small Office	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	Furnace	DX-Coil	Two-Speed Fans	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	Code Min	Single Zone Reset to Thermostat	none	n/a

		HVAC System Components	Ventilation Conditioning		Fan Type	Fan Airflow Control	Ventilation Amount	Supply Air Setpoint	Ventilation Heat Recovery System	Zone Fan Airflow Control
			Heat	Cool						
		Two Speed Single Zone Heat Pump Units	Heat Pump	DX-Coil	Two-Speed Fans	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	Code Min	Single Zone Reset to Thermostat	none	n/a
	DOAS Design	HRV (DOAS) with Mini-Splits	none	none	Constant Volume	n/a	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		HRV (DOAS) with RTUs	none	none	Constant Volume	n/a	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		HRV (DOAS) with Air-Source VRF	none	none	Constant Volume	n/a	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
		DX-DOAS with Air-Source VRF	Furnace	DX-Coil	Constant Volume	n/a	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat

		HVAC System Components	Ventilation Conditioning		Fan Type	Fan Airflow Control	Ventilation Amount	Supply Air Setpoint	Ventilation Heat Recovery System	Zone Fan Airflow Control
			Heat	Cool						
Primary School Building	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	Furnace	DX-Coil	Two-Speed Fans	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	Code Min	Single Zone Reset to Thermostat	none	n/a
	DOAS Design	DX-DOAS with Air-Source VRF	Furnace	DX-Coil	Variable Volume	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	1.5 x Code	DX-DOAS SAT Reset, Cooling and Reheat	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
Secondary School	Mixed Air Economizer Design	VAV with Reheat and CHW Cooling Coil	n/a	CHW Plant	Variable Volume	DCV & Pressure Setpoint Reset	Code Min	SAT Reset based on Zone, 5 deg F	none	n/a
	DOAS Design	HRV (DOAS) with Air-Source VRF	none	none	Variable Volume	DCV & Pressure Setpoint Reset	1.5 x Code	Constant SAT Setpoint	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat
	DOAS Design	DX-DOAS with Air-Source VRF	DX-Coil	Furnace	Variable Volume	DCV & Pressure Setpoint Reset	1.5 x Code	SAT Reset at Cooling, SAT Reset at Fan/ Reheat	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Cycle On/Off by Thermostat

Metrics for Evaluation of DOAS Economizer Exception

For California code compliance, end uses for electricity and gas of regulated loads are compared from a standard model to a proposed model using a metric called Time Dependent Values (TDVs) for each fuel type and climate zone. TDV represents the life cycle cost of energy for the building type (nonresidential or residential) and specific fuel type. While there are many factors that go into TDV, it overall represents the anticipated cost of energy owners would experience over the life of the building based on forecasts of the energy sector.

A second metric which is being considered by the Energy Commission for 2022 compliance though has not yet been adopted is Source Energy. Source energy multipliers for each climate zone and fuel type have been developed by the Energy Commission and published in a draft form. The Energy Commission is considering adopting both metrics, requiring buildings to meet a TDV limit and meet a Source Energy limit. Source energy, while not a direct indicator of greenhouse gas emissions, does track very closely with greenhouse gas emissions based on statements made by the Energy Commission during metric workshops. A separate carbon metric has also been developed by climate zone and fuel type along with TDV and source though is not currently planned to be used. Since it is the intention for California to move towards zero carbon buildings all metrics were included in this analysis for demonstration purposes of the potential difference between DOAS and mixed-air HVAC.

Annual TDV for 2022

For the 2022 Title 24 code cycle the energy cost metrics of electricity and gas underwent a significant upgrade to reflect the current time of use trends and future forecasts of changing energy costs. The weather files for each location were also updated to capture more recent weather patterns for California typical climates which are in-line with forecasted trends of temperature in the future. For the energy cost metrics, the overall cost of electricity per unit decreased and the overall cost of gas per unit increased. As an example, average Time Dependent Value (TDV) values were pulled from Climate Zone 12 to demonstrate the change in electric values from 2019 to 2022 and in gas, from 2016 to 2019 to 2022.

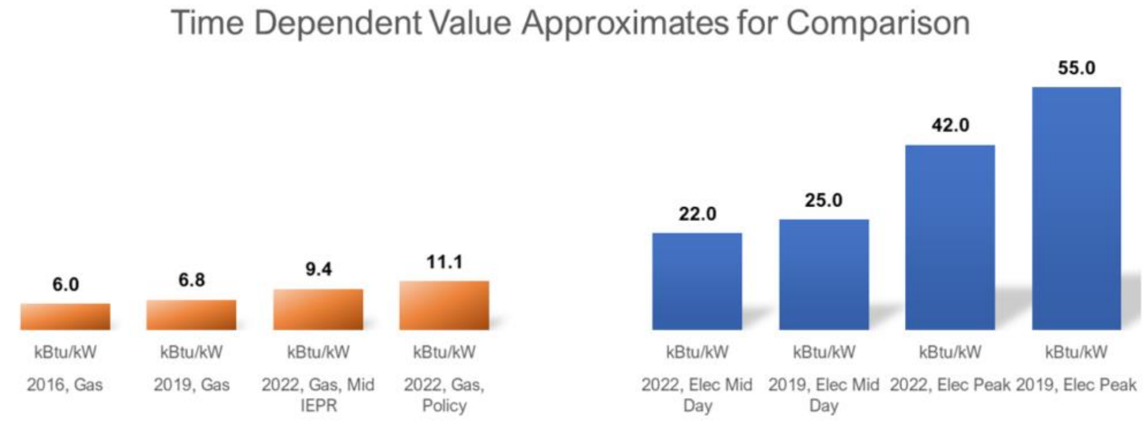


Figure 24: Comparison of TDV costs from 2019 and 2022 for Climate Zone 12

In the electric rates, both mid-day and the peak demand cost metric were reduced, from 25 to 22 mid-day and from 55 to 42 at peak. In the gas metric, the cost of gas forecasted in the TDV metric went up significantly, from 6.8 to 9.4 in one scenario or from 6.8 to 11.1 in another from 2019 to 2022. The final metrics for 2022 are not yet completed and the electricity metric is planned to be further reduced during mid-day periods to reflect the true costs of lower retail rates at this time.

This change in the forecasted cost of energy metric directly impacts the energy cost effectiveness of DOAS verses a mixed air system when evaluating the economizer exception. As an example of this metric, when TDV is applied to the hourly modeled energy results a majority of the airside economizer cooling energy align with mid-day low costs for electricity.

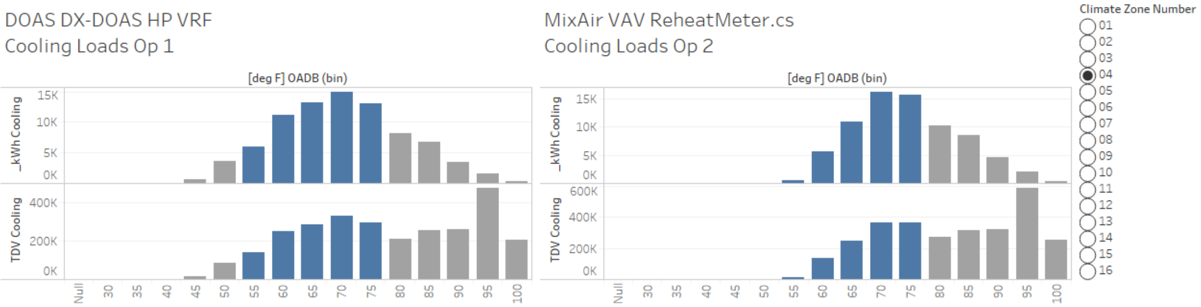


Figure 25: Comparison of cooling energy and TDV of DX-DOAS with VRF and VAV packaged unit

Reviewing the cooling only results from two prototype medium office energy models, a DX-DOAS with VRF on the left shows the sum of cooling energy used binned by outdoor air dry bulb. The same cooling energy is shown for a mixed air VAV packaged unit system on the right. The top graph shows the straight kWh by temperature bin for the two cases. The DOAS uses significantly more energy at 65F and below than the mixed air system. When the TDV factor is applied as is shown in the bottom graphs, the value of energy use in the outdoor air bins of 70F or above increases in significance.

This increase in cooling energy still exists though is less significant than using site energy directly for comparison. When this energy increase is weighed with the peak demand reduction from ventilation heat recovery and heating energy decrease the overall result is a lower or equivalent energy use between the systems.

Source Energy Metrics

Source energy factors convert the fuel types of a building to the amount of energy consumed at a power plant to produce it. Each climate zone includes nonresidential source multipliers and were utilized to evaluate.

Carbon Emissions Metrics

Hourly carbon emissions were also developed by the Energy Commission for each climate zone for nonresidential buildings and each fuel type. The emissions factors require converting site energy to source and then applying the metrics to convert source energy to tons of carbon equivalent. For this

Parameters for Evaluating Results

Equivalency was evaluated for any DOAS configuration which would result in energy savings > -5 percent with the economizer standard system. This criterion resulted in consistent results across models for climate zones.

Additional Analysis with Alternate Equipment Loads

Due to initial results of different DOAS configurations being within a small proximity of mixed-air systems, some higher, some lower by a small percentage, an additional analysis was done to demonstrate the impacts on HVAC energy performance from system sizing and sensitivity to internal loads. While there are many factors which impact the overall energy use in a building, few parameters would change the incremental energy use of one HVAC configuration to another HVAC configuration as much as internal loads, specifically receptacle loads. In ASHRAE Research Project 1742 found that office equipment ranges from 0.34 W/sf for offices with laptops and docking stations to 1.53 W/sf for heavy desktop computer use. This range, while broad, resulted in a reduction in the internal loads assumption for the 2017 ASHRAE Handbook Fundamentals by 10 percent to 33 percent from the 2009 version. In several net zero energy buildings, plug loads are a continued source of reduction as well, with many office buildings now operate close to 0.75 W/sf on peak.

In the prototype buildings, receptacle loads in office buildings represents one of the most obvious discrepancies between how buildings once were assumed to operate and how they do today. This prototype assumes office areas all have 1.5 W/sf of receptacle loads. This amount of internal equipment effectively is cooled by airside economizers and contributes to heating a building in winter and shoulder seasons. In buildings without this source of internal heat, a mixed-air system effectively needs to economize less and provide additional heating during colder conditions.

The medium office prototype was modified for a special scenario in addition to the standard set of models to evaluate this impact on receptacle loads, assuming receptacle loads of 0.75 W/sf. This was applied to the design day for sizing and to the operational schedule for weekdays.

Energy Result Findings

Below are results of the difference between Mixed air HVAC configurations and DOAS for four building types, specific configurations of DOAS, and each of the 16 California climate zones. These results would be placed in the detailed section with a condensed version in this findings section.

	Small Office				
	Percent TDV Savings of DOAS verses SZPU with multi-speed fans and economizers.				
Climate Zone	**DX-DOAS with VRF***	**DX-DOAS, DCV with VRF**	**HRV with Mini-Splits**	**HRV with Recirc RTU**	**HRV with VRF**
Z01	11.2%	39.2%	20.2%	26.6%	23.1%
Z02	4.9%	22.0%	11.9%	14.2%	12.0%
Z03	(3.0%)	19.0%	12.4%	12.9%	8.6%
Z04	0.6%	16.9%	9.6%	10.7%	7.6%
Z05	(6.7%)	17.7%	12.1%	13.7%	7.5%
Z06	(11.7%)*	6.5%	4.5%	4.1%	2.5%
Z07	(15.3%)*	5.9%	3.4%	2.7%	(0.5%)
Z08	(3.8%)	10.4%	5.0%	5.2%	3.4%
Z09	(0.3%)	11.6%	7.0%	7.2%	4.5%
Z10	2.0%	13.9%	8.1%	8.6%	6.2%
Z11	11.2%	23.9%	13.8%	15.5%	14.6%
Z12	6.4%	21.7%	11.0%	13.3%	11.4%
Z13	9.0%	19.8%	11.3%	13.1%	11.5%
Z14	10.6%	21.7%	12.0%	14.5%	12.9%
Z15	10.8%	15.4%	11.2%	11.3%	11.5%
Z16	14.7%	35.5%	7.1%	25.0%	20.4%

Medium Office					
Percent TDV Savings of DOAS verses VAV Reheat with DX.					
Climate Zone	**Alt Receptacle Loads DX-DOAS with VRF**	**DX-DOAS with VRF**	**HP-DOAS with VRF**	**HRV with FPFC**	**HRV with VRF**
Z01	13.6%	7.6%	4.6%	5.6%	4.2%
Z02	8.4%	3.6%	2.4%	5.0%	7.8%
Z03	7.6%	1.1%	(0.4%)	3.4%	1.9%
Z04	5.3%	1.1%	0.0%	3.4%	4.3%
Z05	5.8%	(0.2%)	(1.8%)	1.2%	(0.1%)
Z06	1.0%	(2.9%)	(3.9%)	4.0%	6.6%
Z07	3.4%	(2.1%)	(3.2%)	2.3%	1.9%
Z08	2.0%	(1.1%)	(2.0%)	3.9%	6.7%
Z09	2.5%	0.0%	(0.9%)	3.2%	6.2%
Z10	3.5%	1.3%	0.4%	4.2%	6.4%
Z11	9.0%	6.4%	5.6%	7.9%	11.3%
Z12	8.5%	4.9%	4.0%	5.7%	7.9%
Z13	7.2%	3.5%	2.7%	4.3%	7.2%
Z14	8.0%	5.1%	4.4%	6.2%	10.8%
Z15	4.9%	3.4%	2.7%	3.0%	10.1%
Z16	14.8%	4.8%	2.7%	9.1%	6.9%

*Based on limitations in EnergyPlus 9.01, DX-DOAS is the primary cooling system before the space conditioning system. All active cooling DOAS show an energy penalty due to modeling simplifications required at this time. Actual energy usage is not anticipated to be far greater than HRV DOAS for mid climates 6 and 7.

Primary Schools	
Percent TDV Savings of DOAS verses vs VAV Reheat with DX.	
Climate Zone	DX-DOAS with VRF
Z01	16.5%
Z02	8.1%
Z03	9.4%
Z04	9.2%
Z05	4.8%
Z06	0.5%
Z07	(0.9%)
Z08	3.2%
Z09	8.5%
Z10	10.2%
Z11	18.2%
Z12	11.8%
Z13	12.8%
Z14	18.6%
Z15	19.8%
Z16	10.3%

Secondary Schools	
Percent TDV Savings of DX-DOAS with VRF verses vs VAV Reheat	
Climate Zone	DX-DOAS with VRF vs Packaged DX
Z01	14.1%
Z02	13.8%
Z03	12.9%
Z04	13.6%
Z05	11.2%
Z06	12.0%
Z07	11.0%
Z08	14.4%
Z09	13.8%
Z10	14.7%
Z11	14.4%
Z12	15.0%
Z13	14.5%
Z14	13.7%
Z15	12.6%
Z16	12.2%

The results show the following:

3. The DOAS configurations with HRV only and utilizing zone cooling systems to provide cooling achieve the lowest energy use. This configuration is used in CA climates due to the mild winter condition above freezing and mild summer humidity, typically hot and dry.
4. In DOAS configurations with active cooling, TDV energy use was within -3 percent of any mixed air system with air-source cooling, such as DX.
5. In the secondary schools, DOAS configurations verses a mixed air system with a water cooled chilled water plant exceeded the threshold of -5 percent. This finding set the upper limit allowance for the types of buildings, based on size and floors, the exception would be allowed for.
6. A medium office with equipment loads of 0.75 percent shows an energy savings in all climate zones with a DOAS configuration with active ventilation cooling compared to a mixed air system with economizers.

The following recommendations for a code equivalency exception are as follows:

1. DOAS with the economizer exception must be designed and operated at 50 percent increased ventilation and or exhaust requirements.
2. Systems achieving a minimum of 60 percent sensible energy recovery ratio and include bypass controls for free cooling based on a fixed upper limit per economizer limits table and lower limit of 55F.
3. DOAS with economizer exception should include DCV and occupancy based ventilation controls if an economizer would have otherwise been used for systems 1,000 cfm or greater.
4. At this time, the applications of DOAS with air source cooling systems were found to be equivalent or exceed TDV. The analysis did not include water cooled configurations of DOAS at this time though results with regards to incremental difference are anticipated to reflect the same order of magnitude of those found so far.

Detailed Energy Result Findings

The following detailed energy results are included to unpack how energy is used in the different configurations of DOAS and Mixed-Air HVAC systems.

1. Total Energy Savings By Metric, Site Energy Electric, Gas, Source Total
2. Energy by Fuel Type, Mixed-Air and DOAS, Annual Energy
    a. Representative building, medium office, climate zones 6 and 12.
3. End-Use Energy of Mixed-Air and DOAS, Annual Energy
    a. Representative building, medium office, climate zones 6 and 12.
4. Typical Summer Week, Energy Use of Representative Case
    a. Representative building, medium office, climate zone 4.
5. Typical Winter Week, Energy Use of Representative Case
    a. Representative building, medium office, climate zone 4.
6. Seasonal Energy Shifting, Representative Case

Total Energy by Metric

Site Electric Savings

DOAS shows overall increased electrical use and decreased gas in site energy.

Table 170: Comparison of site electrical savings relative to baseline configuration (Small Office & Medium Office)

SMALL OFFICE				
Site kBtu/sf Electrical Savings vs SZPU with multi-speed fans and economizers.				
Climate Zone	DX-DOAS with VRF	HRV with Mini-Splits	HRV with Recirc RTU	HRV with VRF
Z01	(3.1)	(3.5)	(0.7)	(3.4)
Z02	(2.1)	(2.0)	(0.4)	(2.3)
Z03	(2.5)	(1.6)	(0.6)	(2.3)
Z04	(1.9)	(1.2)	(0.4)	(1.8)
Z05	(2.3)	(1.5)	(0.6)	(2.2)
Z06	(2.6)	(0.5)	(0.3)	(1.0)
Z07	(2.6)	(0.6)	(0.5)	(1.3)
Z08	(1.7)	(0.6)	(0.2)	(0.9)
Z09	(1.3)	(0.6)	(0.2)	(1.1)
Z10	(1.1)	(0.6)	0.0	(1.0)
Z11	(1.0)	(1.3)	0.3	(1.4)
Z12	(1.7)	(1.8)	(0.2)	(1.9)
Z13	(0.9)	(1.1)	0.2	(1.3)
Z14	(0.8)	(1.3)	0.4	(1.3)
Z15	1.6	1.5	1.7	1.3
Z16	(2.6)	(4.9)	0.0	(3.5)

MEDIUM OFFICE					
Site kBtu/sf Electrical Savings vs VAV Reheat with DX and economizers.					
Climate Zone	Alt DX-DOAS with VRF	DX-DOAS with VRF	HP-DOAS with VRF	HRV with FPFC	HRV with VRF
Z01	(2.8)	(2.8)	(3.1)	(2.4)	(2.8)
Z02	(1.6)	(1.8)	(2.1)	(1.2)	(1.6)
Z03	(2.0)	(2.1)	(2.4)	(1.6)	(2.0)
Z04	(1.3)	(1.6)	(1.8)	(1.0)	(1.3)
Z05	(1.8)	(1.9)	(2.2)	(1.4)	(1.8)
Z06	(1.1)	(1.5)	(1.7)	(0.4)	(1.1)
Z07	(1.0)	(1.4)	(1.5)	(0.6)	(1.0)
Z08	(0.8)	(1.2)	(1.4)	(0.3)	(0.8)
Z09	(0.8)	(1.2)	(1.4)	(0.5)	(0.8)
Z10	(0.8)	(1.1)	(1.3)	(0.3)	(0.8)
Z11	(1.2)	(1.3)	(1.5)	(0.5)	(1.2)
Z12	(1.3)	(1.5)	(1.7)	(0.8)	(1.3)
Z13	(1.0)	(1.2)	(1.4)	(0.5)	(1.0)
Z14	(1.0)	(1.3)	(1.5)	(0.5)	(1.0)
Z15	(0.3)	(0.5)	(0.7)	0.2	(0.3)
Z16	(2.1)	(2.5)	(3.0)	(1.5)	(2.1)

Table 171: Comparison of site energy savings relative to baseline configuration (Primary School and Secondary School)

Primary Schools	
Site kBtu/sf Electrical Savings vs VAV Reheat with DX and economizers.	
Climate Zone	**DX-DOAS with VRF**
Z01	(0.1)
Z02	(0.1)
Z03	(0.5)
Z04	(0.1)
Z05	(0.5)
Z06	(0.6)
Z07	(0.9)
Z08	0.0
Z09	0.7
Z10	0.8
Z11	1.4
Z12	0.4
Z13	1.3
Z14	1.7
Z15	3.6
Z16	(0.9)

Secondary Schools	
Site kBtu/sf Electrical Savings vs VAV Reheat OF DX-DOAS with VRF	
Climate Zone	**Packaged DX**
Z01	(0.9)
Z02	0.6
Z03	0.2
Z04	1.2
Z05	0.5
Z06	1.7
Z07	1.3
Z08	2.2
Z09	2.0
Z10	2.3
Z11	1.7
Z12	1.4
Z13	2.1
Z14	1.5
Z15	3.5
Z16	(1.3)

Site Gas Savings

Table 172: Comparison of site gas savings relative to baseline configuration (Small Office & Medium Office)

SMALL OFFICE				
Site kBtu/sf Gas Savings vs SZPU with multi-speed fans and economizers.				
Climate Zone	DX-DOAS with VRF	HRV with Mini-Splits	HRV with Recirc RTU	HRV with VRF
Z01	18.2	20.1	13.0	20.1
Z02	10.0	11.5	7.5	11.5
Z03	8.6	9.2	6.2	9.2
Z04	6.7	7.4	5.0	7.4
Z05	7.9	8.6	6.0	8.6
Z06	3.0	3.2	2.5	3.2
Z07	2.8	2.9	2.1	2.9
Z08	3.4	3.6	2.5	3.6
Z09	3.8	4.1	3.0	4.1
Z10	4.4	5.0	3.5	5.0
Z11	9.2	10.8	6.7	10.8
Z12	9.0	10.3	6.5	10.3
Z13	7.5	8.7	5.5	8.7
Z14	8.3	10.0	6.3	10.0
Z15	2.0	2.1	1.6	2.1
Z16	17.4	21.7	12.3	21.7

MEDIUM OFFICE					
Site kBtu/sf Gas Savings vs VAV Reheat with DX and economizers.					
Climate Zone	Alt DX-DOAS with VRF	DX-DOAS with VRF	HP-DOAS with VRF	HRV with FPFC	HRV with VRF
Z01	11.3	7.8	8.1	6.8	8.1
Z02	7.0	4.9	5.2	4.4	5.2
Z03	6.4	4.4	4.5	3.9	4.5
Z04	4.8	3.3	3.4	2.9	3.4
Z05	5.5	3.8	3.9	3.4	3.9
Z06	3.0	2.0	2.1	1.9	2.1
Z07	2.8	1.9	1.9	1.8	1.9
Z08	3.0	2.1	2.1	1.9	2.1
Z09	3.0	2.0	2.1	1.8	2.1
Z10	3.3	2.3	2.4	2.0	2.4
Z11	6.4	4.6	4.9	4.0	4.9
Z12	6.2	4.4	4.6	3.8	4.6
Z13	5.1	3.6	3.8	3.1	3.8
Z14	5.0	3.6	3.8	2.9	3.8
Z15	1.7	1.2	1.2	1.1	1.2
Z16	10.7	7.8	8.6	5.9	8.6

Table 173: Comparison of site gas savings relative to baseline configuration (Primary Schools and Secondary Schools)

Primary Schools	
Site kBtu/sf Gas Savings vs VAV Reheat with DX and economizers.	
Climate Zone	DX-DOAS with VRF
Z01	4.8
Z02	2.6
Z03	1.8
Z04	1.4
Z05	1.4
Z06	0.4
Z07	0.4
Z08	0.6
Z09	0.6
Z10	0.8
Z11	2.9
Z12	2.6
Z13	2.1
Z14	2.3
Z15	0.3
Z16	7.6

Secondary Schools	
Site kBtu/sf Gas Savings vs VAV Reheat OF DX-DOAS with VRF	
Climate Zone	Packaged DX
Z01	9.2
Z02	6.1
Z03	4.8
Z04	4.0
Z05	3.9
Z06	2.2
Z07	2.1
Z08	2.6
Z09	2.5
Z10	2.8
Z11	6.1
Z12	5.6
Z13	5.0
Z14	5.0
Z15	1.5
Z16	11.7

Source Energy

Source energy difference is shown for all combinations of DOAS simulated. In all combinations, the DOAS uses less source energy. Most DOAS configurations included gas heating only in the DX-DOAS, as noted with the word Furnace. In the Medium office and Small office, a DOAS configuration with space heating using gas was included; the FPFC with a natural gas boiler and the RTU with furnaces cycling on and off respectfully.

