DOCKETED	
Docket Number:	19-BSTD-03
Project Title:	2022 Energy Code Pre-Rulemaking
TN #:	235290
Document Title:	CASE Report Multifamily Indoor Air Quality
Description:	Codes and Standards Enhancement (CASE) Initiative Report for the 2022 California Building Energy Efficiency Standards, submitted by staff
Filer:	Haile Bucaneg
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	10/19/2020 7:32:37 AM
Docketed Date:	10/19/2020

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

Multifamily Indoor Air Quality

2022-MF-IAQ-F | Multifamily HVAC | October 2020

FINAL CASE REPORT

Prepared by TRC

Please submit comments to info@title24stakeholders.com.

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

Document Information

Category:	**Codes and Standards**
Keywords:	Statewide Codes and Standards Enhancement (CASE) Initiative; California Statewide Utility Codes and Standards Team; Codes and Standards Enhancements; 2022 California Energy Code; 2022 Title 24, Part 6; efficiency; indoor air quality, multifamily, heat recovery ventilator (HRV), energy recovery ventilator (ERV), balanced ventilation, duct sealing, shaft sealing, duct testing, range hood, kitchen exhaust
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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 public 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 will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein 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 multifamily indoor air quality (IAQ). The report contains pertinent information supporting the code change.

Measure Description

Background Information

This report provides proposed updates to Title 24, Part 6 for three submeasures related to ventilation in multifamily dwelling units. Submeasure A would require heat or energy recovery in multifamily units for whole dwelling unit ventilation in select climate zones and primarily provides energy benefits. Submeasure B addresses kitchen ventilation to reduce pollution from cooking and kitchen appliances, and primarily provides IAQ benefits. The requirements are structured by dwelling unit size; while the scope of this Final CASE Report is only multifamily buildings, the Statewide CASE Team recommends that similar requirements be made for single family multifamily units. Submeasure C addresses sealing of central ventilation ducts in multifamily buildings; it primarily provides IAQ benefits, but also results in statewide energy savings. While all relate to dwelling unit ventilation, each is a stand-alone measure and discussed separately in this report.

A. Energy or heat recovery ventilator (ERV or HRV). This proposed measure builds on existing language in the 2019 Title 24, Part 6 Standards that require that all new construction multifamily units either provide balanced ventilation or demonstrate "compartmentalization"—i.e., demonstrate through a blower door test that leakage of the dwelling unit envelope area does not exceed a certain value. For projects following the balanced ventilation path, the proposed requirement for the 2022 Title 24, Part 6 code cycle adds HRV or ERV as a prescriptive requirement in California Climate Zones 1-2 and 11-16. This proposal aligns with a measure in American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90.1 (added to the 2019 version) that will require an HRV or ERV for high-rise (buildings with four occupiable floors or higher) multifamily dwelling units of new construction in all climate zones except ASHRAE—International Energy Conservation Code (IECC) 3C (mild, marine climate zone), which generally maps to California Climate Zones 3 through 6. The proposed prescriptive requirement specifies the following, to be verified by the building inspector:

   a. Unitary equipment (one ERV or HRV serving each dwelling unit) must have a sensible heat recovery efficiency of at least 67 percent, and fan efficacy ≤ 0.6 W/ cubic feet per minute (cfm);

   b. Central equipment (one ERV or HRV serving multiple dwelling units) must have a sensible heat recover effectiveness[1] of at least 67 percent, minimum fan efficacy as required in Section 140.4, and include a bypass function whereby the intake air bypasses the heat exchanger and the equipment functions similar to an economizer.

[1] Unitary equipment is typically packaged and rated with a sensible recovery *efficiency*, which accounts for the heat transferred from the outgoing air to the incoming airstream and includes the recovery core and fan. Central equipment is typically rated with a sensible recovery *effectiveness*, which accounts for the heat transferred from the outgoing air to the incoming airstream and includes only the recovery core, since it is sometimes paired with different fans.

These requirements would be assumed for the standard design in the performance path in Climate Zones 1, 2, and 11-16. In addition, the proposal adds a mandatory measure for fan efficacy of 1.0 W/cfm for unitary ERVs/HRVs for all climate zones. Projects using central ERVs/HRVs in climate zones not regulated under the proposed requirement would continue to comply with applicable requirements in Title 24, Part 6 Section 140.4.