Table 174: Comparison of source energy savings relative to baseline configuration (Small Office and Medium Office)

SMALL OFFICE					
Percent Source Energy Savings vs SZPU with multi-speed fans and economizers.					
Climate Zone	DX-DOAS with VRF	DX-DOAS, DCV with VRF	HRV with Mini-Splits	HRV with Recirc RTU	HRV with VRF
Z01	43%	67%	63%	48%	66%
Z02	29%	55%	48%	39%	49%
Z03	23%	50%	48%	38%	47%
Z04	19%	42%	39%	31%	38%
Z05	21%	48%	46%	38%	45%
Z06	(3%)	23%	25%	21%	19%
Z07	(6%)	21%	22%	18%	16%
Z08	3%	25%	23%	19%	20%
Z09	8%	27%	27%	22%	23%
Z10	13%	31%	28%	24%	26%
Z11	30%	50%	41%	33%	43%
Z12	28%	50%	42%	34%	43%
Z13	25%	44%	36%	29%	37%
Z14	29%	47%	39%	33%	41%
Z15	11%	19%	19%	17%	16%
Z16	46%	69%	53%	42%	61%

MEDIUM OFFICE					
Percent Source Energy Savings vs VAV Reheat with DX and economizers.					
Climate Zone	Alt DX-DOAS with VRF	DX-DOAS with VRF	HP-DOAS with VRF	HRV with FPFC	HRV with VRF
Z01	57%	50%	51%	45%	51%
Z02	45%	36%	36%	33%	37%
Z03	43%	35%	34%	32%	35%
Z04	35%	27%	26%	25%	27%
Z05	39%	30%	29%	28%	31%
Z06	25%	18%	17%	19%	21%
Z07	26%	17%	16%	18%	18%
Z08	25%	18%	17%	19%	19%
Z09	26%	18%	17%	17%	18%
Z10	26%	19%	18%	18%	19%
Z11	38%	31%	31%	29%	33%
Z12	40%	32%	32%	29%	33%
Z13	34%	25%	26%	24%	26%
Z14	33%	24%	24%	22%	26%
Z15	13%	7%	6%	9%	10%
Z16	52%	42%	44%	35%	46%

Table 175: Comparison of source energy savings relative to baseline configuration (Primary Schools and Secondary Schools)

Primary Schools	
Percent Source Energy Savings vs VAV Reheat with DX and economizers.	
Climate Zone	DX-DOAS with VRF
Z01	28%
Z02	19%
Z03	16%
Z04	13%
Z05	13%
Z06	6%
Z07	5%
Z08	9%
Z09	12%
Z10	12%
Z11	22%
Z12	19%
Z13	19%
Z14	20%
Z15	15%
Z16	27%

Secondary Schools	
Percent Source Energy Savings vs VAV Reheat OF DX-DOAS with VRF	
Climate Zone	Packaged DX
Z01	49%
Z02	39%
Z03	37%
Z04	33%
Z05	32%
Z06	26%
Z07	25%
Z08	27%
Z09	27%
Z10	27%
Z11	37%
Z12	37%
Z13	34%
Z14	33%
Z15	20%
Z16	47%

Energy by Fuel Type, Mixed-Air and DOAS, Annual Energy

The site energy in kBtu-TDV per building floor area are shown for a Medium Office building with two representative climate zones; Climate Zone 6 which represents a coastal mild condition and Climate Zone 12 which represents a warm inland condition.

In Climate Zone 6, TDV is reduced for two of the four DOAS configurations simulated; HRVs with VRF and HRV with Four Pipe Fan Coils served from air cooled chillers and a boiler. The other two DOAS configurations are within 5 percent of the Standard Mixed-Air energy use for this climate zone. Based on the additional analysis done to evaluate the configurations highlighted, DX-DOAS with VRF and the Standard Mixed Air system, the sensitivity of equipment loads, this result reverses, shown in the Reduced Equipment Load column for each climate zone.

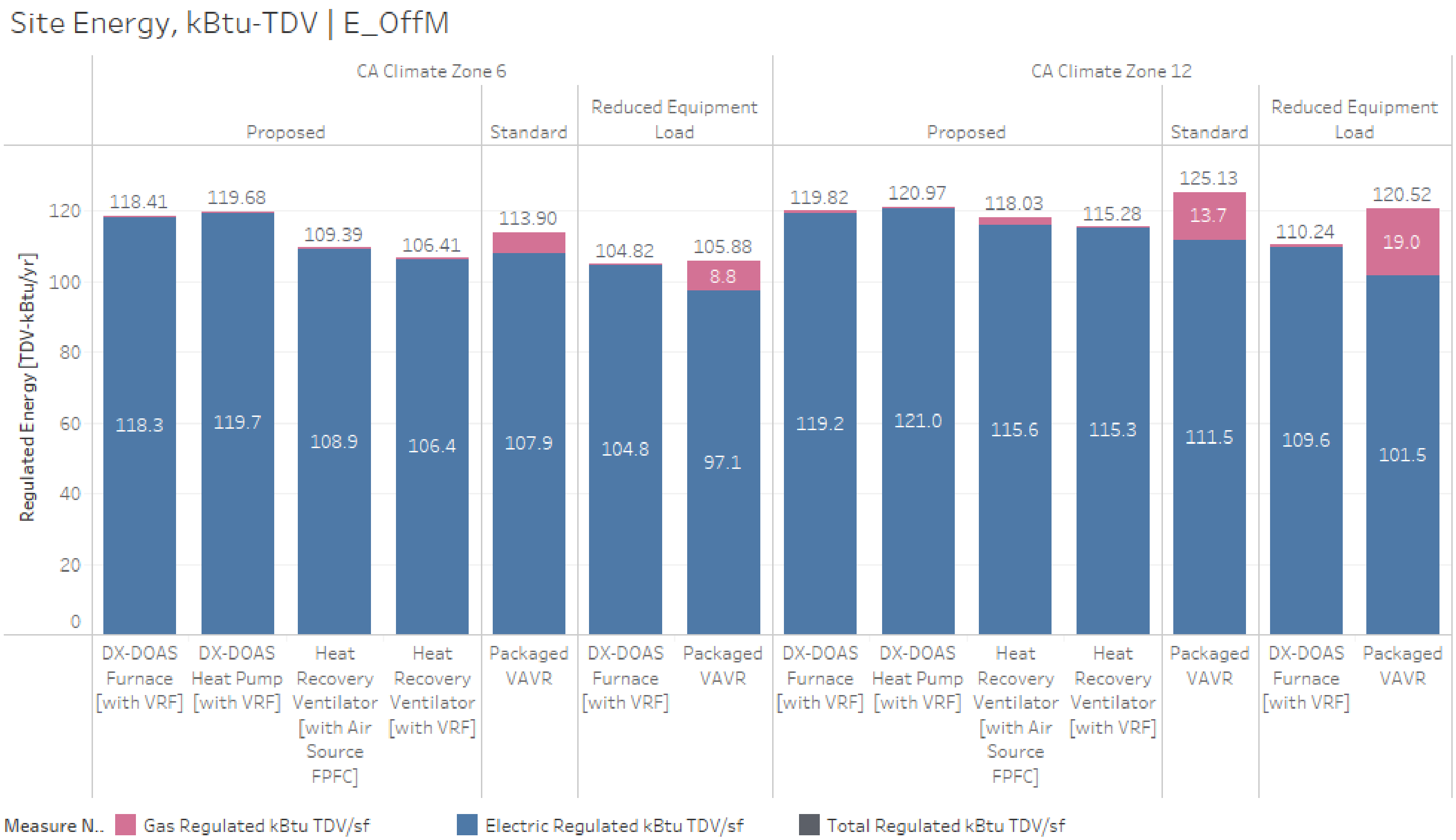


Figure 26: System comparisons of regulated TDV site energy for Climate Zone 6 and Climate Zone 12 for Medium Office.

End-Use Energy of Mixed-Air and DOAS, Annual Energy

Energy use with TDV factors applied is shown in kBtu/sf for HVAC end uses only. The following chart displaces the end uses for a medium office building. In DOAS configurations with ventilation cooling, the overall cooling energy increases as well as fan energy. The DOAS configuration with HRVs and VRF used the least amount of energy followed by the DOAS configuration with four pipe fan coils served from an air cooled chiller and boiler.

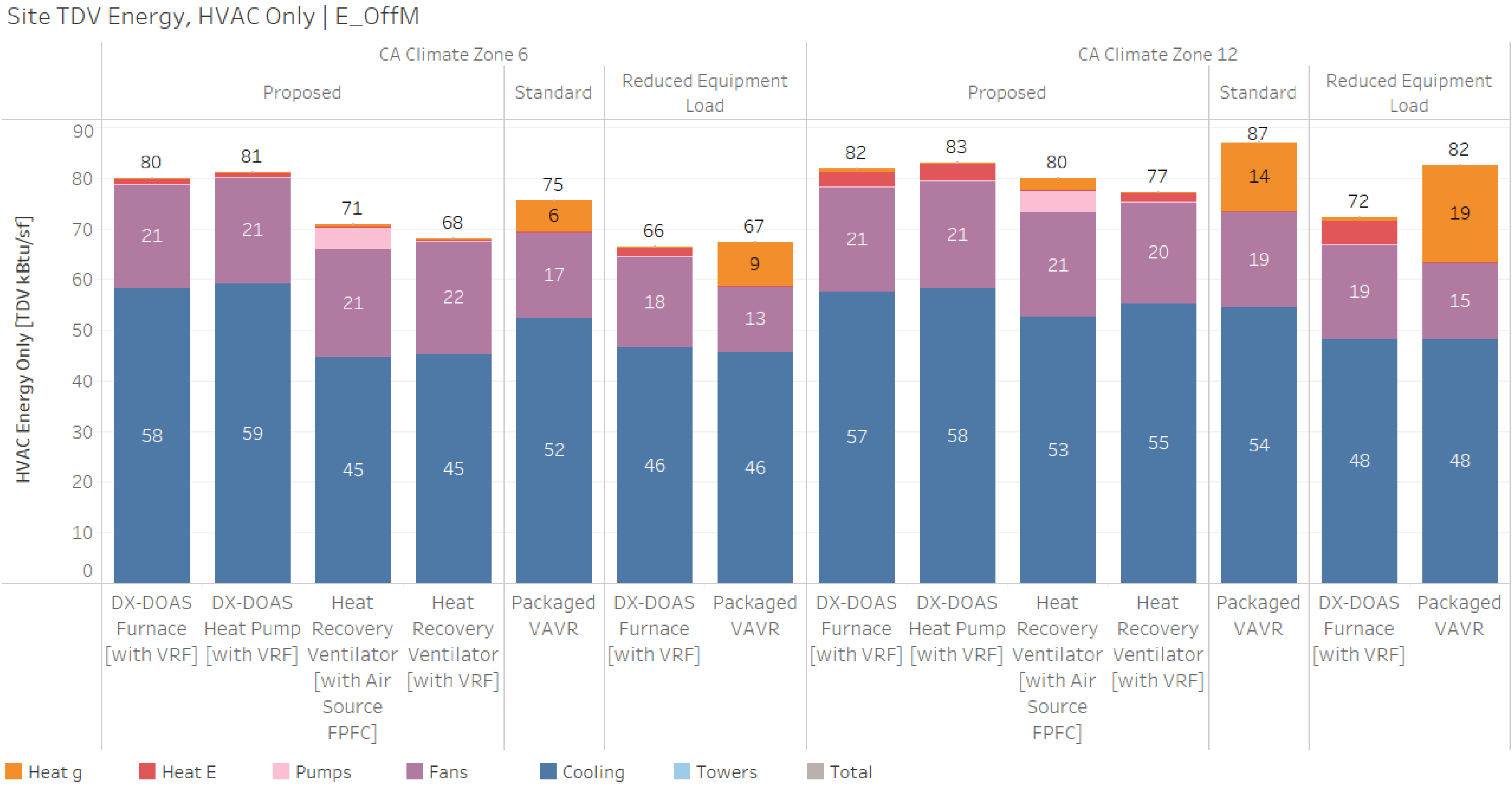


Figure 27: System comparison of HVAC-only TDV site energy for Climate Zone 6 and Climate Zone 12 for Medium Office.

In the secondary school prototype, which represents a building > 200,000 sf, the same two climate zones are shown below. The DX-DOAS configuration with VRF uses more energy than the mixed air system with a chilled water plant, primarily from the high amount of cooling energy as well as an increase in fan energy. When compared to a mixed air system where each unit has its own DX cooling coil, the DOAS configuration uses less energy overall.

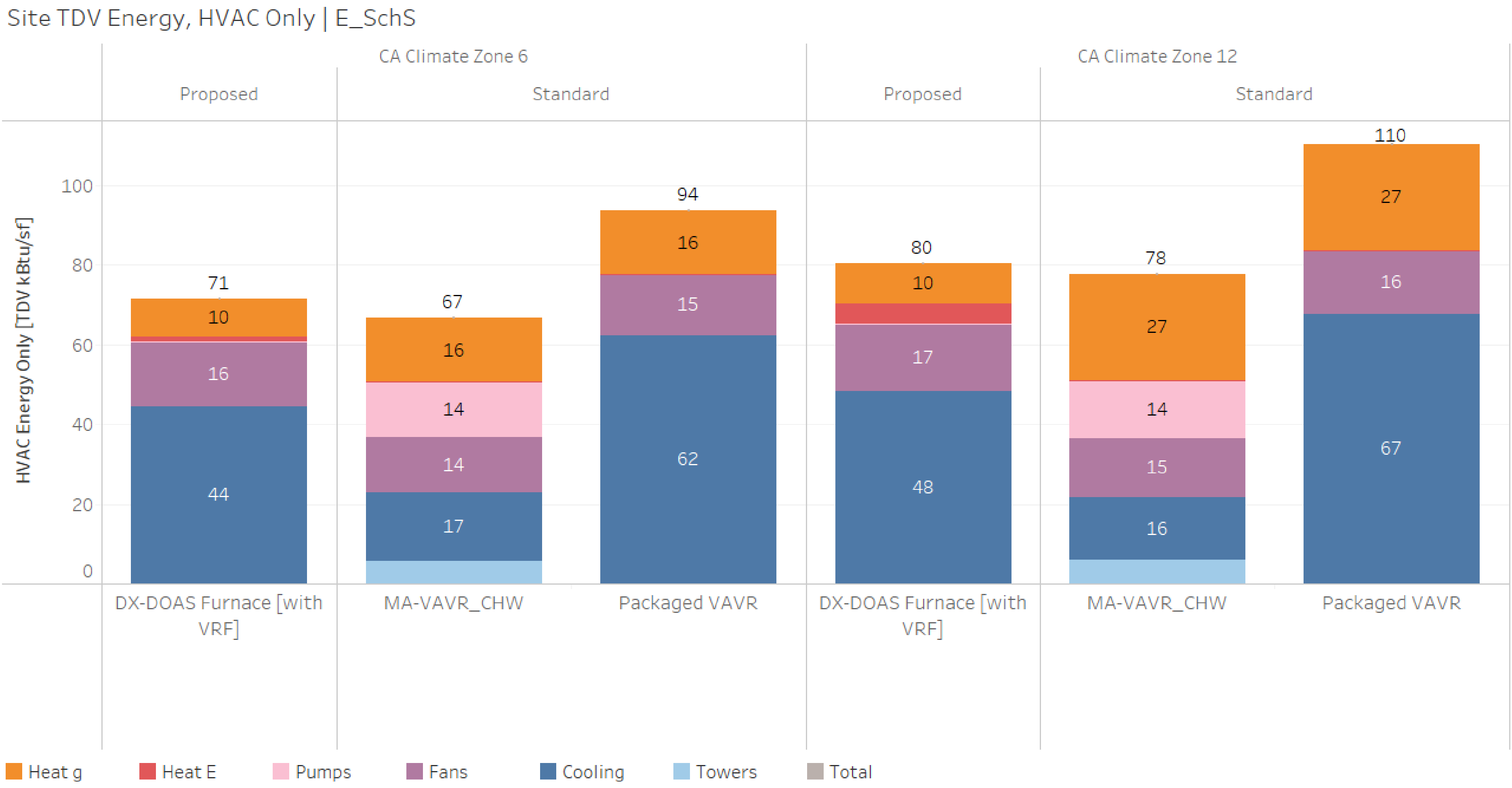


Figure 28: System comparison of HVAC-only TDV site energy for Climate Zone 6 and Climate Zone 12 for Secondary Schools.

In the small office, all DOAS configurations used less energy than the primary standard configuration, single zone variable air volume rooftop packaged units with furnaces. A configuration of single zone variable air volume rooftop with a heat pump was also simulated for reference and shown for completeness.

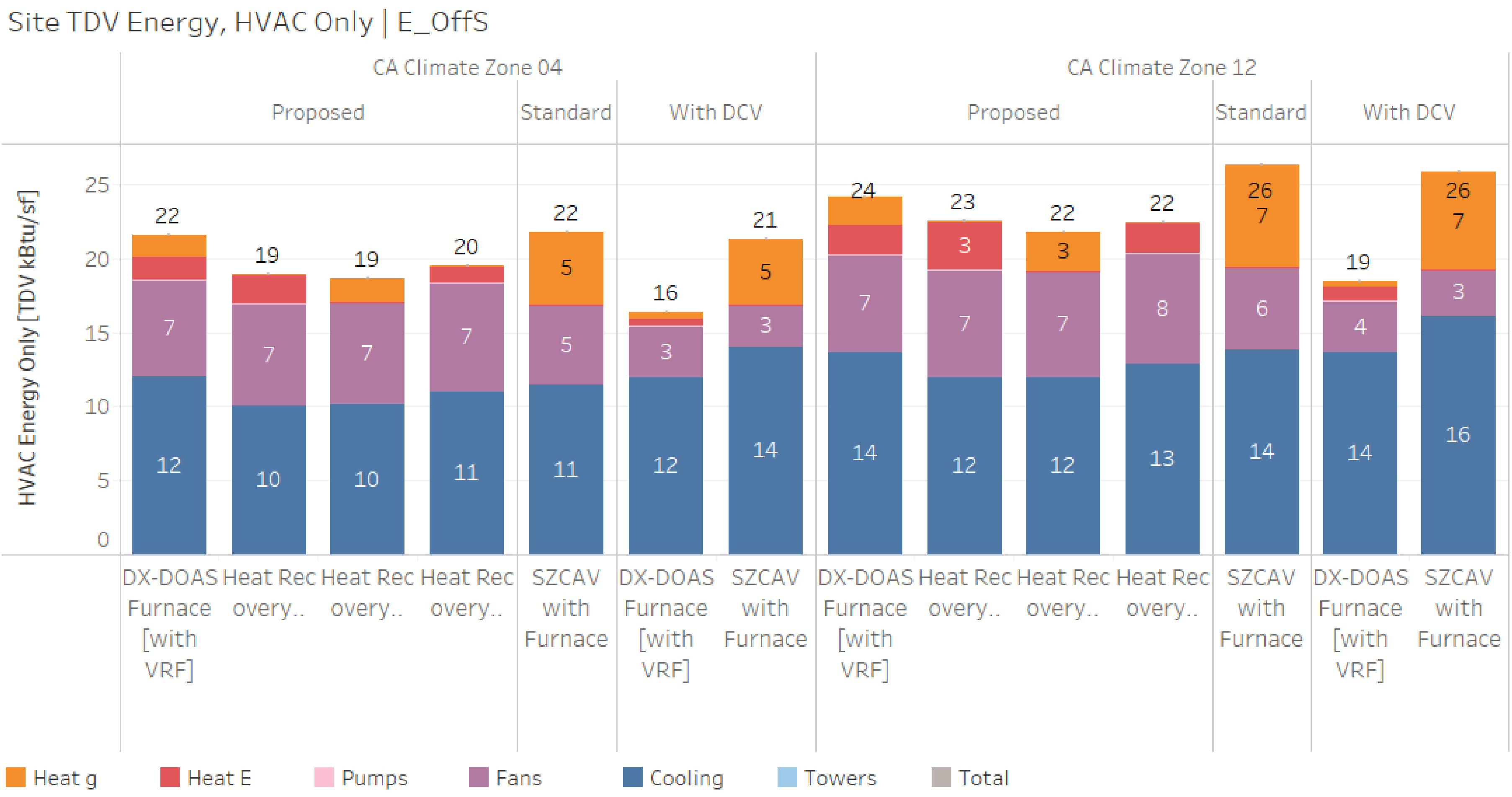


Figure 29: System comparison of HVAC-only TDV site energy for Climate Zone 6 and Climate Zone 12 for Small Offices

Typical Summer Week, Energy Use of Representative Case

To demonstrate the hourly results found, the following tables are included in site energy metrics of kWh for both site electricity and site gas. All site gas is labeled as kWh_equivalent (kWhe) for clarity. Receptacle energy is included (equipment) to demonstrate the day of the week.

Site Energy: Medium Office Climate Zone 4, Week 37 | September

The chart below is of internal loads only to provide clarity to how the building is operating for each configuration simulated. The chart below shows two configurations of DOAS with VRF; a DX-DOAS and an HRV, and one configuration of a Mixed Air system, PVAVR.

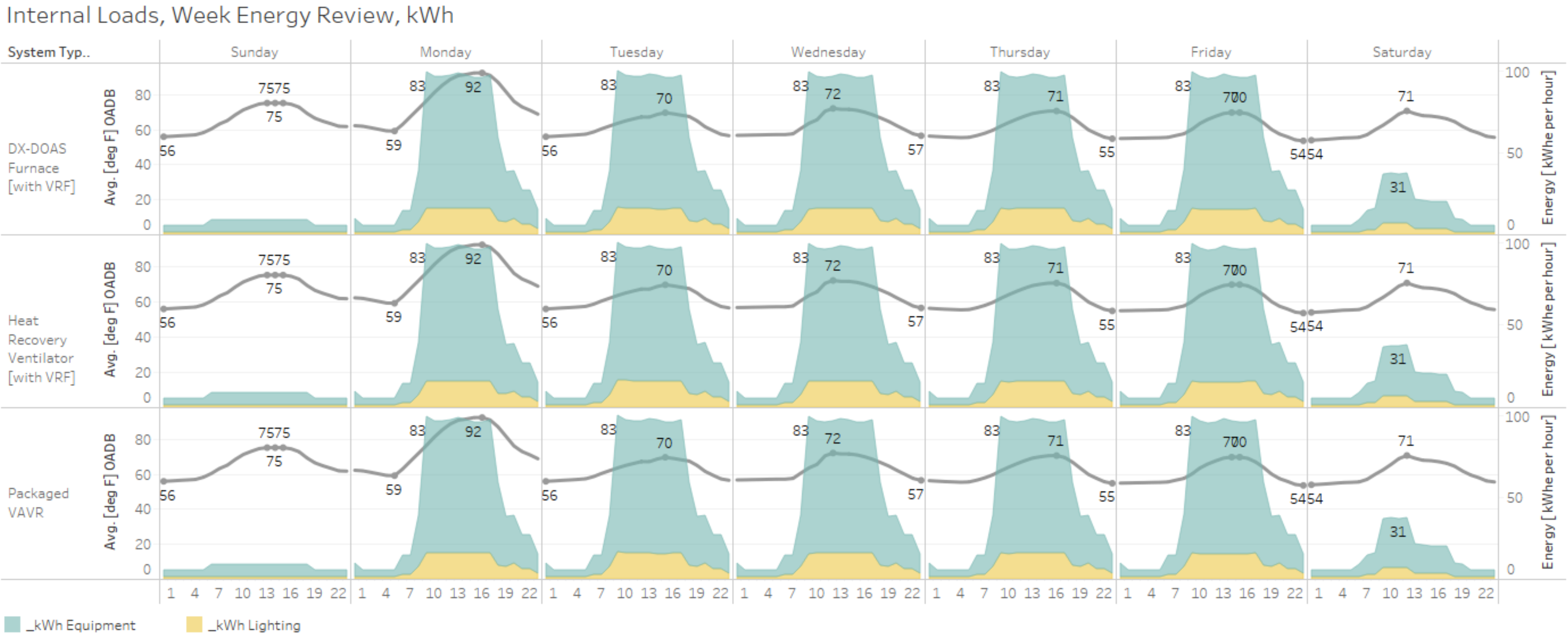


Figure 30: Internal load profile comparison for systems in Climate Zone 4, Week 37 (Medium Offices)

Looking at the HVAC only, on the hottest day, Monday, the mixed air system uses more cooling energy at the peak of the day. In Tuesday through Friday, the DOAS configurations use more cooling energy throughout the day even with a mild outdoor air temperature.

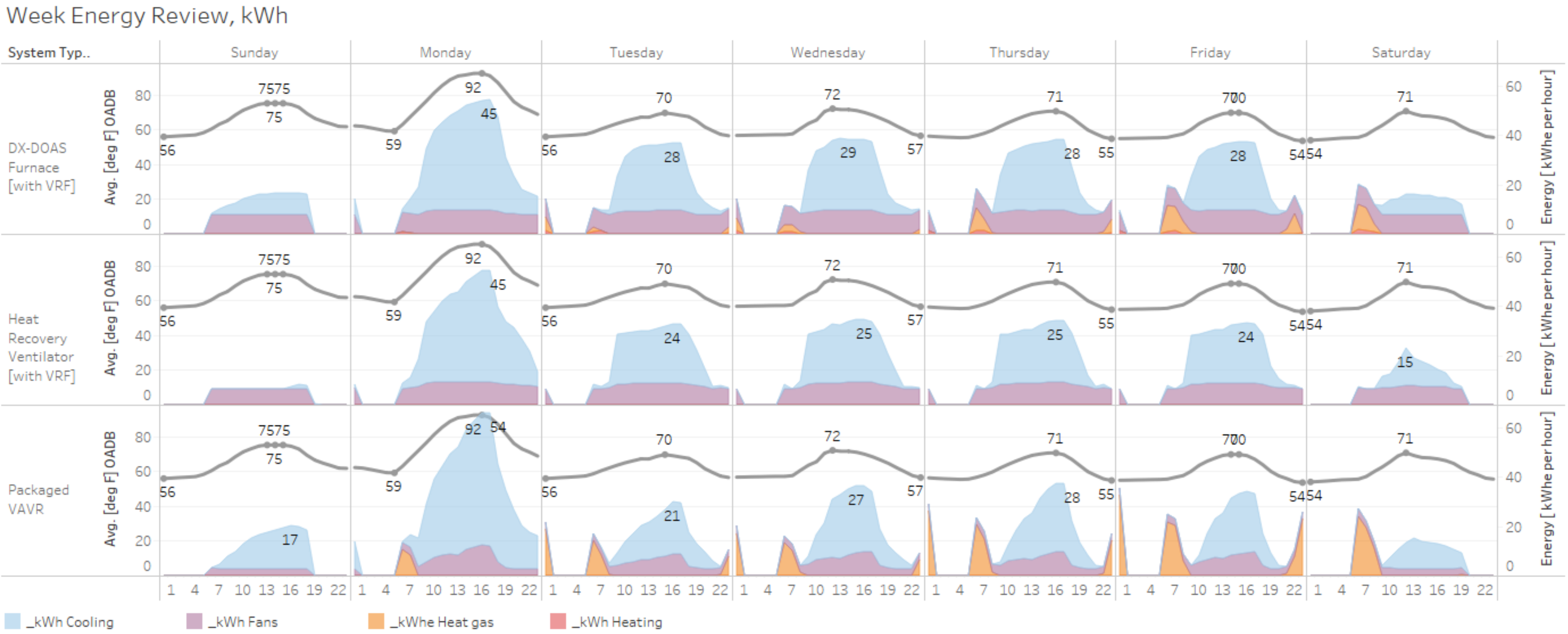


Figure 31: HVAC-only load profile comparison for systems in Climate Zone 4, Week 37 (Medium Offices)

TDV Site Energy: Medium Office Climate Zone 4, Week 37 | September

The same week for the three configurations is shown with the TDV metric applied. In this graph, the impact of mid-day cooling does increase the overall cooling energy in both DOAS configurations. The spike in cooling energy seen in the mixed air system on Monday compared to the DOAS demonstrates the impact of the major difference in these system types.

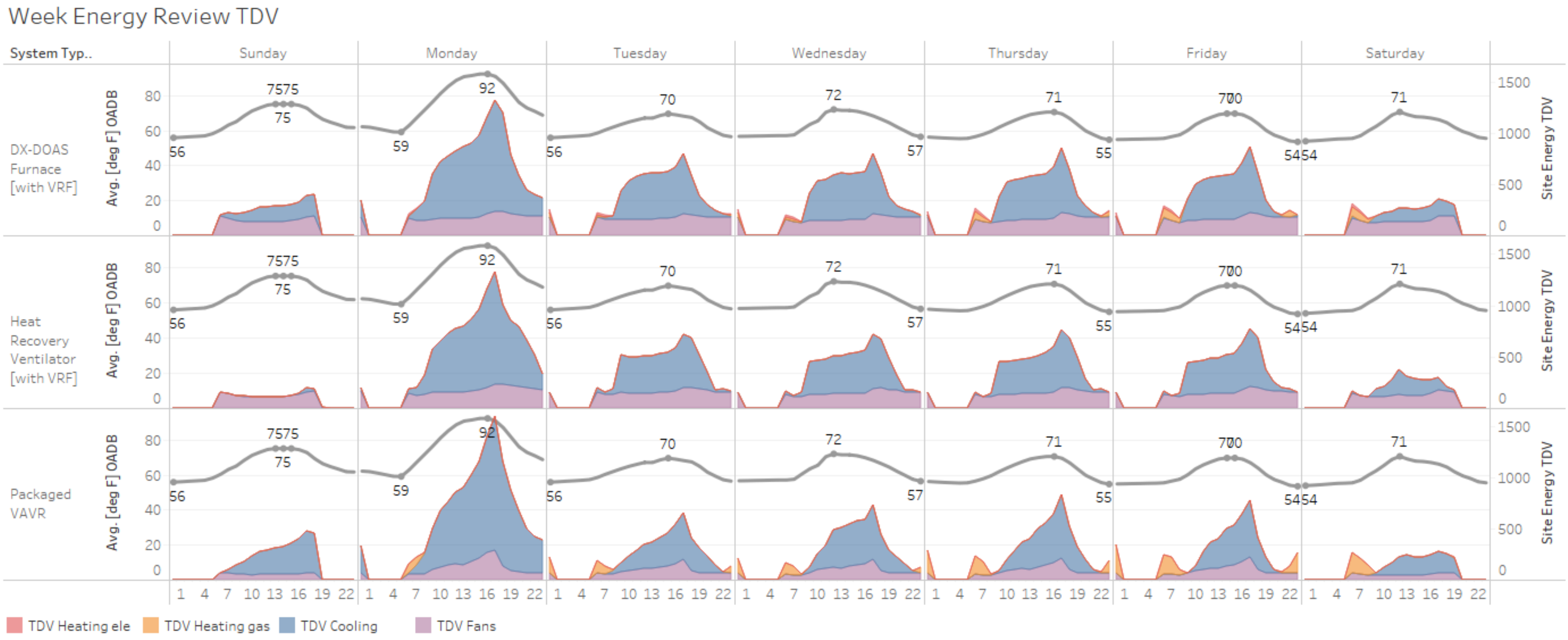


Figure 32: TDV site energy load profile comparison for systems in Climate Zone 4, Week 37 (Medium Offices)

Source Energy: Medium Office Climate Zone 4, Week 37 | September

Looking at source energy, the mid-day energy use of almost all systems drops to zero, where the morning and afternoon periods increase dramatically. This reflects how carbon is currently forecasted on the energy grid in California.

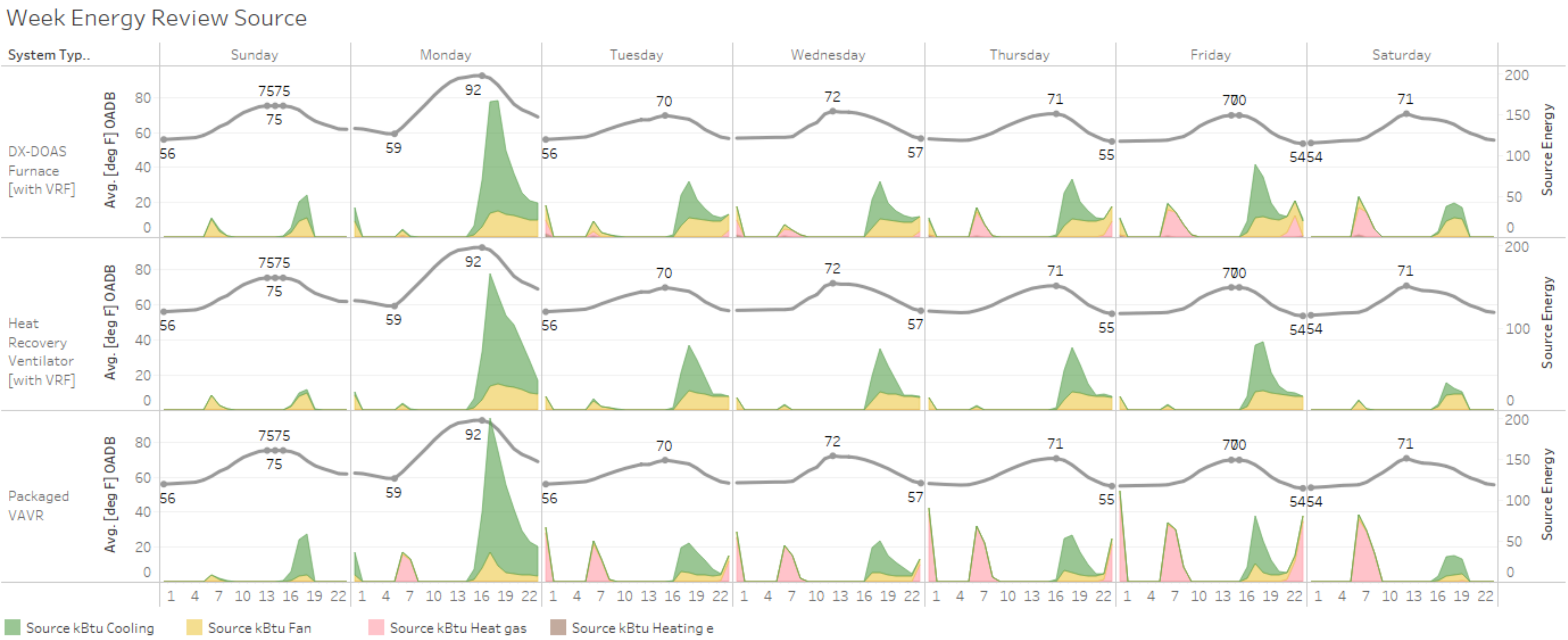


Figure 33: Source energy load profile comparison for systems in Climate Zone 4, Week 37 (Medium Offices)

Carbon Emissions: Medium Office Climate Zone 4, Week 37 | September

The same data is presented in pounds of equivalent carbon emissions. This metric tracks very closely to the Source energy data.

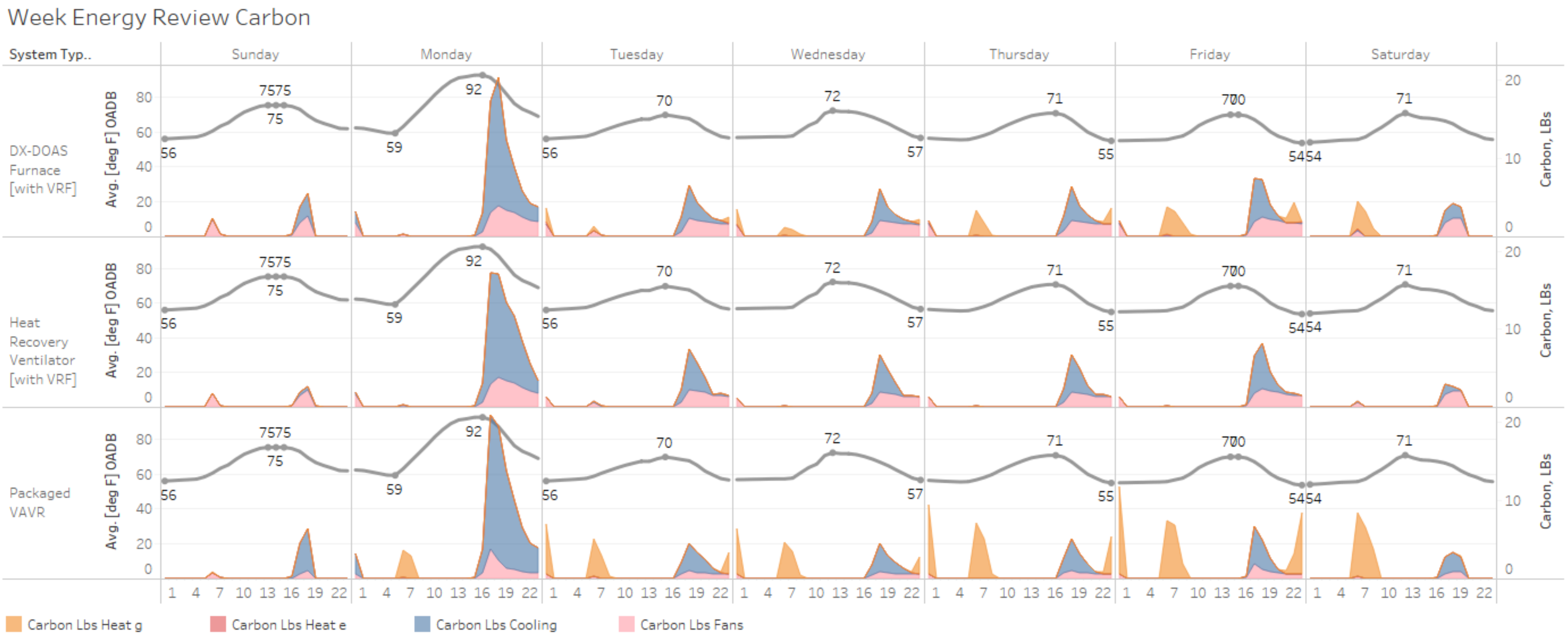


Figure 34: Carbon emissions profile comparison for systems in Climate Zone 4, Week 37 (Medium Offices)

Typical Winter Week, Energy Use of Representative Case

Site Energy: Medium Office Climate Zone 4, Week 6| January

Energy for each component of HVAC is shown for a typical winter week in Climate Zone 4. The data shows the mixed air system utilizing more heating energy during morning warmup than the DOAS configurations which include ventilation heat recovery.

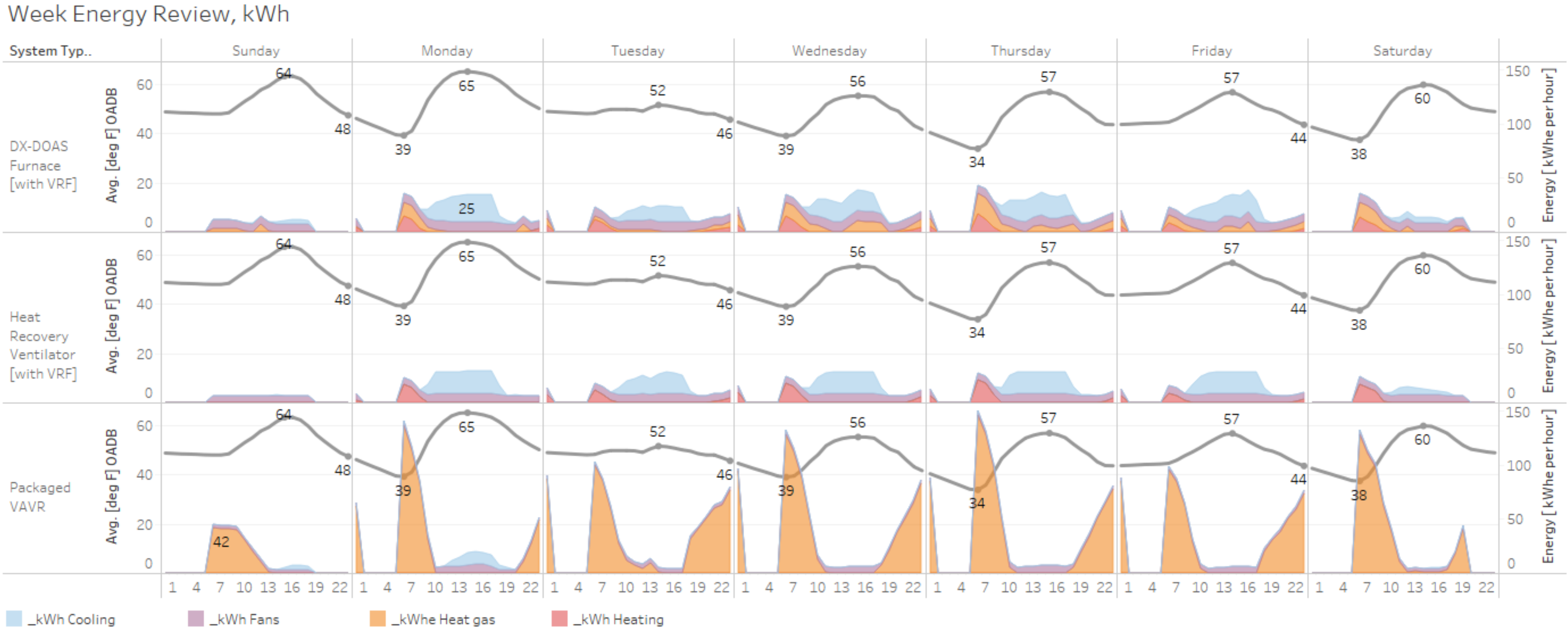


Figure 35: Internal load profile comparison for systems in Climate Zone 4, Week 6 (Medium Offices)

TDV Site Energy: Medium Office Climate Zone 4, Week 6| January

The same week for the three configurations is shown with the TDV metric applied.

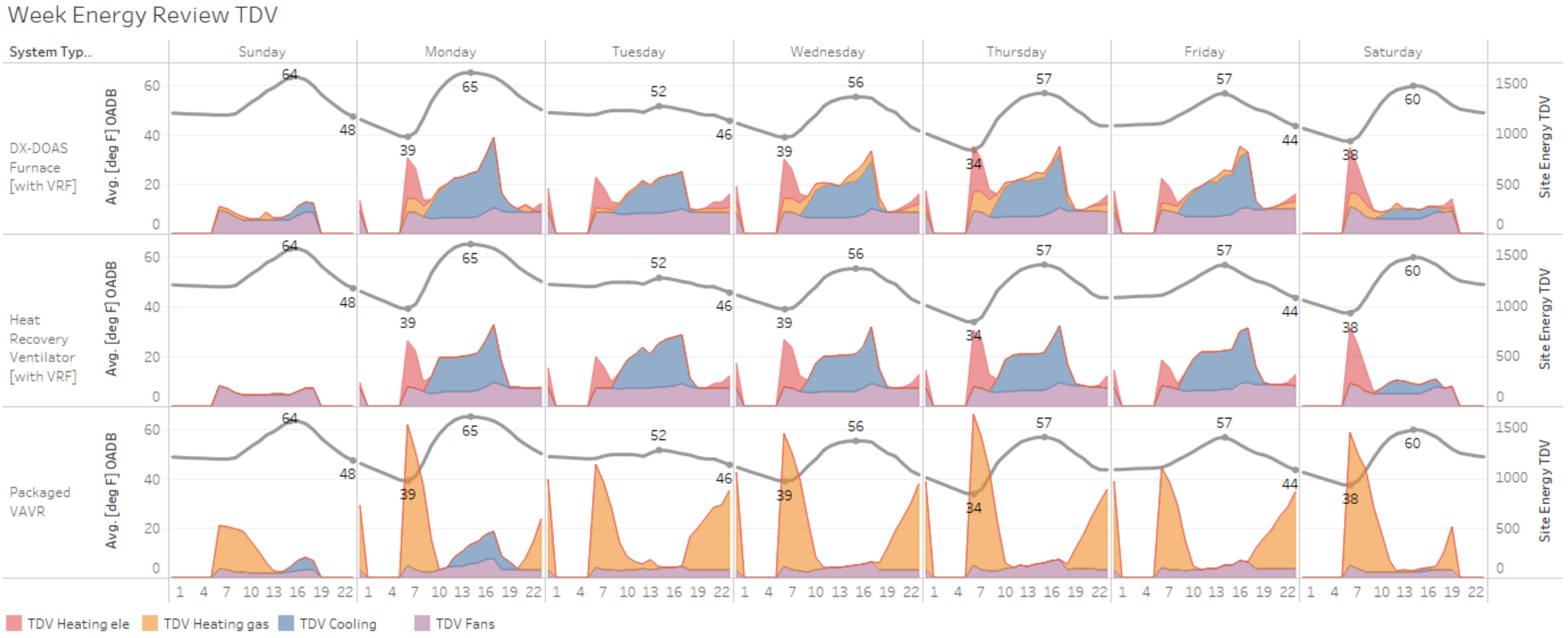


Figure 36: TDV site energy load profile comparison for systems in Climate Zone 4, Week 6 (Medium Offices)

Source Energy: Medium Office Climate Zone 4, Week 6| January

The same week with source energy metric applied.

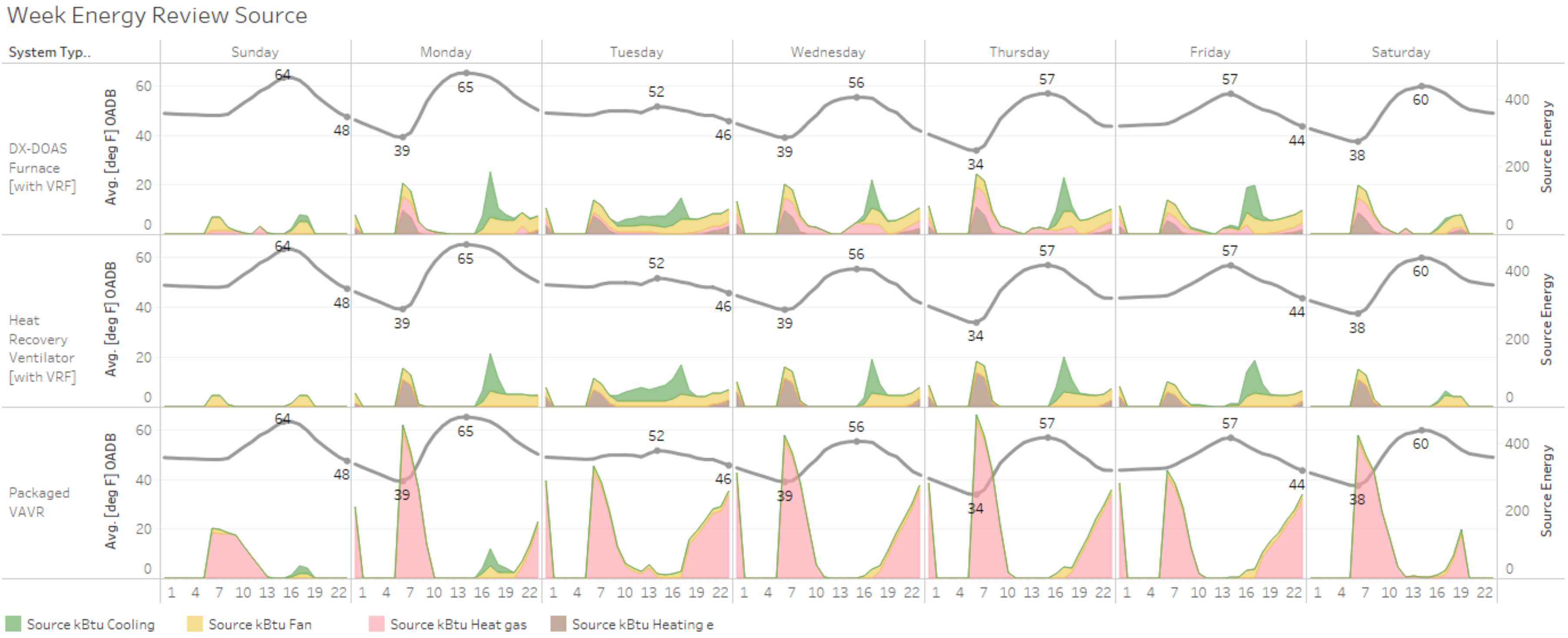


Figure 37: Source energy load profile comparison for systems in Climate Zone 4, Week 6 (Medium Offices)

Carbon Emissions: Medium Office Climate Zone 4, Week 6| January

The same week is presented in pounds of equivalent carbon emissions. This metric tracks very closely to the Source energy data.