B. Kitchen exhaust minimum capture. California's 2019 Title 24, Part 6 Standards require that dwelling units meet all requirements of ASHRAE Standard 62.2, except where specified. The proposed changes are new requirements for range hoods to better ensure that a kitchen exhaust system can adequately remove cooking-related pollution. Specifically, the proposal builds upon recent research from Lawrence Berkeley National Laboratory (LBNL) that estimated the minimum range hood capture efficiency needed to maintain fine particulate matter (PM2.5, for all ranges) and to maintain nitrogen dioxide (NO_2, for natural gas-fueled ranges) at acceptable levels specified, depending on the size of the dwelling unit. Both pollutants have been linked to numerous health problems. While a requirement based exclusively on capture efficiency would be the most direct approach to address IAQ, manufacturers have not yet published the capture efficiency of their equipment, so there is little market data regarding capture efficiency of available products. LBNL research and research conducted for this Final CASE Report have found a direct relationship between airflow and capture efficiency (i.e., a higher airflow generally results in a higher capture efficiency). As additional background, manufacturers are moving toward increasing the static pressure requirements during testing through industry stakeholder groups and through a working group formed by the ASHRAE 62.2 committee. The proposed requirement avoids retesting of range hoods should manufacturer testing requirements change. Consequently, the proposal requires that all multifamily dwelling units have an exhaust system in the kitchen that meets one of the following compliance pathways:

1. A vented range hood with a minimum capture efficiency shown in Table 1, using ASTM Standard E3087-18 at nominal installed airflow (defined in HVI Publication 920), or
2. A vented range hood with a minimum airflow shown in Table 1, at 0.1 inches water column (w.c.) (25 Pascals [Pa]), or
3. A vented downdraft kitchen exhaust fan with a minimum airflow of 300 cfm at 0.1 inches w.c. (25 Pa) or higher, or
4. A continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour at 50 Pa for enclosed kitchens only (an enclosed kitchen is defined as a kitchen whose permanent openings to interior

adjacent spaces do not exceed a total 60 square feet (ft^2) [6 square meters]).

Table 1. Minimum Range Hood Capture Efficiency (CE) or Airflow Requirements by Dwelling Unit Floor Area and Range Fuel, For Demand-Controlled Range Hoods

Floor area of dwelling unit	Hood over electric range	Hood over natural gas range
<750 ft^2	65% CE or 250 cfm	75% CE or 290 cfm
751 – 999 ft^2	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500 ft^2	55% CE or 175 cfm	55% CE or 200 cfm
>1,500 ft^2		50% CE or 175 cfm

Pathway 1 is new and pathway 2 is a modification to the existing standard. Pathways 3 and 4 are kitchen exhaust requirements under ASHRAE Standard 62.2 and adopted under California's 2019 Title 24, Part 6 Standards. California's 2019 Title 24, Part 6 Standards added one amendment to ASHRAE Standard 62.2, allowing sound to be rated at working speed, as defined by HVI Publication 916.[2] The proposed requirement maintains these existing requirements. Capture efficiency and airflow would be determined in a laboratory and published by manufacturers, as is currently done for sound ratings.

C. Central ventilation duct sealing. This proposal defines a "central ventilation duct" (also referred to as a "central ventilation shaft") as ductwork that serves multiple dwelling units and provides dwelling unit ventilation supply or exhaust air. 2019 Title 24, Part 6 Standards include a requirement that central ventilation systems be balanced, to ensure that each dwelling unit receives the required ventilation rate. The proposed measure builds on this requirement by requiring that project teams seal central ventilation duct systems that provide continuous ventilation airflows or that serve as part of dwelling units' balanced ventilation system. The proposed measure requires field verification of shaft leakage using a fan pressurization test to ensure that leakage does not exceed 10 percent of the central (e.g., rooftop) fan airflow rate at 50 Pa (0.2 inches w.c.) for central ventilation duct serving more than six dwelling units, and does not exceed 6 percent of the central fan airflow rate at 25 Pa (0.1 inches w.c.) for central

[2] As defined in HVI Standard 916: working speed is defined as the speed that produces 100 cfm, or the lowest speed above 100 cfm that a hood can produce, when working on the same duct system as the maximum speed test. For consistency, if the airflow is less than 60% of the high speed rating, the Member may rate working speed at 0.03'' w.g. For many products, the HVI database publishes multiple speeds, including the working speed (which may be rated at less than 0.1" w.c.) and low, medium, boost, or high speed, which are typically rated at 0.1" w.c. or 0.25" w.c.

ventilation duct serving six or fewer dwelling units. The lower test pressure for ducts serving fewer units aligns with current low-rise duct testing requirements, and ducts serving fewer units typically have a lower static pressure.