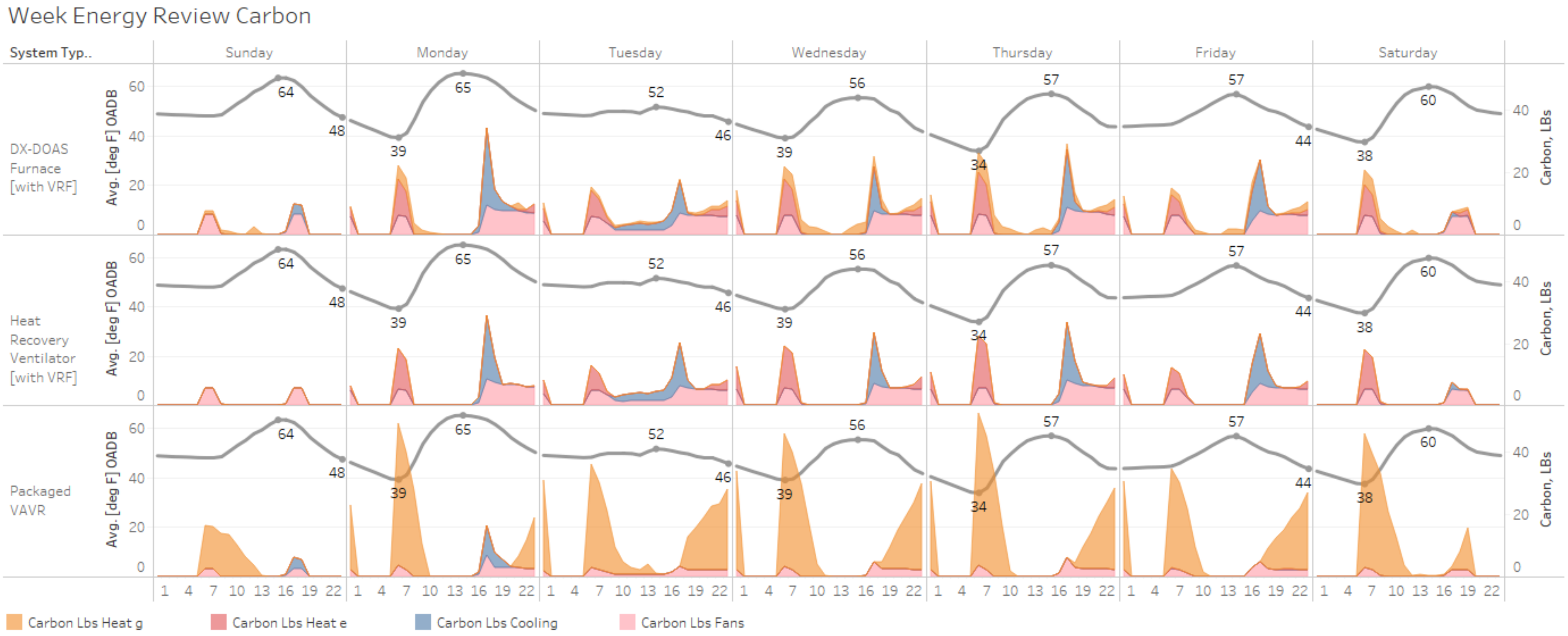
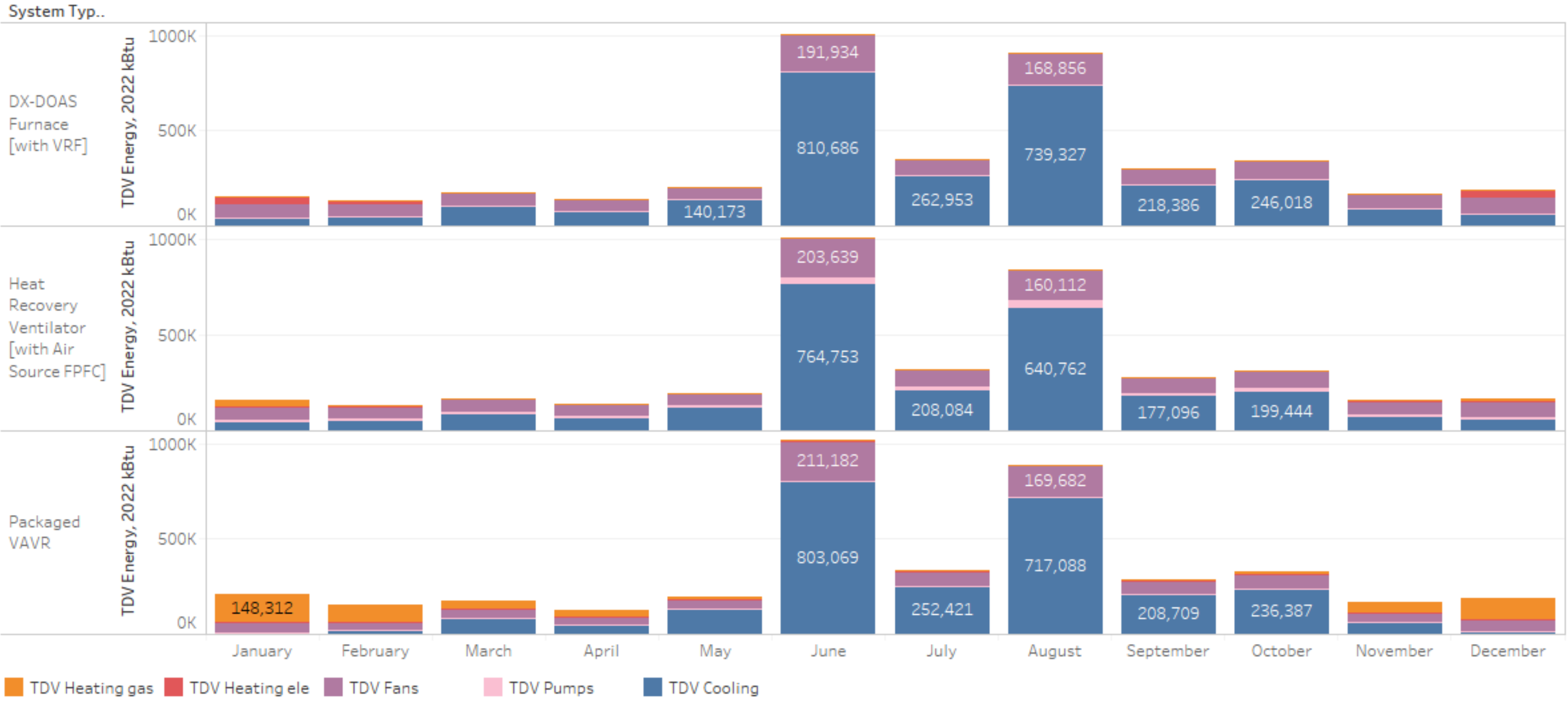


Figure 38: Carbon emissions profile comparison for systems in Climate Zone 4, Week 6 (Medium Offices).

Seasonal Energy Shifting, Representative Case

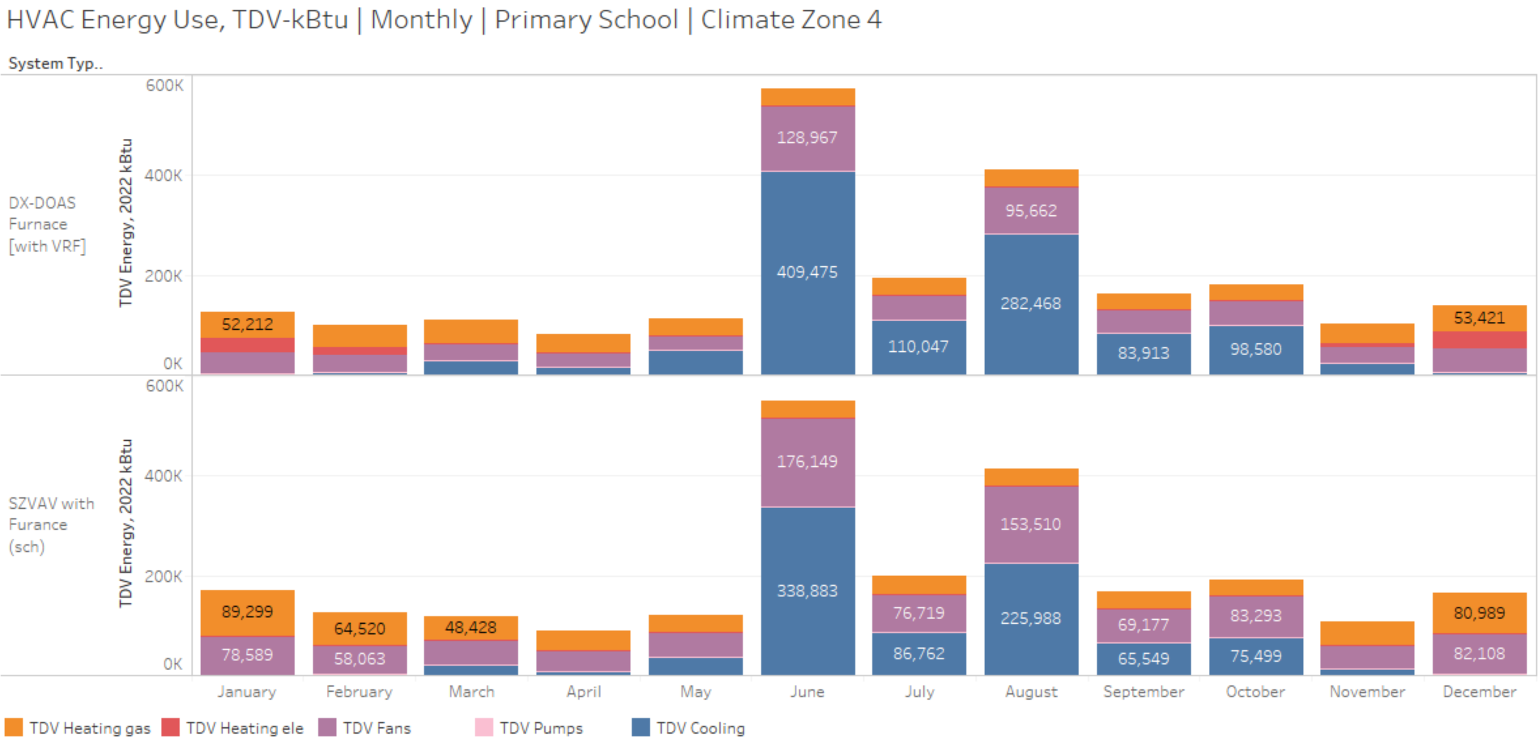
HVAC Energy Use, TDV-kBtu | Monthly | Medium Office | Climate Zone 4



System Typ..		January	February	March	April	May	June	July	August	September	October	November	December
DX-DOAS Furnace [with VRF]	TDV Heating gas	4,452	3,071	304	767	0	0	0	0	0	0	1,789	5,176
	TDV Heating ele	36,329	14,063	4,496	3,717	705	48	97	37	480	1,667	7,587	33,711
	TDV Fans	73,456	64,227	67,214	60,900	61,116	191,934	84,300	168,856	81,669	91,117	69,040	83,971
	TDV Pumps	0	0	0	0	0	0	0	0	0	0	0	0
	TDV Cooling	40,722	50,257	103,867	76,132	140,173	810,686	262,953	739,327	218,386	246,018	88,894	62,340
Heat Recovery Ventilator [with Air Source FPFC]	TDV Heating gas	33,550	10,848	1,733	1,928	167	0	0	0	5	301	4,478	16,498
	TDV Heating ele	4	1	0	0	0	0	0	0	0	0	1	4
	TDV Fans	69,671	61,520	70,646	60,702	62,614	203,639	88,451	160,112	82,722	93,221	68,813	78,472
	TDV Pumps	13,744	11,624	12,706	11,791	14,186	35,943	20,307	37,441	19,473	20,432	12,241	14,916
	TDV Cooling	41,972	49,172	84,746	64,335	114,933	764,753	208,084	640,762	177,096	199,444	70,847	56,218
Packaged VAVR	TDV Heating gas	148,312	89,255	39,516	34,735	11,829	2,865	4,095	2,563	8,367	16,628	55,799	115,889
	TDV Heating ele	42	24	10	10	3	1	1	1	3	5	15	46
	TDV Fans	57,393	45,573	50,606	43,550	50,480	211,182	75,869	169,682	70,848	76,875	51,844	63,427
	TDV Pumps	179	88	48	49	25	17	22	20	29	41	66	166
	TDV Cooling	6,368	17,471	85,145	46,357	131,543	803,069	252,421	717,088	208,709	236,387	60,320	12,249

Figure 39: Monthly comparison of energy end uses for in Climate Zone 4 (Medium Offices).

Seasonally, the DOAS configurations uses more cooling energy during shoulder and winter months from a reduction in economizing capabilities. This energy increase is balanced with a reduction in building heating, as can be seen in November through February.



System Typ..		January	February	March	April	May	June	July	August	September	October	November	December
DX-DOAS Furnace [with VRF]	TDV Heating gas	258,683	213,525	117,147	111,340	71,692	70,011	69,693	66,230	66,633	71,701	131,262	259,490
	TDV Heating ele	110,944	70,201	33,910	37,017	12,985	2,561	5,417	2,278	11,113	16,916	46,647	133,068
	TDV Fans	210,337	176,132	166,475	152,567	139,982	361,662	185,336	311,549	181,924	224,763	171,824	250,025
	TDV Pumps	0	0	0	0	0	0	0	0	0	0	0	0
	TDV Cooling	9,999	20,924	94,248	56,614	145,607	942,472	292,646	711,774	226,602	295,719	68,855	20,342
SZVAV with Furance (sch)	TDV Heating gas	89,299	64,520	48,428	40,383	34,209	34,982	34,760	33,103	32,553	33,578	47,160	80,989
	TDV Heating ele	0	0	0	0	0	0	0	0	0	0	0	0
	TDV Fans	78,589	58,063	49,772	41,432	49,771	176,149	76,719	153,510	69,177	83,293	48,655	82,108
	TDV Pumps	0	0	0	0	0	0	0	0	0	0	0	0
	TDV Cooling	1,105	3,143	19,635	8,091	37,718	338,883	86,762	225,988	65,549	75,499	12,823	2,513

Figure 40 Monthly comparison of energy end uses for in Climate Zone 4 (Primary School)

In the primary school model, the mixed air system is a configuration of single zone packaged units with two speed fans and economizers. Both systems are configured to modulate the fan speed based on space type needs of demand control ventilation and occupancy shut off capabilities. The DOAS is able to provide tighter fan energy control by modulating the DOAS to meet ventilation only needs while cycling zone fans on and off to meet space conditioning.

DOAS Modeling Approach for Prototypes

Prototypical energy models were used to assess DOAS vs Standard Design HVAC. Prototype models were modified in CBECC-Com to create DOAS configurations with separate heating and cooling systems and then exported to EnergyPlus to further configure the DOAS airflow pathways and controls.

This approach assumes the prototype models represent the prescriptive standard for each building type. While this is generally true, many features related to ventilation controls such as DCV and occupancy controls are not explicitly modeled in the prototype models generated by CBECC-Com. An additional advanced medium office prototype was created for this reason and to reflect a more detailed office model of discrete space types and use. This model is described in more detail in another Appendix C of this report.

The major changes were made in this order for each prototype and each DOAS type created:

In CBECC-Com

1. A CBECC-Com prototype model was used as the basis to capture space types, schedules, and constructions.
2. A CBECC-Com model with the basic DOAS components was created.
3. A separate heating and cooling system was built and assigned to each zone as the primary space heating or cooling system. This included VRF, Four Pipe Fan Coils, RTUs, and Mini Splits.
    a. VRF assumed one compressor system for each building.
    b. Four Pipe Fan Coils assumed a central boiler and air-cooled chiller.
    c. RTUs with gas furnaces were configured as one option.
    d. Single zone HP packaged units were configured as the mini split option.
4. The models were simulated in CBECC-Com to produce a working EnergyPlus file.

In EnergyPlus

1. The HVAC system objects were isolated in the EnergyPlus file and all geometry, constructions, and space definitions were put into separate files for each climate zone.

2. DOAS system components were set to autosize to allow the model to be used across all climate zones. The list of items includes:

    a. DOAS airflows
    b. Terminal unit airflows
    c. Cooling system capacities
    d. Heating system capacities
    e. Fan airflows

3. DOAS systems were set to size for ventilation requirements to be 150 percent outside air.
4. Zone heating and cooling fans were set to cycle on and off by default by setting their run schedules.
5. Specified the ventilation heat recovery effectiveness and controls.
6. Removed all zone HVAC direct outdoor air components so all outdoor air is provided only by the DOAS. These objects are default on all VRF fan coils from CBECC-Com, for example.
7. Specified all terminal units for ventilation supply air first before heating and cooling components to ensure proper modeling method and loads.
8. Specified terminal units to be controlled to outdoor air requirements for each space. By default, spaces assume ventilation is on or off unless defined with a schedule at the outdoor air object. This is a major gap in how DCV and occupancy sensor controls are modeled in CBECC-Com.
9. Specified those zones which require DCV to follow the occupancy schedule.
10. Specified any DOAS which serves zones with DCV to have demand control ventilation controls and variable speed fans.
11. Specified correct fan power and efficiencies for zone heating and cooling fans.
12. Specified DOAS fan power to match the maximum allowed prescriptive fan criteria depending on the type of DOAS; variable speed vs constant, HRV vs DX-DOAS with different coils.
13. Specified the cooling and heating efficiencies of DX-DOAS coils and zone heating and cooling systems to the correct COPs. Used the corrections to adjust from rated system efficiency to only compressor efficiency for each component.
14. Added system sizing factors of 1.25 for heating and 1.15 for cooling components per ACM Reference Manual 2.5.2.

Fan Power Inputs

System fan power was set based on the recommended enhancements to fan power and additional pressure credits by system sizes proposed in the FEI CASE 2022 measure. This measure provides static pressure differences by systems and components. This structure was used to set static pressures of both mixed air and DOAS central air systems in both models. This provided a more granular way to set fan power. For example, small mixed air packaged units were set to a realistic TSP of 2.5” and an DX-DOAS of 3.4”.

Cooling System Efficiency Inputs

All cooling system efficiencies and performance curves were based on the Title 24 2019 ACM and performance software default curves from CBECC-Com.

HRV/ERV SAT Controls, Proposed

While the SAT of an HRV or ERV was not explicitly set by the proposed prescriptive language, industry standard setpoints were assumed for these systems. All models assumed a constant setpoint at a temperature just below neutral of 65F. A sample set of inputs from EnergyPlus are included to demonstrate how this was implemented.

```
Schedule:Day:Interval,
  Schedule Day HRVSetPT,        !- Name
  Temperature,                 !- Schedule Type Limits Name
  No,                          !- Interpolate to Timestep
  24:00,                       !- Time 1 {hh:mm}
  18.3333333333334;          !- Value Until Time 1

SetpointManager:Scheduled,
  Setpoint Manager Scheduled 1,     !- Name
  Temperature,                    !- Control Variable
  Schedule Day HRVSetPT,            !- Schedule Name
  BaseSys6 Fan Outlet Node;         !- Setpoint Node or NodeList Name
```

DX-DOAS SAT Controls, Proposed

A sample set of inputs from EnergyPlus are included to demonstrate how this was implemented.

```
SetpointManager:OutdoorAirReset,

  DX DOAS SATR,                         !- Name
  Temperature,                        !- Control Variable
  18.3,                             !- Setpoint at Outdoor Low Temperature {C}
  7.2,                              !- Outdoor Low Temperature {C}
  15.56,                            !- Setpoint at Outdoor High Temperature {C}
  15.56,                              !- Outdoor High Temperature {C}
  BottomVAV SupplyFan Outlet Node;    !- Setpoint Node or NodeList Name

SetpointManager:OutdoorAirReset,

  DX DOAS Cooling Coil,                 !- Name
  Temperature,                        !- Control Variable
  18.3,                             !- Setpoint at Outdoor Low Temperature {C}
  7.2,                              !- Outdoor Low Temperature {C}
```

```
    12.77,                                  !- Setpoint at Outdoor High Temperature {C}
    12.77,                                      !- Outdoor High Temperature {C}
    Bottom VAV CoilCooling Outlet Node;     !- Setpoint Node or NodeList Name
```

DX-DOAS SAT Controls, Market Reference

A sample set of inputs from EnergyPlus are included to demonstrate how this was implemented.

```
SetpointManager:OutdoorAirReset,
    DX DOAS SATR,                               !- Name
    Temperature,                            !- Control Variable
    18.3,                                   !- Setpoint at Outdoor Low Temperature {C}
    7.2,                                        !- Outdoor Low Temperature {C}
    18.3,                                   !- Setpoint at Outdoor High Temperature {C}
    15.56,                                      !- Outdoor High Temperature {C}
    BottomVAV SupplyFan Outlet Node;   !- Setpoint Node or NodeList Name
```

```
SetpointManager:OutdoorAirReset,

    DX DOAS Cooling Coil,                       !- Name
    Temperature,                            !- Control Variable
    18.3,                                   !- Setpoint at Outdoor Low Temperature {C}
    7.2,                                        !- Outdoor Low Temperature {C}
    12.77,                                      !- Setpoint at Outdoor High Temperature {C}
    12.77,                                      !- Outdoor High Temperature {C}
    Bottom VAV CoilCooling Outlet Node;     !- Setpoint Node or NodeList Name
```

Terminal Fan Unit Cycling Controls

For VRF terminal units the schedule for:

```
    !- Supply Air Fan Operating Mode Schedule Name
```

Was set to 0, which enabled the fan to cycle on only with a call from the thermostat.

Zone Demand Control Ventilation

To evaluate the impact of DCV on energy use in both the Mixed Air and DOAS configurations, the zones which required DCV were set to have an occupancy fractional schedule to adjust the airflow quantity.

This schedule may reduce ventilation lower than minimums on some hours, however this minor error is only for a few hours and is present in both models. This was assumed an acceptable parameter to not specify further to save time.

Below is an example of the outdoor air object for a DOAS configuration where ventilation was increased, and a schedule of control was applied:

```
DesignSpecification:OutdoorAir,
   Corner_Class_1_Pod_2_FF_Zn Design Specification Outdoor Air,       !- Name
   Maximum,                                                     !- Outdoor Air Method
   #eval[ 1.5 * 0.007079211648 ],                                   !- Outdoor Air Flow per
Person
   #eval[ 1.5 * 0.000762 ],                                     !- Outdoor Air Flow per
Zone Floor Area
   0.0,                                                       !- Outdoor Air Flow per
Zone
   0,
   SchoolOccupancy;
```

Economizer Controls of DOAS

In DOAS configurations with ventilation heat recovery, the outdoor air controller object was set to economizer controls with an upper and lower limit defined. An example of these properties is as follows:

```
Controller:OutdoorAir,
   BaseSys6 OACtrl,        !- Name
   BaseSys6 OACtrl OA System Relief Stream Outlet Node,  !- Relief Air Outlet Node
Name
   DOAS System 1 Supply Side (Return Air) Inlet Node,  !- Return Air Node Name
   BaseSys6 OACtrl OA System Mixed Air Node,  !- Mixed Air Node Name
   BaseSys6 OACtrl OA System OA Node,  !- Actuator Node Name
   Autosize,       !- 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
   15.56,        !- Economizer Minimum Limit Dry-Bulb Temperature {C}
   NoLockout,             !- Lockout Type
   ProportionalMinimum,     !- Minimum Limit Type
   Always On,             !- Minimum Outdoor Air Schedule Name
   ,                   !- Minimum Fraction of Outdoor Air Schedule Name
   BaseSys6 OACtrl Max OA Schedule,  !- Maximum Fraction of Outdoor Air Schedule
Name
   BaseSys6 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
```

Ventilation heat Recovery Inputs

For DOAS configurations, the following example demonstrates how each system was configured in the various models. Only sensible energy recovery was assumed, including a relationship of increased effectiveness at 75 percent based on reviewing several product selections of a minimum increase of 5 percent at this lower airflow rate. A sample set of inputs from EnergyPlus are included to demonstrate how this was implemented.

```
HeatExchanger:AirToAir:SensibleAndLatent,

   HeatRecovery 2,          !- Name
   Always On Discrete,      !- Availability Schedule Name
   Autosize,        !- Nominal Supply Air Flow Rate {m3/s}
   0.6,                  !- Sensible Effectiveness at 100% Heating Air Flow {dimensionless}
   ,                  !- Latent Effectiveness at 100% Heating Air Flow {dimensionless}
   0.65,                 !- Sensible Effectiveness at 75% Heating Air Flow {dimensionless}
   ,                  !- Latent Effectiveness at 75% Heating Air Flow {dimensionless}
   0.6,                  !- Sensible Effectiveness at 100% Cooling Air Flow {dimensionless}
   ,                  !- Latent Effectiveness at 100% Cooling Air Flow {dimensionless}
   0.65,                 !- Sensible Effectiveness at 75% Cooling Air Flow {dimensionless}
   ,                    !- Latent Effectiveness at 75% Cooling Air Flow {dimensionless}
   BaseSys6 OACtrl-2 OA System OA Node,  !- Supply Air Inlet Node Name
   HeatRecovery 2 OA Stream Outlet Node,  !- Supply Air Outlet Node Name
   BaseSys6 OACtrl-2 OA System Relief Stream Outlet Node,  !- Exhaust Air Inlet Node Name
   BaseSys6 OACtrl-2 OA System Relief Node,  !- Exhaust Air Outlet Node Name
   0,                    !- Nominal Electric Power {W}
   Yes,                   !- Supply Air Outlet Temperature Control
   Plate,                 !- Heat Exchanger Type
   None,                   !- Frost Control Type
   1.7,                   !- Threshold Temperature {C}
   ,                    !- Initial Defrost Time Fraction {dimensionless}
   ,                    !- Rate of Defrost Time Fraction Increase {1/K}
   Yes;                     !- Economizer Lockout
```

Full Input Tables of Efficiencies

Note 1: for all space types where dynamic ventilation control was required the outdoor air object was configured to follow the occupancy schedule for the same space type. This was considered a conservative estimate of control for ventilation given that most schedules for occupancy are above 80 percent for most hours of the day with a ramp in the morning and evening hours. Default CBECC-Com prototypes did not enable this level of ventilation control and did not actually modulate outdoor air or fan speed as Title 24 requires.

Note 2: fan pressure was re-calculated for each case based on the CASE 2022 proposed fan power measure with new incremental pressure credits by fan size and system components. This provided a method of equal comparison for Mixed Air and DOAS at each building type.

Medium Offices

		Medium Office Building				
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design Configurations**			
		VAV with Reheat and DX Cooling	**HRV (DOAS) with FPFC, Chiller, Boiler**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**	**DX-DOAS heat pump with Air-Source VRF**
Systems		One per floor	One DOAS for building	One DOAS for building	One DOAS for building	One DOAS for building
Ventilation Heating Source		n/a	none	none	Gas Furnace	Heat Pump
Ventilation Cooling Source		DX-Coil	none	none	DX-Coil	DX-Coil
Fan Systems						
Fan Type		Variable Speed	Variable Speed	Variable Speed	Variable Speed	Variable Speed
Fan Airflow Control[1]		DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset
Primary Fan Sizing		Sensible	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement
Primary Fan Pressure[2]	PA	1269.9	1020.9	1020.9	1269.9	1294.8
	inches	5.10	4.10	4.10	5.10	5.20

		Medium Office Building				
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design Configurations**			
		VAV with Reheat and DX Cooling	**HRV (DOAS) with FPFC, Chiller, Boiler**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**	**DX-DOAS heat pump with Air-Source VRF**
Primary Fan Efficiency	%	60%	60%	60%	60%	60%
Primary Fan Motor Efficiency	%	93%	93%	93%	93%	93%
Zone Fan Pressure	PA	n/a	317	317	317	317
	inches	n/a	1.27	1.27	1.27	1.27
Zone Fan Efficiency	%	n/a	42.75%	42.75%	42.75%	42.75%
Zone Fan Motor Efficiency	%	n/a	85.50%	85.50%	85.50%	85.50%
Zone Fan Airflow Control		n/a	Cycle On/Off with Thermostat	Multi-Speed, Cycle On/Off with Thermostat	Multi-Speed, Cycle On/Off with Thermostat	Multi-Speed, Cycle On/Off with Thermostat
Central Air Temperature Control						
Supply Air Temperature Control		SAT Reset based on Zone, 5 deg F	Constant SAT Setpoint	Constant SAT Setpoint	DX-DOAS SAT Reset, Cooling and Reheat	DX-DOAS SAT Reset, Cooling and Reheat
Supply Air Setpoint		55F to 60 F Cooling	60 F	60 F	Cooling: 70F at 45F OA/ 55F at 55F OA. Reheat: 70F at 45F OA/ 55F at 60F OA.	Cooling: 70F at 45F OA/ 55F at 55F OA. Reheat: 70F at 45F OA/ 55F at 60F OA.
Economizer Type		Airside Economizing	Ventilation Economizing	Ventilation Economizing	Ventilation Economizing	Ventilation Economizing
Economizer Control		DifferentialDrybulb	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum

		Medium Office Building				
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design Configurations**			
		VAV with Reheat and DX Cooling	**HRV (DOAS) with FPFC, Chiller, Boiler**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**	**DX-DOAS heat pump with Air-Source VRF**
Ventilation Heat Recovery System		none	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow
Ventilation Heat Recovery Control		n/a	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.
Zone Terminal Unit Systems						
Zone Terminal Unit Type		VAV with Reheat	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation
Minimum Airflow Controls		20%	20% or vent min	20% or vent min	20% or vent min	20% or vent min
Zone Heating and Cooling Unit		n/a	Four Pipe Fan Coil Unit	Refrigerant Fan Coil Unit	Refrigerant Fan Coil Unit	Refrigerant Fan Coil Unit
Zone Heating and Cooling Unit Control		n/a	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat
Primary Cooling Heating System						
Cooling System		DX-Coils, 1 per AHU	Air Cooled Chiller	Air-Source VRF	Air-Source VRF	Air-Source VRF
Heating System		Central Boiler	Boiler	Air-Source VRF	Air-Source VRF	Air-Source VRF
Efficiency Source		Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019
Cooling Efficiency	EER	10.6	n/a	10.6	10.6	10.6
Heating Coil Efficiency	% or COP47 or HSPF	80%	n/a	330%	330%	330%

		Medium Office Building				
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design Configurations**			
		VAV with Reheat and DX Cooling	**HRV (DOAS) with FPFC, Chiller, Boiler**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**	**DX-DOAS heat pump with Air-Source VRF**
Heating Coil Efficiency	Unit	Percent	Percent	COP47	COP47	COP47
Rated Capacity of Efficiency	Btu/hr	100000	n/a	100000	100000	100000
Cooling Modeled Eff	COP	3.67	2.99	3.67	3.67	3.67
Heating Modeled Eff	COP	80%	82.25%	3.55	3.55	3.55
Refrigerant Heat Recovery		n/a	n/a	yes	yes	yes
DOAS Ventilation Cooling Heating Coils						
Cooling System		n/a	none	none	DX-Coil	DX-Coil
Heating System		n/a	none	none	Gas Furnace	Heat Pump
Efficiency Source		n/a	n/a	n/a	Title 24 2019	Title 24 2019
Cooling Efficiency	EER	n/a	n/a	n/a	11	11
Heating Coil Efficiency	% or COP47 or HSPF	n/a	n/a	n/a	80%	COP47
Heating Coil Efficiency	Unit	n/a	n/a	n/a	Percent	3.3
Rated Capacity of Efficiency	Btu/hr	n/a	n/a	n/a	65000	65000
Cooling Modeled Eff	COP	n/a	n/a	n/a	3.77	3.77
Heating Modeled Eff	COP	n/a	n/a	n/a	80%	354%

Small Offices

		Small Office Building					
Parameter	**Units**	**Mixed Air Economizer Design**		**DOAS Design**			
		Two Speed Single Zone Packaged Units	**Two Speed Single Zone Heat Pump Units**	**HRV (DOAS) with Mini-Splits**	**HRV (DOAS) with RTUs**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Systems		Two Speed Single Zone Packaged Units	Two Speed Single Zone Heat Pump Units	HRV (DOAS) with Mini-Splits	HRV (DOAS) with RTUs	HRV (DOAS) with Air-Source VRF	DX-DOAS with Air-Source VRF
Ventilation Heating Source		One per Zone	One per Zone	One DOAS for building	One DOAS for building	One DOAS for building	One DOAS for building
Ventilation Cooling Source		Furnace	Heat Pump	none	none	none	Gas Furnace
Fan Systems		DX-Coil	DX-Coil	none	none	none	DX-Coil
Fan Type		Two-Speed Fans	Two-Speed Fans	Constant Volume	Constant Volume	Constant Volume	Constant Volume
Fan Airflow Control		Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	n/a	n/a	n/a	n/a
Primary Fan Sizing	PA	Sensible	Sensible	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement
Primary Fan Pressure	inches	796.8	796.8	647.4	647.4	647.4	846.6
	%	3.20	3.20	2.60	2.60	2.60	3.40
Primary Fan Efficiency	%	56%	56%	56%	56%	56%	56%
Primary Fan Motor Efficiency	PA	86.50%	86.50%	86.50%	86.50%	86.50%	86.50%
Zone Fan Pressure	inches	n/a	n/a	317	317	317	317

		Small Office Building					
Parameter	**Units**	**Mixed Air Economizer Design**		**DOAS Design**			
		Two Speed Single Zone Packaged Units	**Two Speed Single Zone Heat Pump Units**	**HRV (DOAS) with Mini-Splits**	**HRV (DOAS) with RTUs**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
	%	n/a	n/a	1.27	1.27	1.27	1.27
Zone Fan Efficiency	%	n/a	n/a	42.75%	42.75%	42.75%	42.75%
Zone Fan Motor Efficiency		n/a	n/a	85.50%	85.50%	85.50%	85.50%
Zone Fan Airflow Control		n/a	n/a	Cycle On/Off with Thermostat	Cycle On/Off with Thermostat	Multi-Speed, Cycle On/Off with Thermostat	Multi-Speed, Cycle On/Off with Thermostat
Central Air Temperature Control							
Supply Air Temperature Control		Single Zone Reset to Thermostat	Single Zone Reset to Thermostat	Constant SAT Setpoint	Constant SAT Setpoint	Constant SAT Setpoint	Constant SAT Setpoint
Supply Air Setpoint		n/a	n/a	65 F	65 F	65 F	65 F
Economizer Type		Airside Economizing	Airside Economizing	Ventilation Free Cooling	Ventilation Economizing	Ventilation Economizing	Ventilation Economizing
Economizer Control		DifferentialDrybulb	DifferentialDrybulb	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum
Ventilation Heat Recovery System		none	none	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow

		Small Office Building					
Parameter	**Units**	**Mixed Air Economizer Design**		**DOAS Design**			
		Two Speed Single Zone Packaged Units	**Two Speed Single Zone Heat Pump Units**	**HRV (DOAS) with Mini-Splits**	**HRV (DOAS) with RTUs**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Ventilation Heat Recovery Control		n/a	n/a	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.
Zone Terminal Unit Systems							
Zone Terminal Unit Type		VAV No Reheat	VAV No Reheat	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation
Minimum Airflow Controls		50%	50%	Constant, 100%	Constant, 100%	Constant, 100%	Constant, 100%
Zone Heating and Cooling Unit		n/a	n/a	SZ Mini-Split HP	SZ RTU with Furnace	Refrigerant Fan Coil Unit	Refrigerant Fan Coil Unit
Zone Heating and Cooling Unit Control		n/a	n/a	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat
Primary Cooling Heating System							
Cooling System		DX-Coil	DX-Coil	DX-Coil	DX-Coil	Air-Source VRF	Air-Source VRF
Heating System		Furnace	Heat Pump	Heat Pump	Furnace	Air-Source VRF	Air-Source VRF
Efficiency Source	EER	Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019

		Small Office Building					
Parameter	**Units**	**Mixed Air Economizer Design**		**DOAS Design**			
		Two Speed Single Zone Packaged Units	**Two Speed Single Zone Heat Pump Units**	**HRV (DOAS) with Mini-Splits**	**HRV (DOAS) with RTUs**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Cooling Efficiency	% or COP47 or HSPF	11.2	11.2	11.2	11.2	11	11
Heating Coil Efficiency	Unit	80%	350%	330%	80%	7.70	7.70
Heating Coil Efficiency	Btu/hr	Percent	COP47	COP47	Percent	HSPF	HSPF
Rated Capacity of Efficiency	COP	65000	65000	65000	65000	65000	65000
Cooling Modeled Eff	COP	3.84	3.84	3.84	3.84	3.77	3.77
Heating Modeled Eff		80%	3.75	3.54	80%	3.74	3.74
Refrigerant Heat Recovery		n/a	n/a	n/a	n/a	yes	yes
DOAS Ventilation Cooling Heating Coils							
Cooling System		n/a	n/a	none	none	none	DX-Coil
Heating System		n/a	n/a	none	none	none	Furnace
Efficiency Source	EER	n/a	n/a	n/a	n/a	n/a	Title 24 2019
Cooling Efficiency	% or COP47	n/a	n/a	n/a	n/a	n/a	11.2

		Small Office Building					
Parameter	**Units**	**Mixed Air Economizer Design**		**DOAS Design**			
		Two Speed Single Zone Packaged Units	**Two Speed Single Zone Heat Pump Units**	**HRV (DOAS) with Mini-Splits**	**HRV (DOAS) with RTUs**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
	or HSPF						
Heating Coil Efficiency	Unit	n/a	n/a	n/a	n/a	n/a	80%
Heating Coil Efficiency	Btu/hr	n/a	n/a	n/a	n/a	n/a	Percent
Rated Capacity of Efficiency	COP	n/a	n/a	n/a	n/a	n/a	65000
Cooling Modeled Eff	COP	n/a	n/a	n/a	n/a	n/a	3.84
Heating Modeled Eff							

Primary and Secondary Schools

		Primary School Building		Secondary School		
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design**	**Mixed Air Economizer Design**	**DOAS Design**	**DOAS Design**
		Two Speed Single Zone Packaged Units	**DX-DOAS with Air-Source VRF**	**VAV with Reheat and CHW Cooling Coil**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Systems		One per Zone	One DOAS for building	One per floor	One DOAS for building	One DOAS for building
Ventilation Heating Source		Furnace	Furnace	n/a	none	DX-Coil
Ventilation Cooling Source		DX-Coil	DX-Coil	CHW Plant	none	Furnace

		Primary School Building		Secondary School		
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design**	**Mixed Air Economizer Design**	**DOAS Design**	**DOAS Design**
		Two Speed Single Zone Packaged Units	**DX-DOAS with Air-Source VRF**	**VAV with Reheat and CHW Cooling Coil**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Fan Systems						
Fan Type		Two-Speed Fans	Variable Volume	Variable Volume	Variable Volume	Variable Volume
Fan Airflow Control		Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	Thermostat, 50% Flow at 30% Power, Full Flow at Full Power	DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset	DCV & Pressure Setpoint Reset
Primary Fan Sizing		Sensible	1.5 x Ventilation Requirement	Sensible	1.5 x Ventilation Requirement	1.5 x Ventilation Requirement
Primary Fan Pressure	PA	958.65	1220.1	1269.9	1020.9	1220.1
	inches	3.85	4.90	5.10	4.10	4.90
Primary Fan Efficiency	%	56%	60%	60%	60%	60%
Primary Fan Motor Efficiency	%	86.50%	92.40%	92.40%	92.40%	92.40%
Zone Fan Pressure	PA	n/a	317	n/a	317	317
	inches	n/a	1.27	n/a	1.27	1.27
Zone Fan Efficiency	%	n/a	42.75%	n/a	42.75%	42.75%
Zone Fan Motor Efficiency	%	n/a	85.50%	n/a	85.50%	85.50%
Zone Fan Airflow Control		n/a	Cycle On/Off with Thermostat	n/a	Cycle On/Off with Thermostat	Cycle On/Off with Thermostat

		Primary School Building		Secondary School		
Parameter	**Units**	**Mixed Air Economizer Design**	**DOAS Design**	**Mixed Air Economizer Design**	**DOAS Design**	**DOAS Design**
		Two Speed Single Zone Packaged Units	**DX-DOAS with Air-Source VRF**	**VAV with Reheat and CHW Cooling Coil**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Central Air Temperature Control						
Supply Air Temperature Control		Single Zone Reset to Thermostat	DX-DOAS SAT Reset, Cooling and Reheat	SAT Reset based on Zone, 5 deg F	Constant SAT Setpoint	SAT Reset at Cooling, SAT Reset at Fan/ Reheat
Supply Air Setpoint		n/a	Cooling: 70F at 45F OA/ 55F at 55F OA. Reheat: 70F at 45F OA/ 55F at 60F OA.	55F to 60 F Cooling	65 F	Cooling: 70F at 45F OA/ 55F at 55F OA. Reheat: 70F at 45F OA/ 55F at 60F OA.
Economizer Type		Airside Economizing	Ventilation Free Cooling	Airside Economizing	Ventilation Free Cooling	Ventilation Free Cooling
Economizer Control		DifferentialDrybulb	FixedDrybulb with 55F minimum	DifferentialDrybulb	FixedDrybulb with 55F minimum	FixedDrybulb with 55F minimum
Ventilation Heat Recovery System		none	Sensible Recovery: 60% at 100% flow 65% at 75% flow	none	Sensible Recovery: 60% at 100% flow 65% at 75% flow	Sensible Recovery: 60% at 100% flow 65% at 75% flow
Ventilation Heat Recovery Control		n/a	SAT Integrated Bypass Control.	n/a	SAT Integrated Bypass Control.	SAT Integrated Bypass Control.
Zone Terminal Unit Systems						

		Primary School Building		Secondary School		
Parameter	Units	Mixed Air Economizer Design	DOAS Design	Mixed Air Economizer Design	DOAS Design	DOAS Design
		Two Speed Single Zone Packaged Units	**DX-DOAS with Air-Source VRF**	**VAV with Reheat and CHW Cooling Coil**	**HRV (DOAS) with Air-Source VRF**	**DX-DOAS with Air-Source VRF**
Zone Terminal Unit Type		VAV No Reheat	VAV No Reheat	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation	VAV No Reheat for Ventilation
Minimum Airflow Controls		50%	20%	20%	20%	20%
Zone Heating and Cooling Unit		n/a	Refrigerant Fan Coil Unit	n/a	Refrigerant Fan Coil Unit	Refrigerant Fan Coil Unit
Zone Heating and Cooling Unit Control		n/a	Cycle On/Off by Thermostat	n/a	Cycle On/Off by Thermostat	Cycle On/Off by Thermostat
Primary Cooling Heating System						
Cooling System		DX-Coil	Air-Source VRF	Chiller Water Sourced	DX-Coil	Air-Source VRF
Heating System		Furnace	Air-Source VRF	Boiler HW	Boiler HW	Air-Source VRF
Efficiency Source		Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019	Title 24 2019
Cooling Efficiency	EER	11.2	11	n/a	11.2	11
Heating Coil Efficiency	% or COP47 or HSPF	80%	7.70	n/a	80%	7.70

		Primary School Building		Secondary School		
Parameter	Units	Mixed Air Economizer Design	DOAS Design	Mixed Air Economizer Design	DOAS Design	DOAS Design
		Two Speed Single Zone Packaged Units	DX-DOAS with Air-Source VRF	VAV with Reheat and CHW Cooling Coil	HRV (DOAS) with Air-Source VRF	DX-DOAS with Air-Source VRF
Heating Coil Efficiency	Unit	Percent	HSPF	n/a	Percent	HSPF
Rated Capacity of Efficiency	Btu/hr	65000	65000	n/a	65000	65000
Cooling Modeled Eff	COP	3.84	3.77	5.17	3.84	3.77
Heating Modeled Eff	COP	80%	3.74	80.5%	80%	3.74
Refrigerant Heat Recovery		n/a	yes	n/a	n/a	yes
DOAS Ventilation Cooling Heating Coils						
Cooling System		n/a	DX-Coil	n/a	n/a	DX-Coil
Heating System		n/a	Furnace	n/a	n/a	Gas Furnace
Efficiency Source		n/a	Title 24 2019	n/a	n/a	Title 24 2019
Cooling Efficiency	EER	n/a	11.2	n/a	n/a	11.2
Heating Coil Efficiency	% or COP47 or HSPF	n/a	80%	n/a	n/a	80%

		Primary School Building		Secondary School		
Parameter	Units	Mixed Air Economizer Design	DOAS Design	Mixed Air Economizer Design	DOAS Design	DOAS Design
		Two Speed Single Zone Packaged Units	DX-DOAS with Air-Source VRF	VAV with Reheat and CHW Cooling Coil	HRV (DOAS) with Air-Source VRF	DX-DOAS with Air-Source VRF
Heating Coil Efficiency	Unit	n/a	Percent	n/a	n/a	Percent
Rated Capacity of Efficiency	Btu/hr	n/a	65000	n/a	n/a	65000
Cooling Modeled Eff	COP	n/a	3.84	n/a	n/a	3.84
Heating Modeled Eff	COP	n/a	80%	n/a	n/a	80%

Fan Pressure Credits

					Supply Credits													Exhaust Credits		
	Parameter	HVAC System Components	Pressure Drop Inches	Pressure Drop PA	Supply fan system duct and outlet losses	100% Outside air system meeting the requirements of Note 2.	MERV 13 to MERV 16 Filter	Hydronic heating coil	Electric heat	Gas heat	Hydronic/DX cooling coil, or	Reheat coil for dehumidification	Enthalpy recovery	Sensible only	Air blender	Exhaust system duct, plenum,	Filter - any MERV value	Exhaust Enthalpy recovery	Sensible only Exhaust	Return and/or exhaust airflow
Medium Office Building	Mixed Air Economizer Design	VAV with Reheat and DX Cooling	4.9	1220	2.0	-	0.6	-	-	0.2	0.6	-	-	-	-	1.0	-	-	-	0.5
	DOAS Design Configurations	HRV (DOAS) with FPFC, Chiller, Boiler	4.6	1145	2.0	-	0.6	-	-	-	-	-	-	0.5	-	1.0	-	-	0.5	-
		HRV (DOAS) with Air-Source VRF	4.6	1145	2.0	-	0.6	-	-	-	-	-	-	0.5	-	1.0	-	-	0.5	-
		DX-DOAS with Air-Source VRF	5.6	1394	2.0	-	0.6	-	-	0.2	0.6	0.2	-	0.5	-	1.0	-	-	0.5	-

					Supply Credits												Exhaust Credits			
	Parameter	HVAC System Components	Pressure Drop Inches	Pressure Drop PA	Supply fan system duct and outlet losses	100% Outside air system meeting the requirements of Note 2.	MERV 13 to MERV 16 Filter	Hydronic heating coil	Electric heat	Gas heat	Hydronic/DX cooling coil, or	Reheat coil for dehumidification	Enthalpy recovery	Sensible only	Air blender	Exhaust system duct, plenum,	Filter - any MERV value	Exhaust Enthalpy recovery	Sensible only Exhaust	Return and/or exhaust airflow
		DX-DOAS heat pump with Air-Source VRF	5.7	1419	2.0	-	0.6	0.3	-	-	0.6	0.2	-	0.5	-	1.0	-	-	0.5	-
Small Office Building	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	3.0	747	0.8	-	0.4	-	-	0.2	0.6	-	-	-	-	0.5	-	-	-	0.5
		Two Speed Single Zone Heat Pump Units	3.0	747	0.8	-	0.4	0.2	-	-	0.6	-	-	-	-	0.5	-	-	-	0.5
	DOAS Design	HRV (DOAS) with Mini-Splits	2.6	647	0.8	0.3	0.4	-	-	-	-	-	-	0.3	-	0.5	-	-	0.3	-
		HRV (DOAS) with RTUs	2.6	647	0.8	0.3	0.4	-	-	-	-	-	-	0.3	-	0.5	-	-	0.3	-
		HRV (DOAS) with Air-Source VRF	2.6	647	0.8	0.3	0.4	-	-	-	-	-	-	0.3	-	0.5	-	-	0.3	-
		DX-DOAS with Air-Source VRF	3.6	896	0.8	0.3	0.4	-	-	0.2	0.6	0.2	-	0.3	-	0.5	-	-	0.3	-
Primary	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	3.7	909	1.0	-	0.6	-	-	0.2	0.6	-	-	-	-	0.8	-	-	-	0.5
	DOAS Design	DX-DOAS with Air-Source VRF	4.9	1220	1.3	0.5	0.6	-	-	0.2	0.6	-	-	0.5	-	0.8	-	-	0.5	-