D. This measure provides cost-effective energy savings through reduced fan energy and reduced loss of conditioned air. In addition, central ventilation shaft sealing provides IAQ benefits by improving the reliability of supply and exhaust rates, and reducing the leakage of exhausted air, which can include various pollutants such as PM2.5, NO_2, volatile organic compounds (VOCs), and relative humidity (which can cause mold) into other interior spaces, including other dwelling units.

Proposed Code Change

In order to compare proposed code changes to the current language, the Statewide CASE Team refers to the current sections of the 2019 Title 24, Part 6 Standards. The current standard has separate sections for low-rise and high-rise multifamily dwelling units. However, if the proposed code requirement for a unified multifamily section is accepted, the Statewide CASE Team would make one requirement for all multifamily units.

This Final CASE Report proposes three sets of requirements, one that is primarily prescriptive but includes a mandatory fan efficacy requirement, and two that are mandatory, for ventilation in all multifamily new construction and additions:

- Submeasure A: ERV/HRV - For multifamily dwelling units following the balanced ventilation path in Section 150.0(o)1Ei (in the low-rise residential standards) or Section 120.1(b)2Aivb1 (in the nonresidential standard), this proposal would require that an ERV or HRV be installed in California Climate Zones 1, 2, and 11-16. The HRV or ERV must provide sensible heat recovery of at least 67 percent. HRVs or ERVs serving multiple dwelling units must have a bypass function, in which the incoming outdoor air bypasses the heat exchanger when the outdoor air temperature is below the cooling set point. The presence of the bypass function on central ERVs/HRVs would be verified by the building inspector, and functional testing of the bypass function would be conducted by an Acceptance Testing Technician (ATT).
- Submeasure B: Kitchen exhaust minimum capture - All kitchen exhaust systems must meet one of four pathways. The first path is a minimum capture efficiency and the second is a minimum airflow for demand-controlled hoods. As shown in Table 2, the requirements vary by dwelling unit size, because a smaller unit provides less volume for diluting pollutants, and requirements are higher for hoods over natural gas ranges because of the nitrogen dioxide and other pollutants released. Capture efficiency is measured at nominal installed airflow (defined by HVI Publication 920) and airflow at 0.1 inches w.c. (25 Pa).

Table 2. Minimum Range Hood Capture Efficiency (CE) or Airflow Requirements by Dwelling Unit Floor Area and Range Fuel, for Demand-Controlled Range Hoods

Floor area of dwelling unit	Hood over electric range	Hood over natural gas range
<750 ft^2	65% CE or 250 cfm	75% CE or 290 cfm
751 – 999 ft^2	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500 ft^2	55% CE or 200 cfm	55% CE or 200 cfm
>1,500 ft^2		50% CE or 175 cfm

The third path is kitchen exhaust systems may consist of a downdraft kitchen exhaust with a minimum airflow of at least 300 cfm at 0.1 inches w.c. (25 Pa) fan. The fourth path (available for enclosed kitchens only) is a continuous exhaust system with a minimum airflow of at least 5 air changes per hour at 50 Pa.

- Submeasure C: Central ventilation duct sealing—All ventilation ducts serving multiple dwelling units that provide continuous airflows or serve as part of dwelling units' balanced ventilation systems must be sealed. Field verification must be done by an ATT. The ATT must show that leakage does not exceed 6 percent of central (e.g., rooftop) fan design airflow rate at 50 Pa (0.2 inches w.c.) for central ventilation ducts serving more than six units and at 25 Pa (0.1 inches w.c.) for those serving six or fewer units, and the ATT can use sampling for the field verification.

Scope of Code Change Proposal

Table 3 summarizes the scope of the proposed changes and which sections of standards, Reference Appendices, Alternative Calculation Method Reference Manual, and compliance documents would be modified as a result of the proposed change(s). All proposed changes would apply to new construction and additions. Alterations would only be affected if the existing ventilation systems are replaced as part of an alteration to an existing building for low-rise multifamily units (under existing language in Section 150.2), and if the existing range hood system is replaced as part of an alteration to an existing building for high-rise multifamily units (under proposed language in Section 141.0).

Table 3: 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)
ERV/HRV	Prescriptive	120.1(b)2Aivb and 140.X for high-rise, 150.0(o)1E, 150.1(c)X for low-rise multifamily	Nonresidential Appendix 2.4, Residential Appendix 3.4.4	Y	CF1R, CF2R, CF3R, NRCA, NRCC, NRCV
Kitchen Exhaust Minimum Capture	Mandatory	120.1(b)2Avi, 141.0(a), 141.0(b) for high-rise; 150.0(o)1G for low-rise multifamily	Nonresidential Appendix 2.2.4.1.3, Residential Appendix 3.7.4.3	N	CF2R, CF3R, NRCA, NRCC, NRCV
Central Ventilation Duct Sealing	Mandatory	120.4(g), 120.5(a)3, 140.4(l) and 141.0(b)2 for high-rise, 150.0(m)11 for low-rise multifamily	Nonresidential Appendix 1.6.3, 1.9.1, 2.1.4.2 Residential Appendix 2.6.2	Y	CF2R, CF3R, NRCA, NRCC, NRCV

Market Analysis and Regulatory Assessment

In general, this analysis found that all three measures are technically feasible for all multifamily new construction prototypes.

ERVs and HRVs are not frequently used in the market for multifamily projects,[3] but are sometimes used under local ordinances such as San Francisco Article 38 (which requires MERV-13 filtered balanced or supply-only ventilation in areas of San Francisco with high outdoor particulate matter). ERVs and HRVs are likely to become more common as a balanced ventilation pathway under 2019 Title 24, Part 6, which requires

[3] ERVs and HRVs have become more common for single family homes under Title 24-2016, in part because the modeling software allowed projects to assume a balanced ventilation (with two fans) as the standard model, which allowed the projects to claim more energy savings than compared to an exhaust-only (one-fan) ventilation system.

either balanced ventilation or air tightness (“compartmentalization”) for all new construction multifamily dwelling units. Under the proposed requirement for HRVs or ERVs project teams could choose to install either unitary ERVs or HRVs—i.e., one per dwelling unit, or central ERVs or HRVs—i.e., each ERV or HRV serves multiple dwelling units. Different approaches may be optimal under different scenarios.

Kitchen ventilation should always be installed in new construction multifamily units under current requirements. This proposal adds a new compliance path for kitchen exhaust: a minimum capture efficiency for range hoods. Because the capture efficiency test method is new and manufacturer organizations are in the process of establishing rating points for capture efficiency, there are no published capture efficiency values in product specifications or range hood databases. Consequently, the Statewide CASE Team provides alternative compliance paths based on airflows. The second compliance path increases the minimum airflow rate of range hoods from 100 cfm (in 2019 Title 24, Part 6 by reference to ASHRAE Standard 62.2). The minimum capture efficiency and airflow depend on unit size and fuel type. In general, the minimum range hood capture efficiency and airflow are higher for small dwelling units due to the smaller volume of air for dilution, and over natural gas ranges due to the nitrogen dioxide they generate. The alternative pathways based on airflow (cfm) enable project teams to immediately identify which products can comply and would help ensure that adequate capture efficiency is achieved until the industry transitions to the capture efficiency metric.

The Statewide CASE Team conducted analyses of products in the Home Ventilating Institute (HVI) database and found that most products comply with the proposed requirements, except for microwave range hoods over natural gas ranges in dwelling units smaller than 750 ft^2.