					Supply Credits												Exhaust Credits			
	Parameter	HVAC System Components	Pressure Drop Inches	Pressure Drop PA	Supply fan system duct and outlet losses	100% Outside air system meeting the requirements of Note 2.	MERV 13 to MERV 16 Filter	Hydronic heating coil	Electric heat	Gas heat	Hydronic/DX cooling coil, or	Reheat coil for dehumidification	Enthalpy recovery	Sensible only	Air blender	Exhaust system duct, plenum,	Filter - any MERV value	Exhaust Enthalpy recovery	Sensible only Exhaust	Return and/or exhaust airflow
Secondary School	Mixed Air Economizer Design	VAV with Reheat and CHW Cooling Coil	4.9	1220	2.0	-	0.6	-	-	0.2	0.6	-	-	-	-	1.0	-	-	-	0.5
	DOAS Design	HRV (DOAS) with Air-Source VRF	4.1	1021	1.3	0.5	0.6	-	-	-	-	-	-	0.5	-	0.8	-	-	0.5	-
	DOAS Design	DX-DOAS with Air-Source VRF	4.9	1220	1.3	0.5	0.6	-	-	0.2	0.6	-	-	0.5	-	0.8	-	-	0.5	-
Retail Stand	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	3.0	747	0.8	-	0.4	-	-	0.2	0.6	-	-	-	-	0.5	-	-	-	0.5
	DOAS Design	HRV (DOAS) with Air-Source VRF	2.6	647	0.8	0.3	0.4	-	-	-	-	-	-	0.3	-	0.5	-	-	0.3	-

Fan Power Credits by Component

	Multi-Zone VAV System[1]	Constant Volume/Single -zone VAV >10,000 cfm	Constant Volume/Single-zone VAV >5,000 cfm and ≤10,000 cfm	Constant Volume/Single-zone VAV ≤5,000 cfm
System Type and Design Airflow				
Supply fan system duct and outlet losses	2	1.25	1	0.8
100% Outside air system meeting the requirements of Note 2.	0	0.5	0.5	0.3
MERV 13 to MERV 16 Filter	0.6	0.6	0.6	0.4
Hydronic heating coil	0.3	0.3	0.2	0.2
Electric heat	0.2	0.2	0.2	0.2
Gas heat	0.2	0.2	0.2	0.2
Hydronic/DX cooling coil, or heat pump coil	0.6	0.6	0.6	0.6
Reheat coil for dehumidification	0.2	0.2	0.2	0.2
Enthalpy recovery	0.6	0.6	0.6	0.6
Sensible only	0.5	0.5	0.5	0.3
Air blender	0.2	0.2	0.2	0.2
Exhaust system duct, plenum, inlet, and outlet	1	0.75	0.75	0.5
Filter - any MERV value	0.2	0.2	0.2	0.2
Exhaust Enthalpy recovery	0.6	0.6	0.6	0.6
Sensible only Exhaust	0.5	0.5	0.5	0.3
Return and/or exhaust airflow control devices	0.5	0.5	0.5	0.5

Fan Types Assigned to Each System

Medium Office Building	Mixed Air Economizer Design	VAV with Reheat and DX Cooling	Multi-Zone VAV System
	DOAS Design Configurations	HRV (DOAS) with FPFC, Chiller, Boiler	Constant Volume/Single-zone VAV >10,000 cfm
		HRV (DOAS) with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
		DX-DOAS with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
		DX-DOAS heat pump with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
Small Office Building	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	Constant Volume/Single-zone VAV ≤5,000 cfm
		Two Speed Single Zone Heat Pump Units	Constant Volume/Single-zone VAV ≤5,000 cfm
	DOAS Design	HRV (DOAS) with Mini-Splits	Constant Volume/Single-zone VAV ≤5,000 cfm
		HRV (DOAS) with RTUs	Constant Volume/Single-zone VAV ≤5,000 cfm
		HRV (DOAS) with Air-Source VRF	Constant Volume/Single-zone VAV ≤5,000 cfm
		DX-DOAS with Air-Source VRF	Constant Volume/Single-zone VAV ≤5,000 cfm
Primary School Building	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	Constant Volume/Single-zone VAV >5,000 cfm and ≤10,000 cfm
	DOAS Design	DX-DOAS with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
Secondary School	Mixed Air Economizer Design	VAV with Reheat and CHW Cooling Coil	Multi-Zone VAV System
	DOAS Design	HRV (DOAS) with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
	DOAS Design	DX-DOAS with Air-Source VRF	Constant Volume/Single-zone VAV >10,000 cfm
RetailStandAlone	Mixed Air Economizer Design	Two Speed Single Zone Packaged Units	Constant Volume/Single-zone VAV ≤5,000 cfm
	DOAS Design	HRV (DOAS) with Air-Source VRF	Constant Volume/Single-zone VAV ≤5,000 cfm

Medium Office Enhancements for DCV

The medium office model was enhanced to have more discrete space types vs using only one space type blended in all zones. Spaces were re-assigned using Title 24 space options. The blended Open Office space was maintained for some areas.

	Zone Name	**Space Type**
1	CORE_BOTTOM THERMAL ZONE	Office Area (>250 square feet)
2	CORE_MID THERMAL ZONE	Corridor
3	CORE_TOP THERMAL ZONE	Office Area (>250 square feet)
4	FIRSTFLOOR_PLENUM THERMAL ZONE	plenum
5	MIDFLOOR_PLENUM THERMAL ZONE	plenum
6	PERIMETER_BOT_ZN_1 THERMAL ZONE	Breakroom
7	PERIMETER_BOT_ZN_2 THERMAL ZONE	Conference
8	PERIMETER_BOT_ZN_3 THERMAL ZONE	Office Area (Open Plan)
9	PERIMETER_BOT_ZN_4 THERMAL ZONE	Office Area (Open Plan)
10	PERIMETER_MID_ZN_1 THERMAL ZONE	Office Area (<250 square feet)
11	PERIMETER_MID_ZN_2 THERMAL ZONE	Office Area (>250 square feet)
12	PERIMETER_MID_ZN_3 THERMAL ZONE	Office Area (Open Plan)
13	PERIMETER_MID_ZN_4 THERMAL ZONE	Office Area (>250 square feet)
14	PERIMETER_TOP_ZN_1 THERMAL ZONE	Conference
15	PERIMETER_TOP_ZN_2 THERMAL ZONE	Office Area (Open Plan)
16	PERIMETER_TOP_ZN_3 THERMAL ZONE	Corridor
17	PERIMETER_TOP_ZN_4 THERMAL ZONE	Office Area (Open Plan)
18	TOPFLOOR_PLENUM THERMAL ZONE	plenum

All space types triggered either DCV or occupancy based ventilation shut off controls. To simulate these, all outdoor air components for each room were set to control their ventilation air to use the occupancy fractional schedule. This is the default office occupancy schedule defined by Title 24. This method was used to provide a level of dynamic control for ventilation, even if not a perfect representation of occupancy shut off. The schedule never assumes a fully off hour during the middle of the day, so this approach was considered to be reasonable and potentially conservative. This approach does scale the ventilation, which is defined as a single input per space with this fractional schedule. This approach may result in lower fractions of outdoor air on a few hours below a DCV space minimum, however it is very unlikely. The fractional schedule is only at 10 percent for 7am and hours past 7pm, otherwise all values are at least 20 percent with most above 90 percent. This simplification is considered adequate to meeting the energy use patterns of these control strategies.

Appendix M: Exhaust Air Heat Recovery - Supplemental Surface Plots

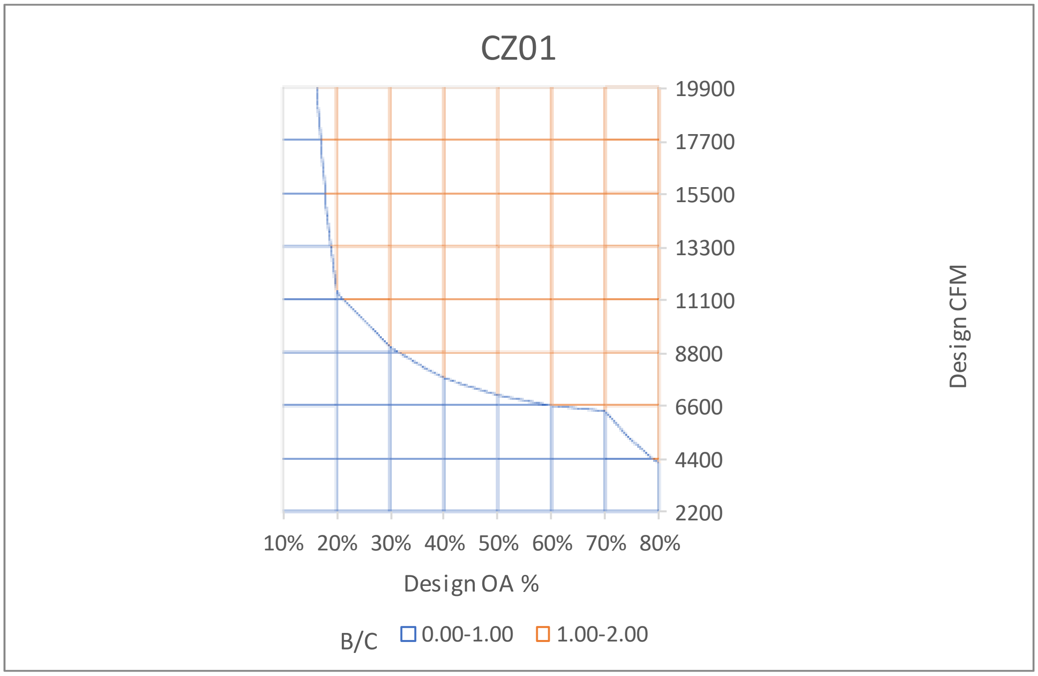


Figure 41: Cost effectiveness of EAHR in CZ1 with 4,644 hours of operation.

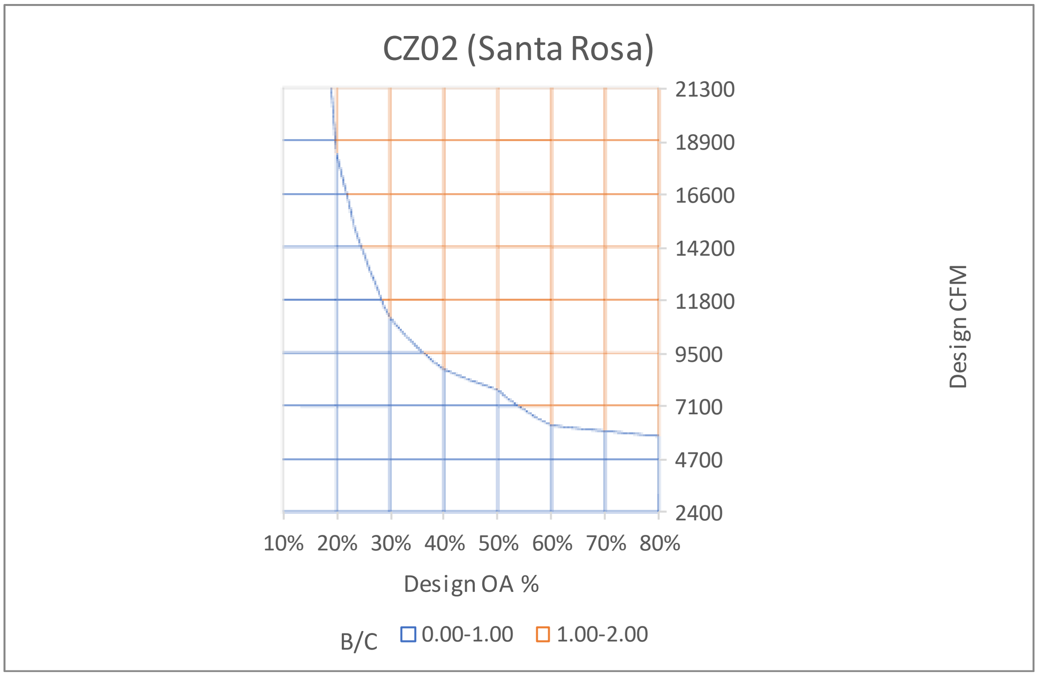


Figure 42: Cost effectiveness of EAHR in CZ2 with 4,644 hours of operation.

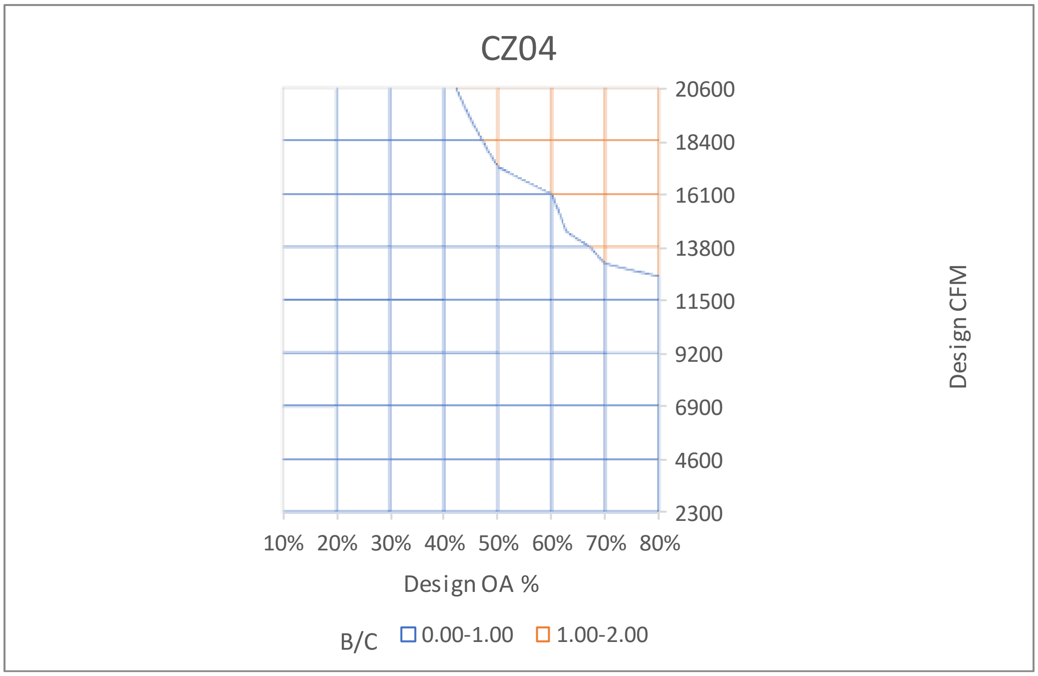


Figure 43: Cost effectiveness of EAHR in CZ4 with 4,644 hours of operation.

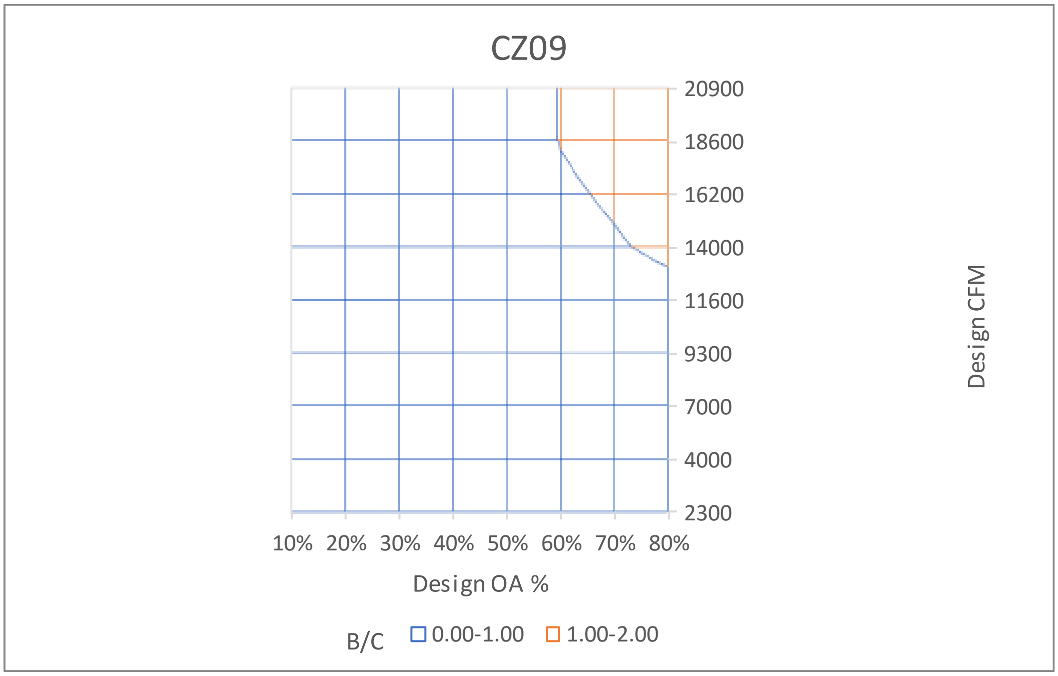


Figure 44: Cost effectiveness of EAHR in CZ9 with 4,644 hours of operation.

Figure 45: Cost effectiveness of EAHR in CZ10 with 4,644 hours of operation.

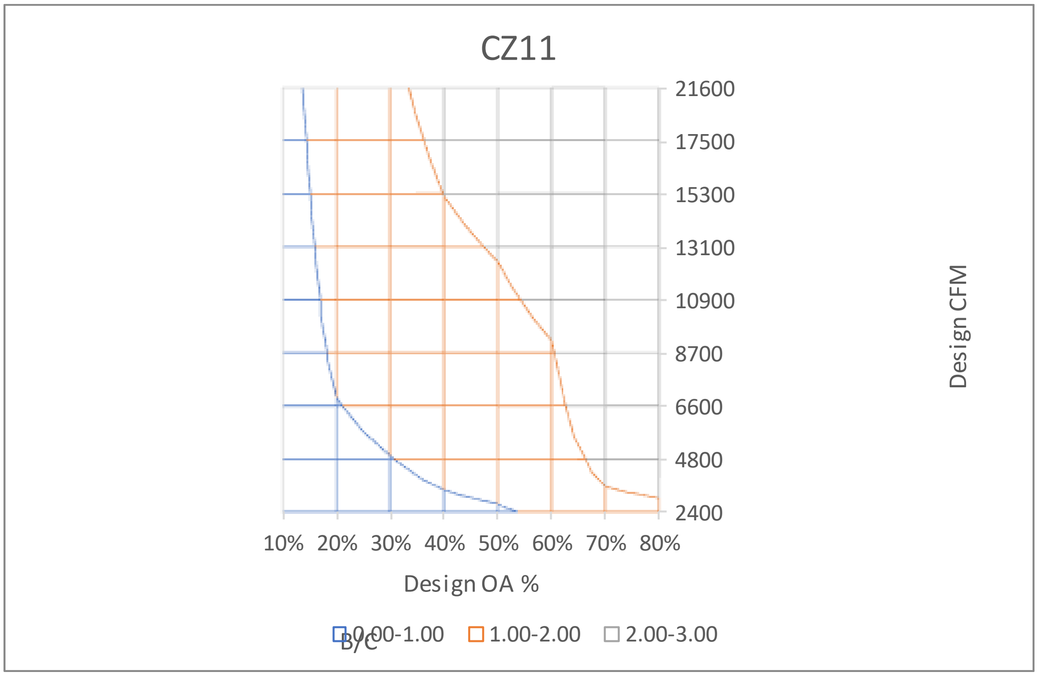


Figure 46: Cost effectiveness of EAHR in CZ11 with 4,644 hours of operation.

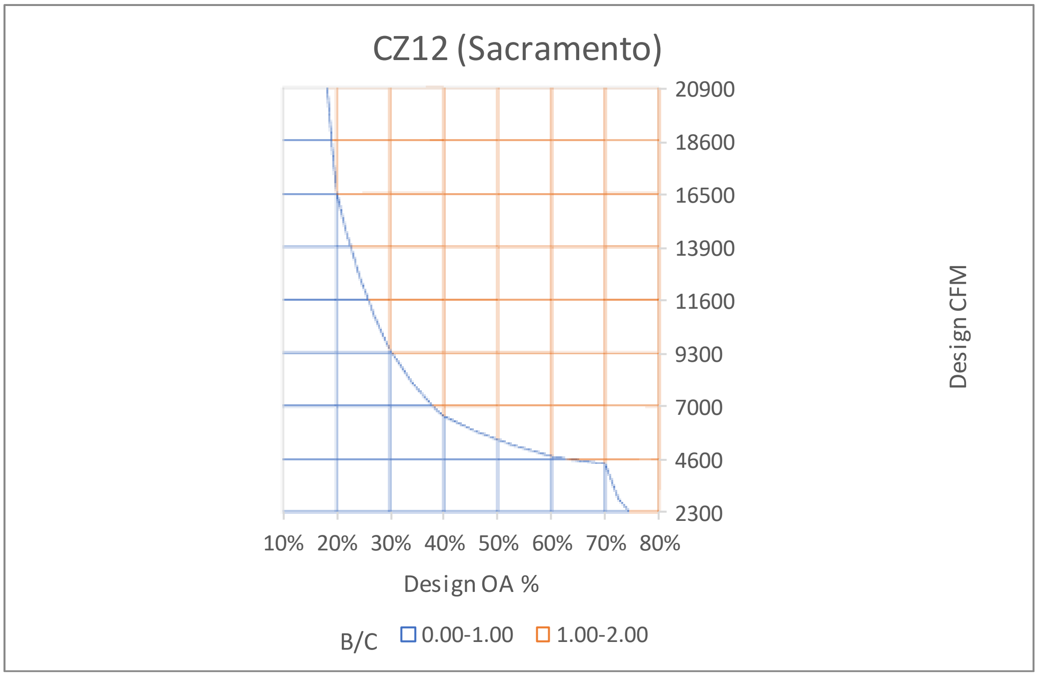


Figure 47: Cost effectiveness of EAHR in CZ12 with 4,644 hours of operation.

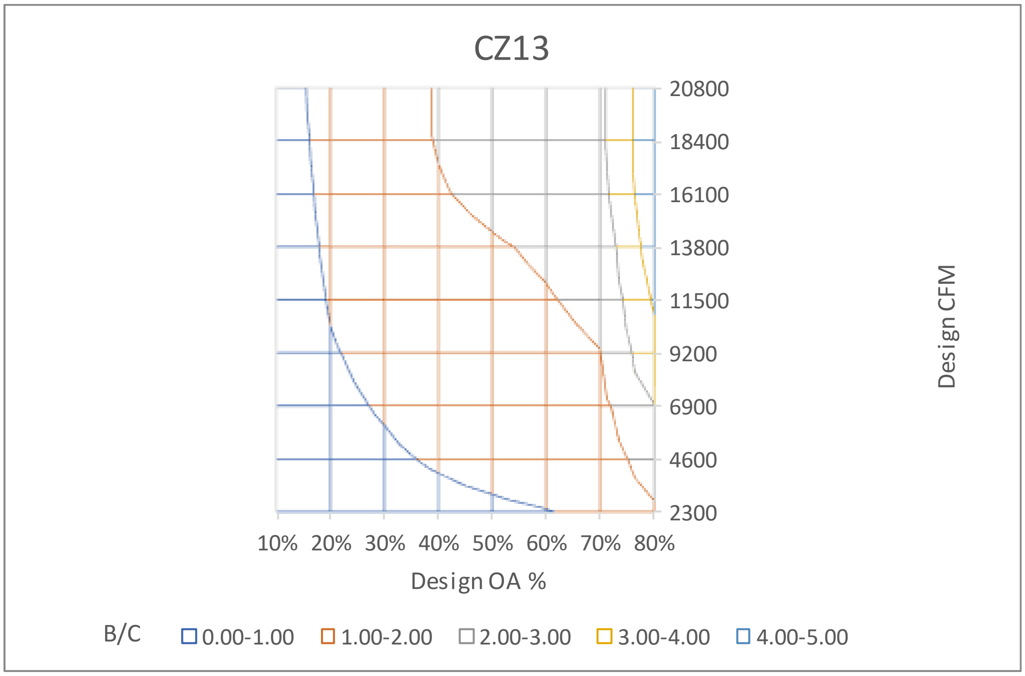


Figure 48: Cost effectiveness of EAHR in CZ13 with 4,644 hours of operation.