Table 4: Percent of compliant range hood products with proposed requirements

Minimum airflow	Trigger under proposal	Percent of compliant products (vertical discharge)
≥175 cfm	Hoods over electric ranges in units 1,000 ft^2 or larger, or hoods over natural gas ranges in units 1,500 ft^2 or larger	93% microwave, 98% undercabinet, 100% chimney
≥200 cfm	Hoods over electric ranges in units 750 to 1,000 ft_2, or hoods over natural gas ranges in units 1,000 to 1,500 ft^2	93% microwave, 98% undercabinet, 100% chimney
≥250 cfm	Hoods over electric ranges in units smaller than 750 ft_2, or hoods over natural gas ranges in units 750 to 1,000 ft^2	77% microwave, 84% undercabinet, 100% chimney

≥290 cfm	Hoods over natural gas ranges in units smaller than 750 ft^2	19% microwave, 67% undercabinet, 92% chimney

In addition, the proposed requirement retains two other compliance options (in 2019 Title 24, Part 6 by reference to ASHRAE I Standard 62.2): downdraft exhaust with a minimum airflow rate of 300 cfm, or, in enclosed kitchens only, continuous airflow of five kitchen air changes per hour at 50 Pa (0.2 inches w.c.) (ACH50).

Central ventilation ducts are sometimes used in new construction multifamily buildings, particularly for high-rise buildings. While 2019 Title 24, Part 6 required leakage testing for certain types of ducts—including some types of ducts carrying conditioned air in commercial buildings and ducts carrying conditioned air in residential buildings—leakage testing is not required for ventilation ducts in multifamily buildings. Industry standard practice also does not call for leakage testing of multifamily ventilation ducts, because they typically have a pressure lower than the 3 inches w.c. that has traditionally been the recommended minimum for triggering duct testing. Because ATTs (as well as HERS Raters) test leakage in other types of ducts, the market should be equipped for leakage testing multifamily ventilation ducts.

Cost Effectiveness

The benefit-to-cost (B/C) ratio compares the benefits or cost savings to the costs over the 30-year period of analysis. Proposed code changes with 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. All cost-effectiveness analysis was done for new construction buildings. The same analysis should apply for additions. The proposals do not apply to alterations except where these types of ventilation systems are replaced as part of alterations to an existing building in low-rise multifamily units (under existing language in Section 150.2) and if the existing range hood system is replaced as part of an alteration to an existing building for high-rise multifamily units (under proposed language in Section 141.0).

- Submeasure A: ERV/HRV - The proposed ERV/HRV code change was found to be cost effective for all climate zones where it is proposed to be required: California Climate Zones 1, 2, and 11-16. The B/C ratio for this measure ranged between 1.25 and 4.5 depending on climate zone, for all climate zones where the measure is proposed.
- Submeasure B: Kitchen exhaust minimum capture - The Statewide CASE Team did not estimate cost effectiveness for the proposed kitchen exhaust system code change, because the primary purpose is improving IAQ. The purpose of this measure is to ensure adequate IAQ, given new envelope requirements that

should reduce natural infiltration. These requirements include the requirement for Quality Insulation Installation (QII) for low-rise multifamily buildings in 2019 Title 24, Part 6; a proposed version of QII for high-rise multifamily buildings for 2022 Title 24, Part 6; and the compartmentalization path added in 2019 Title 24, Part 6. Consequently, the Statewide CASE Team does not need to show that the measure is cost effective. Based on a comparison of a sample of ranges that do and do not comply with the proposed minimum airflow requirement of 250 cfm and 290 cfm (for units less than 750 ft^2 with electric range or less than 1,000 with gas range), the Statewide CASE Team found compliant products were on average more expensive than non-compliant products at these high airflows, which are required for small dwelling units, and particularly with natural gas ranges. However, research has highlighted higher airflows are needed to maintain acceptable IAQ in these scenarios.

- Submeasure C: Central ventilation duct sealing - The proposed code change was found to be cost effective for all climate zones. The B/C ratio for this measure ranged between 4 and 50 depending on climate zone and prototype. The Statewide CASE Team proposes that ATTs can test a sample of central ventilation ducts to reduce costs, when conducting the leakage test.

CASE Reports have historically assumed 30 years for residential measures, 30 years for commercial envelope measures, and 15 years for other commercial measures (such as lighting and heating, ventilation, and air conditioning [HVAC] proposals). Because these measures only affect the residential spaces in multifamily buildings, the Statewide CASE Team applied the residential assumptions of 30 years. Furthermore, the Statewide CASE Team used a 30-year period of analysis instead of a 15-year period of analysis for the ERV/HRV and central ventilation duct sealing measures because a strategy that includes heat or energy recovery, particularly the associated supply and exhaust ductwork, would be expensive to switch out. As such, the ductwork is expected to be maintained for at least 30 years. For the central ventilation duct sealing measure, the general ventilation strategy is unlikely to change in the future. For example, if a building has central ventilation ducts, it is unlikely that it would be altered to individual dwelling unit (unitary) ventilation within 30 years.

See Section 5 for the methodology, assumptions, and results of the cost-effectiveness analysis.

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

Table 5 presents the estimated energy and demand impacts of the proposed code changes for the ERV/HRV and central ventilation duct sealing measures that would 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 (million therms/yr), and time dependent valuation (TDV) energy savings in British thermal units per year (TDV kBtu/yr). See Section 6 for more details on the first-year statewide impacts, and Section 4 contains details on the per-unit energy savings calculated by the Statewide CASE Team.

Table 5 does not include energy savings for the Submeasure B kitchen exhaust minimum capture proposed code change, because the primary purpose of this measure is to improve IAQ. As described in Section 2.2.2 cooking pollution includes PM2.5, NO2 (from gas-fired cooking equipment), and carbon monoxide (CO), which have significant deleterious health effects, and it is important that occupants have an appliance that can effectively remove this pollution, particularly as the industry moves to tighten envelopes for energy efficiency. In general, the Statewide CASE Team does not anticipate a significant energy impact from the proposed kitchen exhaust measure, as described in Section 4.2.

Table 5: First-Year Statewide Energy and Impacts

Measure	Electricity Savings (GWh/yr)	Peak Electrical Demand Reduction (MW)	Natural Gas Savings (million therms/yr)	TDV Energy Savings (TDV kBtu/yr)
Submeasure A: ERV/ HRV (Total)	0.04	1.23	0.20	81.52
New Construction	0.04	1.23	0.20	81.52
Additions and Alterations	N/A	N/A	N/A	N/A
Submeasure C: Central Ventilation Duct Sealing (Total)	0.29	0.91	0.20	59.18
New Construction	0.29	0.91	0.20	59.18
Additions and Alterations	N/A	N/A	N/A	N/A

Table 6 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 Section 6.3.2 and 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.

Table 6: First-Year Statewide GHG Emissions Impacts

Measure	Avoided GHG Emissions (Metric Tons CO2e/yr)	Monetary Value of Avoided GHG Emissions ($2023)
Submeasure A: ERV/ HRV (Total)	1,117	$118,580
Submeasure C: Central Ventilation Duct Sealing (Total)	1,146	$34,377
Total	2,263	$152,957

Water and Water Quality Impacts

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

Compliance and Enforcement

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 for each measure is described in Sections 2.1.5, 2.2.5, and 2.3.5. Impacts that the proposed measure would have on market actors are described in Sections 3.1.3, 3.2.3, 3.3.3, and Appendix E. The key issues related to compliance and enforcement are summarized below:

- Submeasure A: ERV/HRV
  - The project team shall identify if an ERV or HRV is required in the prescriptive path or is included in the performance path. They would determine this based on the project's compliance path (i.e., balanced ventilation, which triggers the ERV/HRV proposed requirement; or compartmentalization, which does not) and if the project is in Climate Zone 1, 2, 11, 12, 13, 14, 15, or 16. The compliance software should also trigger the proper enforcement documentation requirements and functional testing (of the bypass function for central ERVs/HRVs) by ATTs.
  - If an ERV or HRV is required
    - The project team chooses and installs qualifying equipment, including equipment with the minimum sensible recovery

efficiency (SRE)[4] and fan efficacy. If a central ERV or HRV would be used, the project team would ensure the system includes a bypass function. The CBECC-Com performance compliance form (NRCC-PRF-01) indicates whether the bypass function has been checked.

        - The building inspector verifies that the equipment is installed if required, and it has bypass (if required). A HERS Rater or ATT verifies that the ERV or HRV meets the minimum SRE and fan efficacy requirements based on the model number, and that the bypass (for central ERVs/HRVs) is reported in the compliance document.

    - If an ERV or HRV is not required but the project team elects to install one, the building inspector verifies that it meets the minimum fan efficacy in the mandatory requirements proposed for ERVs/HRVs in this Final CASE Report.