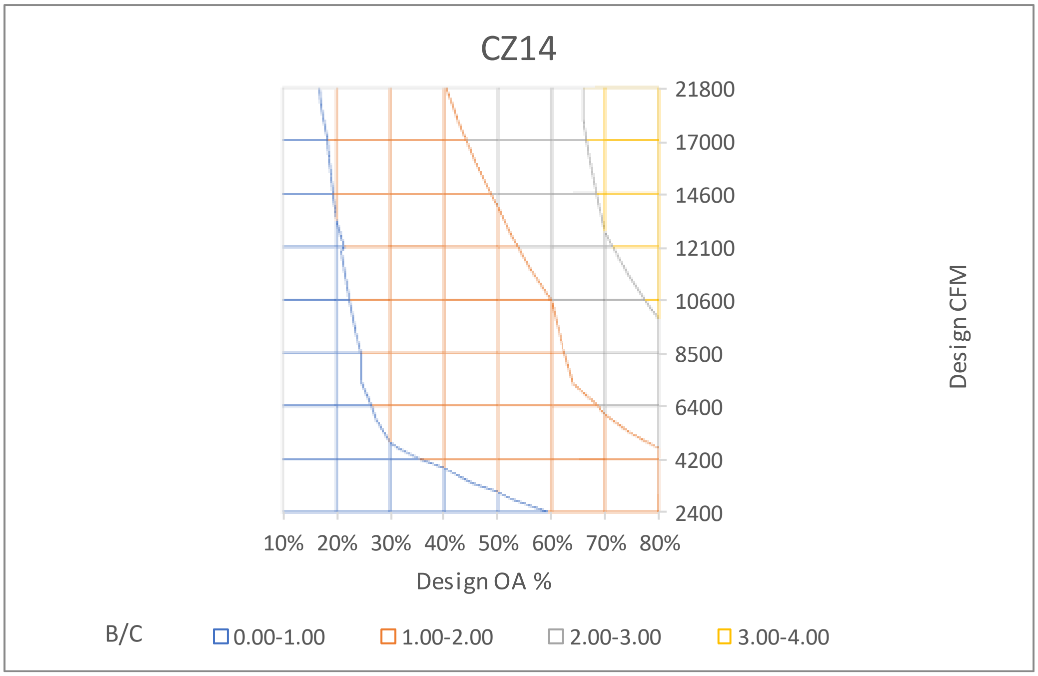


Figure 49: Cost effectiveness of EAHR in CZ14 with 4,644 hours of operation.

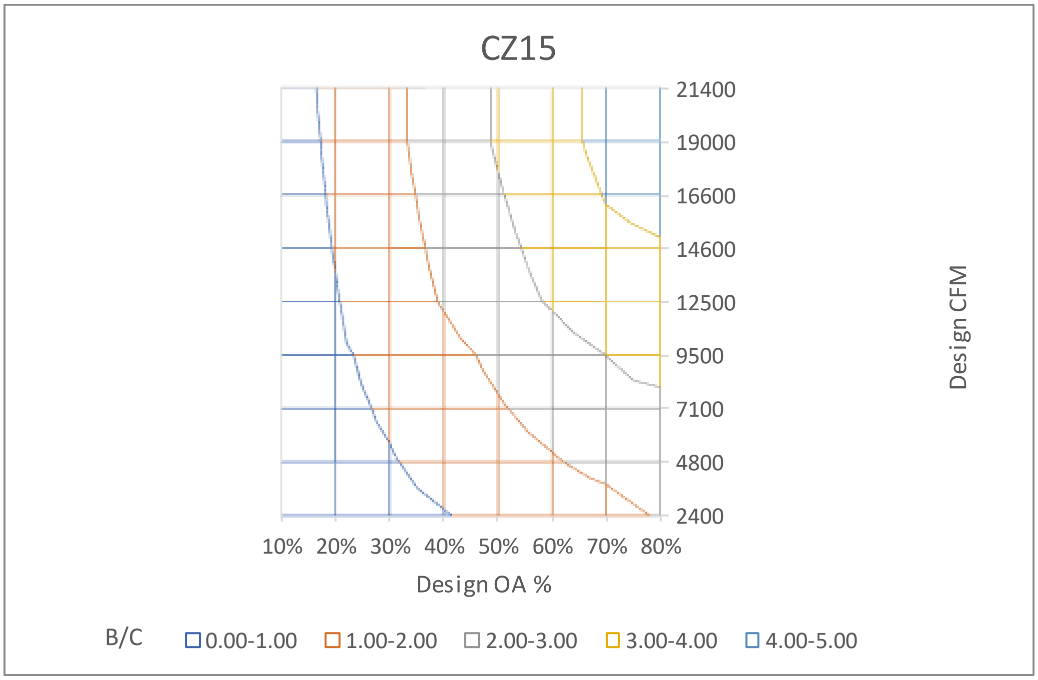


Figure 50: Cost effectiveness of EAHR in CZ15 with 4,644 hours of operation.

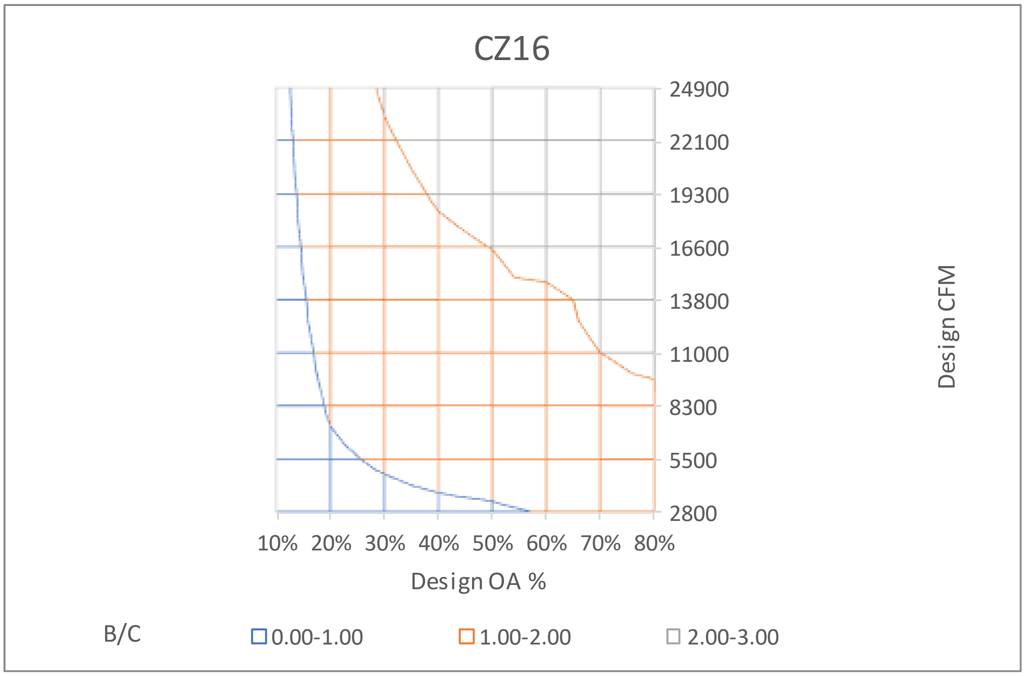


Figure 51: Cost effectiveness of EAHR in CZ16 with 4,644 hours of operation.

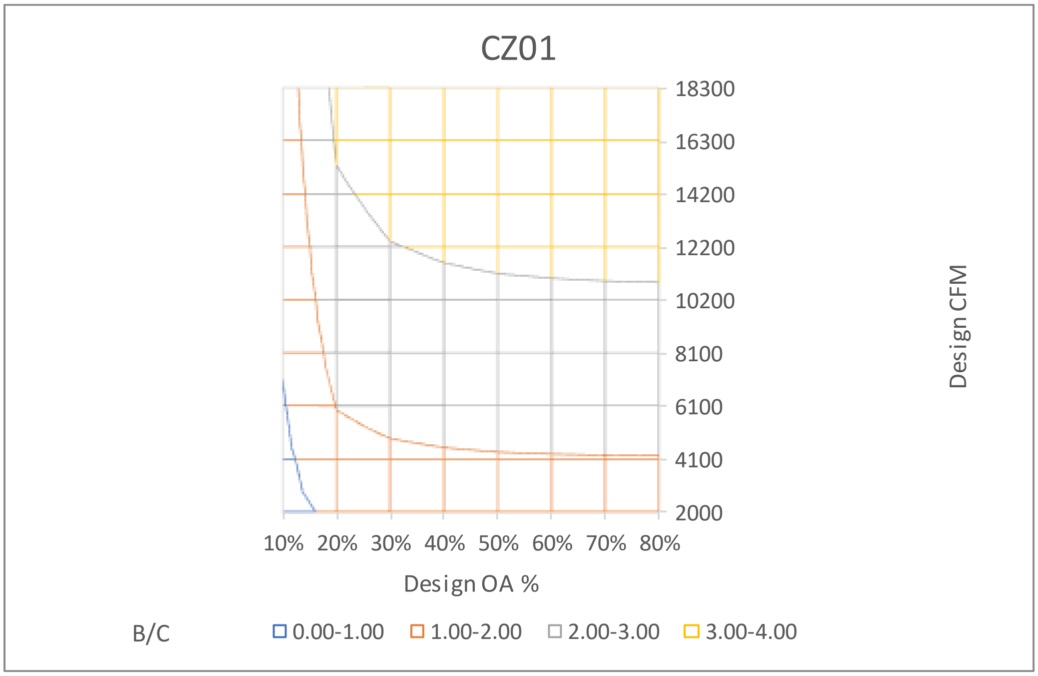


Figure 52: Cost effectiveness of EAHR in CZ1 with 8,760 hours of operation.

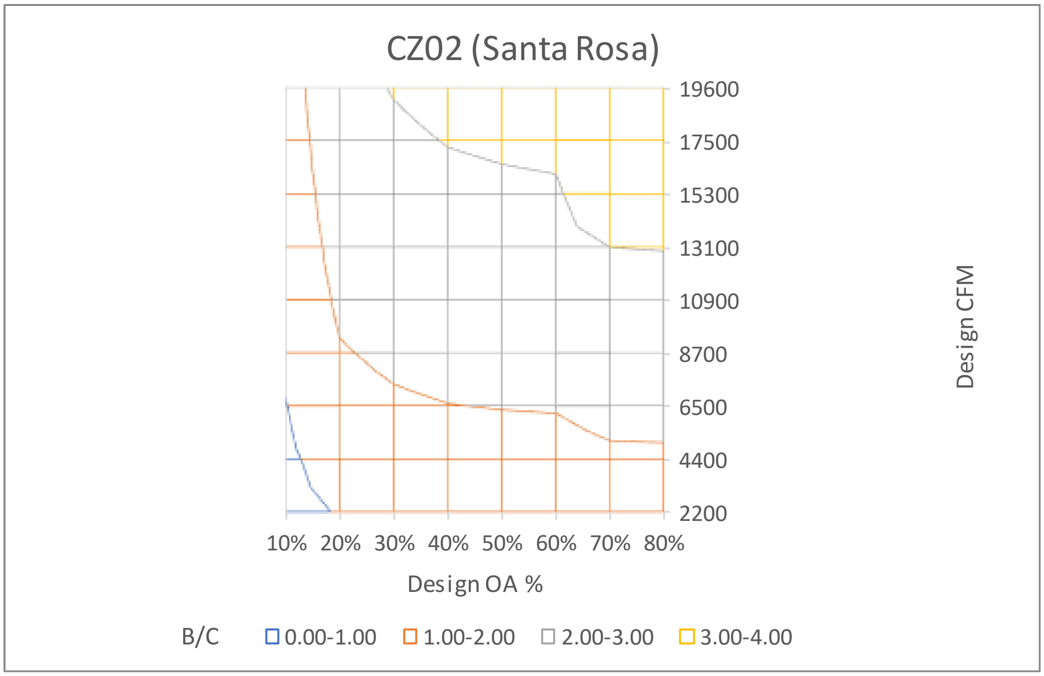


Figure 53: Cost effectiveness of EAHR in CZ 2 with 8,760 hours of operation.

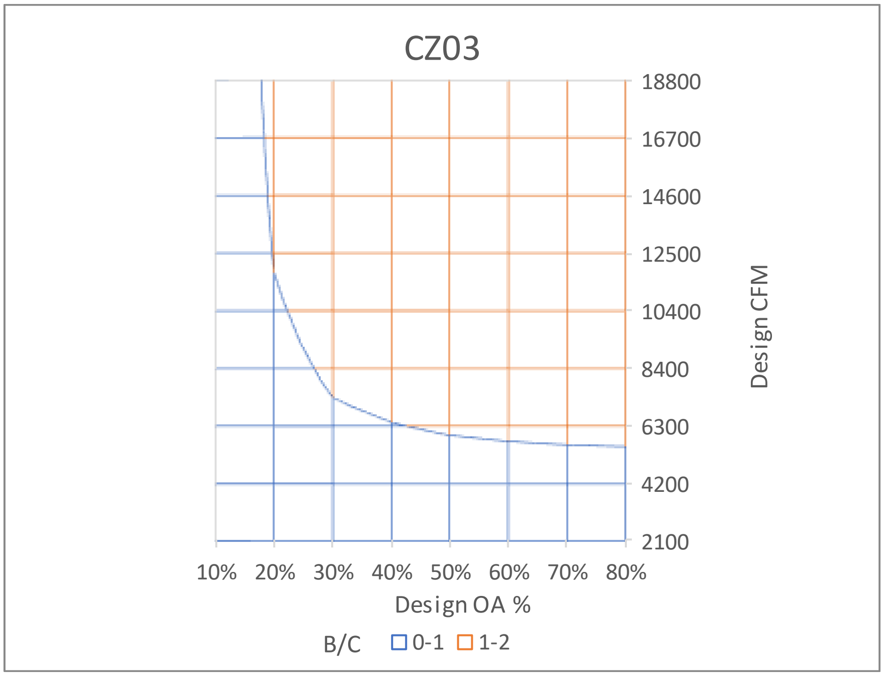


Figure 54: Cost effectiveness of EAHR in CZ 3 with 8,760 hours of operation.

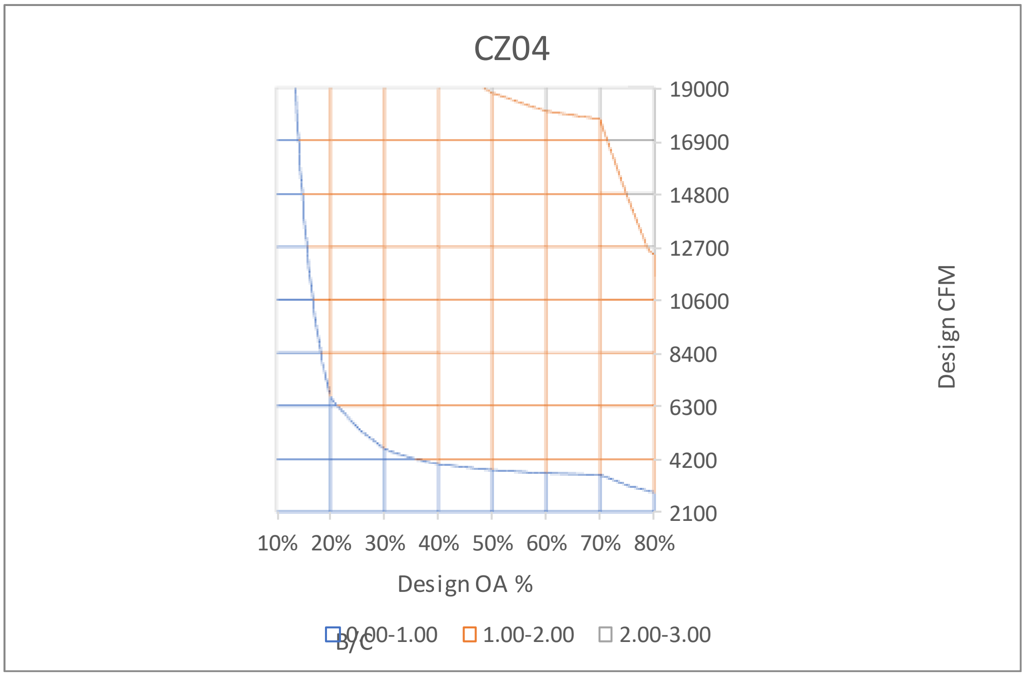


Figure 55: Cost effectiveness of EAHR in CZ 4 with 8,760 hours of operation.

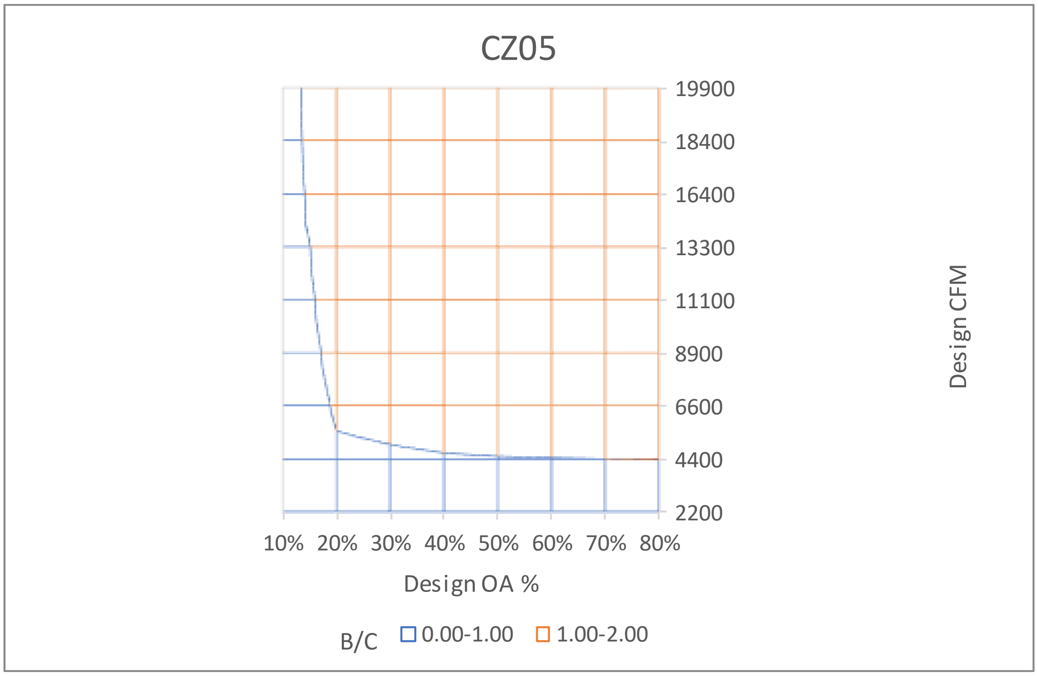


Figure 56: Cost effectiveness of EAHR in CZ 5 with 8,760 hours of operation.

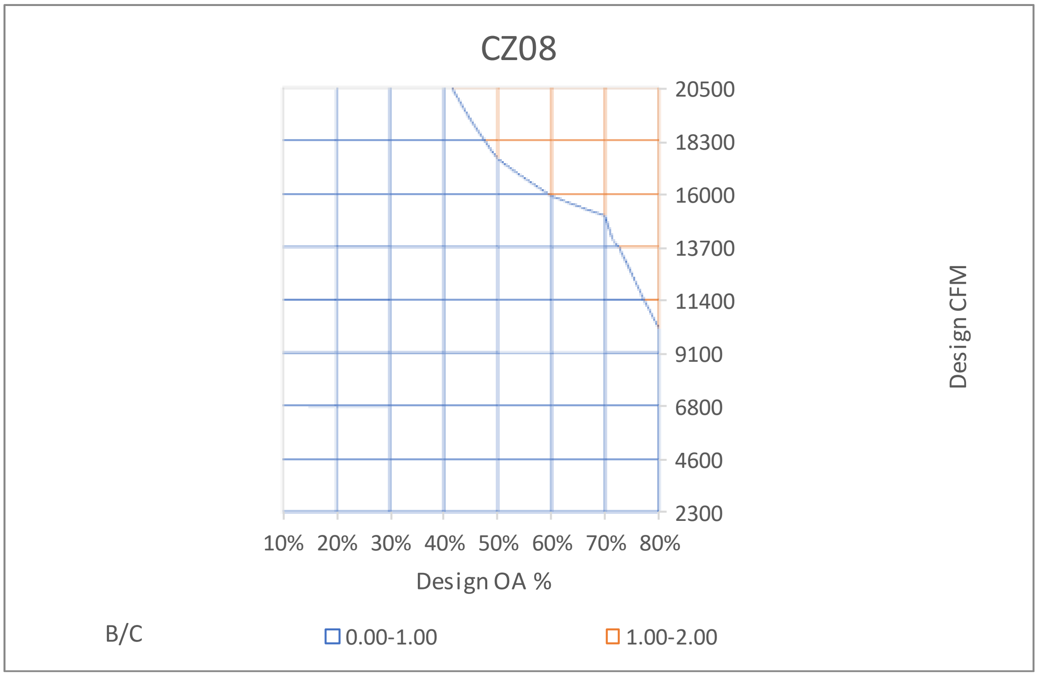


Figure 57: Cost effectiveness of EAHR in CZ 8 with 8,760 hours of operation.

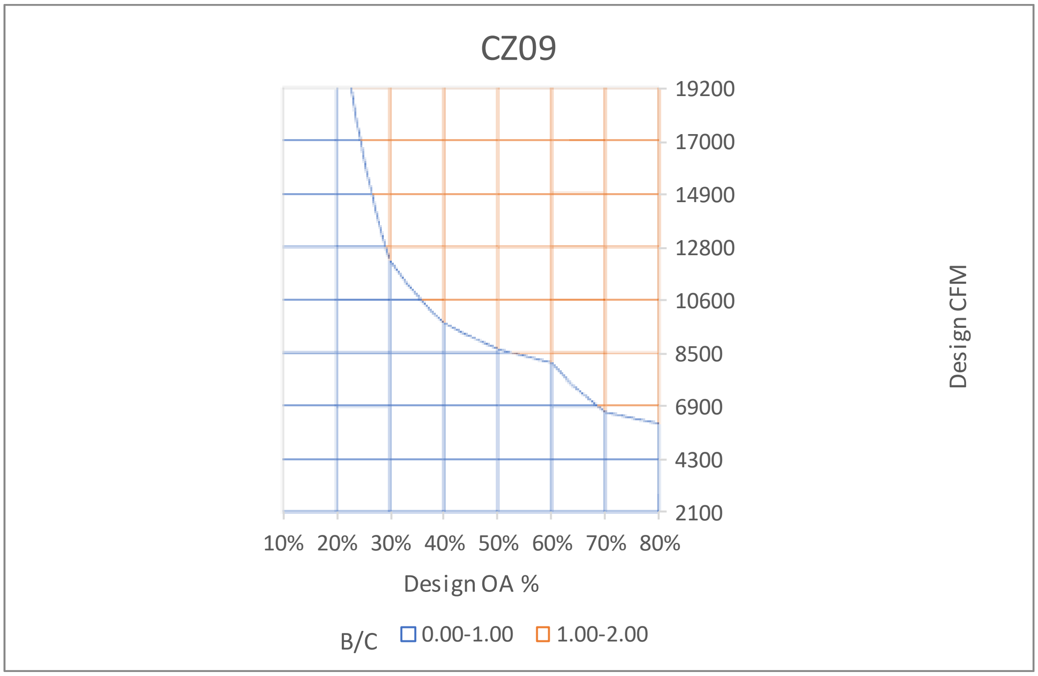


Figure 58: Cost effectiveness of EAHR in CZ 9 with 8,760 hours of operation.

Figure 59: Cost effectiveness of EAHR in CZ 10 with 8,760 hours of operation.

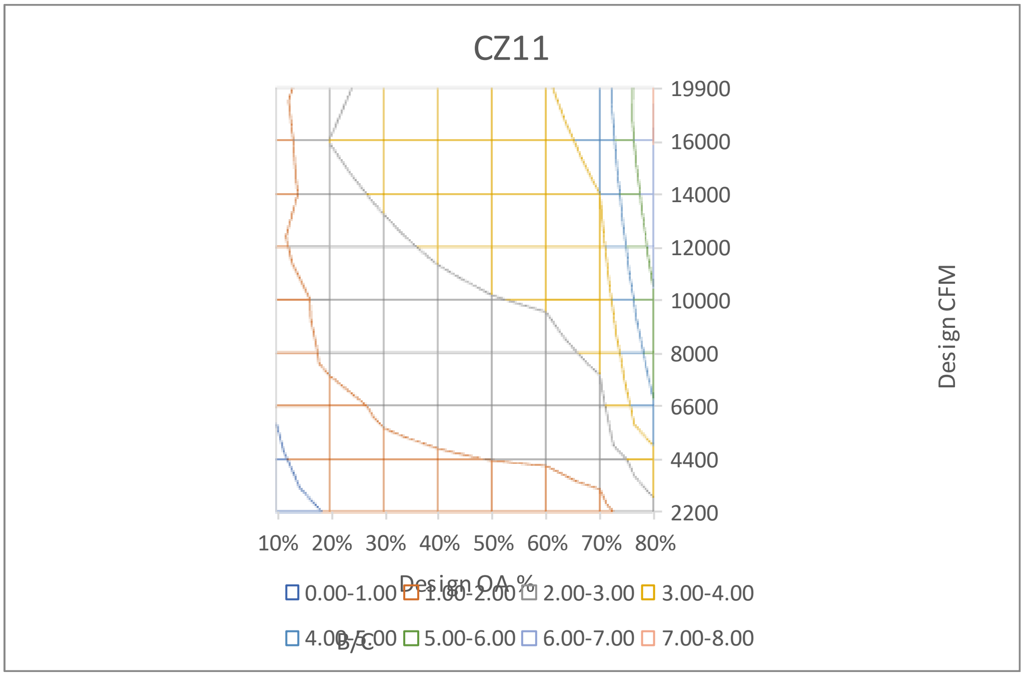


Figure 60: Cost effectiveness of EAHR in CZ 11 with 8,760 hours of operation.

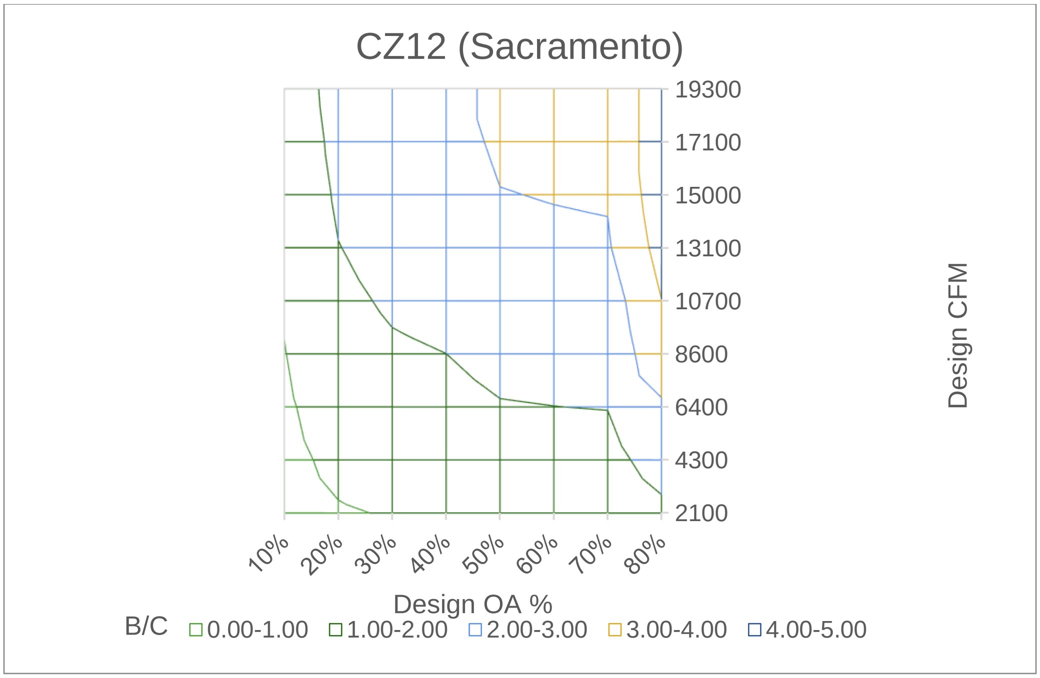


Figure 61: Cost effectiveness of EAHR in CZ 12 with 8,760 hours of operation.

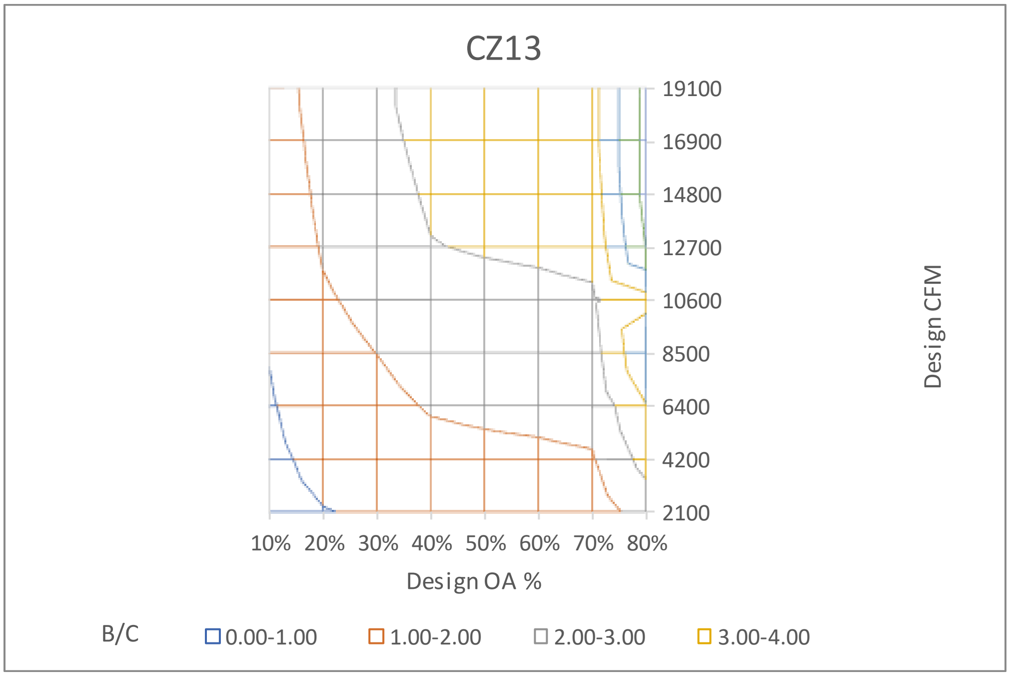


Figure 62: Cost effectiveness of EAHR in CZ 13 with 8,760 hours of operation.

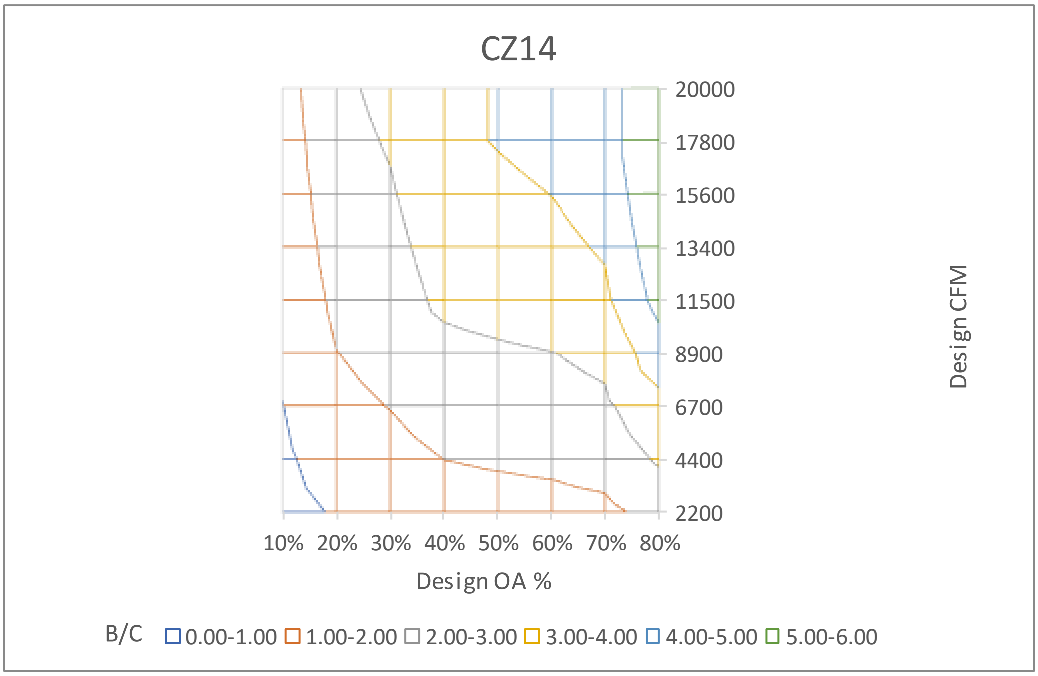


Figure 63: Cost effectiveness of EAHR in CZ 14 with 8,760 hours of operation.

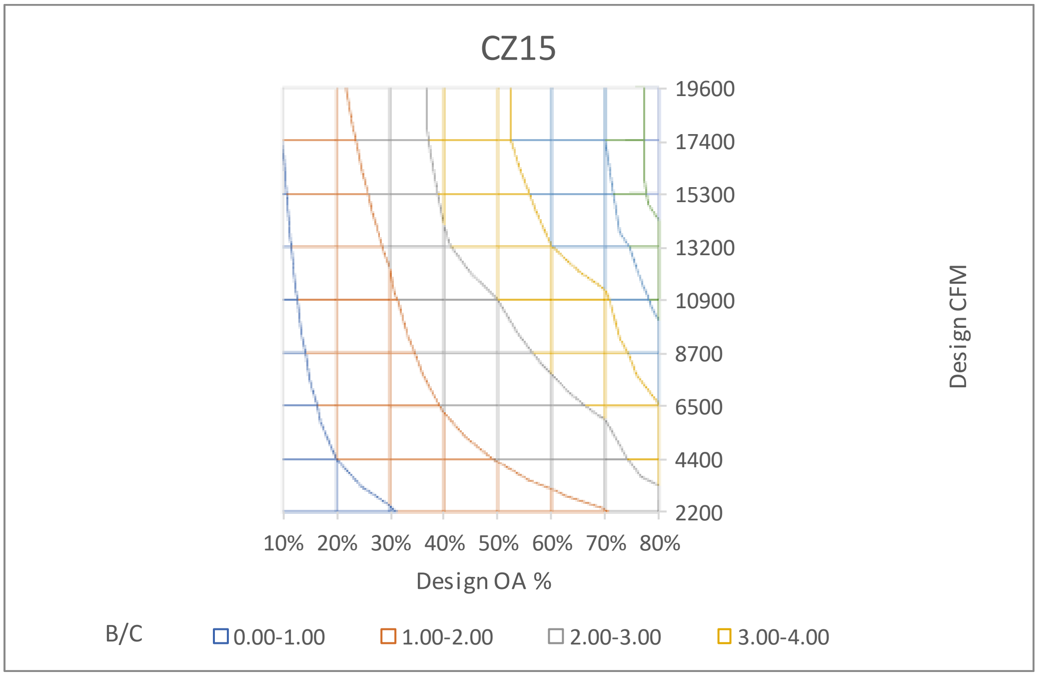


Figure 64: Cost effectiveness of EAHR in CZ 15 with 8,760 hours of operation.

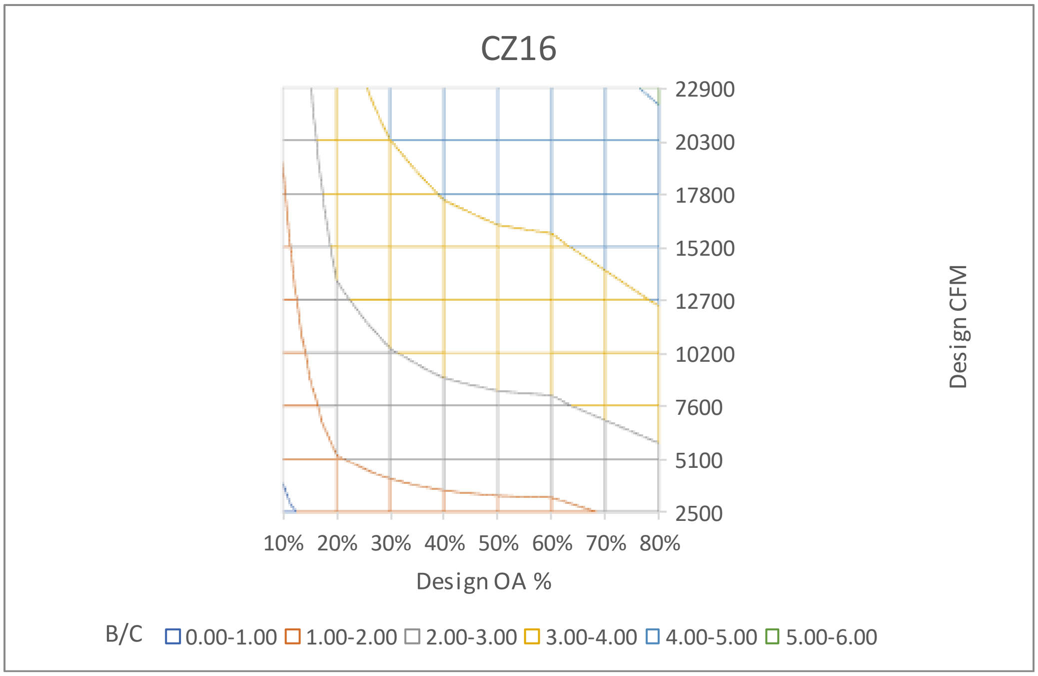


Figure 65: Cost effectiveness of EAHR in CZ 16 with 8,760 hours of operation.

Appendix N: Supplemental Nominal TDV Savings Results

This appendix presents energy cost savings in nominal dollars. Energy costs are escalating as in the TDV analysis but the time value of money is not included so the results are not discounted in the tables below.

VAV Deadband Airflow

Table 176: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - ApartmentHighRise

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.09	($0.01)	$0.08
2	$0.09	($0.01)	$0.09
3	$0.08	($0.00)	$0.07
4	$0.06	($0.00)	$0.06
5	$0.06	($0.00)	$0.06
6	$0.04	($0.00)	$0.04
7	$0.03	$0.00	$0.04
8	$0.04	($0.00)	$0.04
9	$0.05	($0.00)	$0.05
10	$0.05	($0.00)	$0.05
11	$0.09	($0.00)	$0.09
12	$0.08	($0.00)	$0.08
13	$0.08	($0.01)	$0.07
14	$0.06	($0.01)	$0.05
15	$0.04	($0.00)	$0.03
16	$0.06	($0.01)	$0.04

Table 177: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.09	($0.19)	($0.10)
2	$0.09	($0.02)	$0.07
3	$0.12	$0.08	$0.21
4	$0.08	$0.10	$0.18
5	$0.12	($0.01)	$0.11
6	$0.14	$0.22	$0.37
7	$0.17	$0.26	$0.43
8	$0.13	$0.21	$0.34
9	$0.09	$0.17	$0.25
10	$0.10	$0.12	$0.22
11	$0.09	$0.02	$0.11
12	$0.09	$0.08	$0.17
13	$0.08	$0.03	$0.10
14	$0.07	($0.00)	$0.07
15	$0.03	$0.15	$0.18
16	$0.10	($0.04)	$0.06

Table 178: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.08	($0.12)	($0.04)
2	$0.06	($0.10)	($0.04)
3	$0.13	($0.05)	$0.07
4	$0.07	($0.03)	$0.04
5	$0.13	($0.07)	$0.05
6	$0.19	$0.03	$0.22
7	$0.23	$0.04	$0.27
8	$0.15	$0.02	$0.17
9	$0.08	($0.01)	$0.07
10	$0.08	($0.01)	$0.07
11	$0.06	($0.02)	$0.04
12	$0.07	($0.04)	$0.03
13	$0.06	($0.04)	$0.02
14	$0.02	($0.07)	($0.04)
15	$0.06	$0.05	$0.11
16	$0.10	($0.09)	$0.01

Table 179: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - OfficeMediumLab

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.04	($0.02)	$0.02
2	$0.05	$0.02	$0.07
3	$0.07	$0.03	$0.10
4	$0.06	$0.05	$0.11
5	$0.06	$0.02	$0.09
6	$0.12	$0.08	$0.20
7	$0.13	$0.08	$0.21
8	$0.11	$0.09	$0.20
9	$0.07	$0.08	$0.16
10	$0.08	$0.08	$0.16
11	$0.06	$0.06	$0.12
12	$0.06	$0.05	$0.11
13	$0.06	$0.05	$0.11
14	$0.05	$0.06	$0.11
15	$0.06	$0.10	$0.16
16	$0.08	$0.03	$0.11

Table 180: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – New Construction & Alterations/Additions - SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.04	($0.04)	$0.01
2	$0.04	($0.02)	$0.03
3	$0.06	($0.01)	$0.05
4	$0.04	($0.00)	$0.04
5	$0.05	($0.01)	$0.03
6	$0.04	$0.02	$0.06
7	$0.05	$0.03	$0.07
8	$0.04	$0.02	$0.06
9	$0.03	$0.01	$0.04
10	$0.03	$0.01	$0.04
11	$0.04	($0.00)	$0.04
12	$0.04	($0.01)	$0.04
13	$0.03	$0.00	$0.03
14	$0.03	($0.01)	$0.02
15	$0.03	$0.02	$0.04
16	$0.09	($0.03)	$0.06

Expand Economizer Requirements

Table 181: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Expand Economizer Requirements – RestaurantFastFood (1 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$1.73	($0.50)	$1.24
2	$2.31	($0.42)	$1.89
3	$3.01	($0.44)	$2.58
4	$2.56	($0.34)	$2.22
5	$3.55	($0.50)	$3.05
6	$3.56	($0.31)	$3.25
7	$3.74	($0.27)	$3.48
8	$2.97	($0.26)	$2.71
9	$2.75	($0.27)	$2.48
10	$2.53	($0.29)	$2.24
11	$1.67	($0.30)	$1.37
12	$2.13	($0.33)	$1.80
13	$1.69	($0.25)	$1.44
14	$1.90	($0.35)	$1.55
15	$1.67	($0.15)	$1.52
16	$2.06	($0.38)	$1.69

Table 182: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Expand Economizer Requirements – RetailMixedUse (2 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.75	($0.19)	$0.56
2	$1.06	($0.12)	$0.94
3	$1.66	($0.08)	$1.58
4	$1.21	($0.08)	$1.14
5	$1.84	($0.11)	$1.73
6	$1.83	($0.01)	$1.82
7	$2.20	($0.00)	$2.20
8	$1.38	($0.02)	$1.36
9	$1.23	($0.03)	$1.20
10	$1.03	($0.05)	$0.98
11	$0.67	($0.08)	$0.58
12	$0.91	($0.09)	$0.83
13	$0.74	($0.06)	$0.67
14	$0.84	($0.10)	$0.74
15	N/A	N/A	N/A
16	$0.87	($0.10)	$0.77

Table 183: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Expand Economizer Requirements – RetailStripMall (3 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.44	($0.22)	$0.22
2	$0.76	($0.14)	$0.62
3	$1.27	($0.13)	$1.14
4	$1.14	($0.11)	$1.03
5	$1.39	($0.15)	$1.24
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	$0.88	($0.06)	$0.82
9	$0.92	($0.07)	$0.85
10	N/A	N/A	N/A
11	$0.42	($0.10)	$0.32
12	$0.68	($0.10)	$0.58
13	$0.56	($0.08)	$0.48
14	$0.60	($0.11)	$0.48
15	N/A	N/A	N/A
16	$0.73	($0.12)	$0.61

Table 184: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Per Square Foot – Expand Economizer Requirements – PrimarySchool (4 of 4)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	$0.07	($0.03)	$0.05
2	$0.13	($0.01)	$0.11
3	$0.20	($0.02)	$0.18
4	$0.16	($0.01)	$0.15
5	$0.21	($0.02)	$0.19
6	$0.15	($0.01)	$0.15
7	$0.26	($0.01)	$0.25
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	$0.13	($0.01)	$0.12
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

Dedicated Outside Air Systems

Table 185: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Total – New Construction (DOAS market percentages applied)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal Millions $)	15-Year TDV Natural Gas Cost Savings (Nominal Millions $)	Total 15-Year TDV Energy Cost Savings (Nominal Millions $)
1	$0.37	$0.02	$0.40
2	$2.28	$0.09	$2.37
3	$11.95	$0.39	$12.34
4	$5.92	$0.13	$6.06
5	$1.16	$0.04	$1.20
6	$8.01	$0.12	$8.12
7	$5.78	$0.18	$5.97
8	$11.18	$0.09	$11.27
9	$20.00	$0.04	$20.04
10	$7.31	$0.24	$7.55
11	$1.64	$0.08	$1.72
12	$10.61	$0.25	$10.87
13	$2.93	$0.16	$3.09
14	$2.03	$0.04	$2.07
15	$0.97	$0.02	$1.00
16	$0.68	$0.03	$0.71

Table 186: Nominal TDV Energy Cost Savings Over 15-Year Period of Analysis – Total – Alterations (DOAS market percentages applied)

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal Millions $)	15-Year TDV Natural Gas Cost Savings (Nominal Millions $)	Total 15-Year TDV Energy Cost Savings (Nominal Millions $)
1	$0.22	$0.02	$0.24
2	$1.30	$0.10	$1.40
3	$6.64	$0.46	$7.11
4	$3.22	$0.17	$3.39
5	$0.66	$0.05	$0.71
6	$4.57	$0.18	$4.75
7	$3.49	$0.16	$3.66
8	$6.22	$0.20	$6.42
9	$10.66	$0.30	$10.96
10	$4.89	$0.26	$5.16
11	$0.99	$0.08	$1.07
12	$5.82	$0.33	$6.15
13	$1.79	$0.17	$1.96
14	$1.26	$0.06	$1.33
15	$0.63	$0.02	$0.65
16	$0.43	$0.03	$0.46

Exhaust Air Heat Recovery

Table 187: Nominal TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations - OfficeLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	($0.04)	$0.16	$0.12
2	($0.00)	$0.11	$0.10
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.03	$0.09	$0.13
12	$0.01	$0.09	$0.10
13	$0.04	$0.08	$0.11
14	$0.03	$0.09	$0.12
15	$0.08	$0.01	$0.09
16	($0.02)	$0.16	$0.14

Table 188: Nominal TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction – OfficeMedium

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.64	$1.21	$1.85
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	($0.41)	$2.20	$1.79

Table 189: Nominal TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations - RetailLarge

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	($0.04)	$0.42	$0.37
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A

Table 190: Nominal TDV Energy Cost Savings Over 15-year Period of Analysis - per Square Foot - New Construction & Alterations – SchoolSecondary

Climate Zone	15-Year TDV Electricity Cost Savings (Nominal $)	15-Year TDV Natural Gas Cost Savings (Nominal $)	Total 15-Year TDV Energy Cost Savings (Nominal $)
1	($0.45)	$2.68	$2.23
2	$0.09	$1.66	$1.75
3	N/A	N/A	N/A
4	N/A	N/A	N/A
5	N/A	N/A	N/A
6	N/A	N/A	N/A
7	N/A	N/A	N/A
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	$0.59	$1.51	$2.10
12	$0.24	$1.44	$1.68
13	$0.60	$1.35	$1.95
14	$0.44	$1.39	$1.83
15	$1.49	$0.16	$1.65
16	($0.54)	$3.51	$2.97