- Submeasure B: Kitchen exhaust minimum capture
    - The project team specifies a kitchen exhaust system that complies with the requirement based on its sound rating and either its capture efficiency or its airflow information, using product information in the Home Ventilating Institute (HVI) or Association of Home Appliance Manufacturers (AHAM) Certified Products Directory. The project team installs the equipment.
    - The building inspector verifies that the kitchen has exhaust that vents to outside the building per one of the allowable kitchen exhaust compliance paths.
    - A HERS Rater or ATT verifies that the installed equipment complies with at least one of the compliance paths using the product make and model number and the HVI or AHAM database.
- Submeasure C: Central ventilation duct sealing
    - The project team identifies the location of central ventilation ducts and specifies sealing materials and strategies.
    - The project team seals the central ventilation ducts during construction.

[4] Or in the case of a central HRV or ERV, minimum sensible recovery effectiveness

    - The ATT determines the maximum amount of leakage based on the number of units it serves and verifies that the total measured leakage rate of the central ventilation ducts meets the maximum leakage requirement using a fan pressurization test. Field verification of the system total leakage for all systems in a building may use sampling according to the procedures described in RA2 and NA1, although the Statewide CASE Team proposes a higher sampling rate for this measure (one in three) than exists for other measures (one in seven).

Field Verification and Diagnostic Testing

- Submeasure A: ERV/HRV
    - A HERS Rater or ATT confirms that the equipment and intake and exhaust ducting are installed where required, documents the model number, confirms that it meets SRE and fan efficacy requirements, and (if it is a central ERV or HRV) verifies that it includes bypass.
- Submeasure B: Kitchen exhaust minimum capture
    - An ATT or HERS Rater documents the model number and verifies that the installed equipment complies with at least one of the compliance paths.
- Submeasure C: Central ventilation duct sealing
    - The ATT verifies that a sample of central ventilation ducts meet the maximum leakage requirement using a fan pressurization test and documents the leakage test results, using sampling procedures. The Statewide CASE Team is proposing that the sampling procedures described in RA2 and NA1 be expanded to address this measure but specify that a minimum of one in three central ventilation duct systems be tested. This is more stringent than the sampling requirement of one in seven used for other measures. The Statewide CASE Team proposes a higher sampling rate for this measure, because some buildings would only have a few central ventilation duct systems (e.g., seven systems in the strategy assumed for the high-rise prototype), so testing only one system would not provide enough rigor. In addition, the cost of testing is fairly low (as documented in this report), and the measure is still cost effective at the higher sampling rate of one in three. For each system sampled for testing, the ATT must test the entire central ventilation duct system from its connection point with the central fan to the connection point within the unit; testing sections of the system is not permitted.

See Section 2.1.5, Section 2.2.5, and 2.3.5 for additional information on compliance and enforcement for the ERV/HRV, kitchen exhaust minimum capture, and central ventilation duct sealing submeasures, respectively.

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 Public 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.

The overall goal of this Final CASE Report is to present a code change proposal for multifamily indoor air quality. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including manufacturers, mechanical engineers, HERS Raters, sheet metal workers, utility incentive program managers, Title 24, Part 6 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during public stakeholder workshops that the Statewide CASE Team held on August 22, 2019 and on March 25, 2020. The Energy Commission also hosted an IAQ workshop to discuss research related to the range hood topic on September 30, 2020. Notes from the stakeholder meetings are available here:

https://title24stakeholders.com/wp-content/uploads/2019/07/T24-2022-MF-HVAC-Envelope-Meeting-Notes_Final.pdf

The following is a brief summary of the contents of this report:

- Section 2: Measure Description of this Final CASE Report provides 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.
- Section 3: In addition to the Market Analysis, this section includes a review of the current market structure. Sections 3.1.2, 3.2.2, and 3.3.2 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.
- Section 4: 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.
- Section 5: This section includes a discussion and presents analysis of 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.
- Section 6: First-Year Statewide Impacts presents 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 will be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic by the State of California. Statewide water consumption impacts are also reported in this section.
- Section 7: Proposed Revisions to Code Language concludes the report with specific recommendations with ~~strikeout~~ (deletions) and <u>underlined</u> (additions) language for the Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, Compliance Manual, and compliance documents.
- Section 8: Bibliography presents the resources that the Statewide CASE Team used when developing this report.

- Appendix A: Statewide Savings Methodology 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: Environmental Impacts Methodology presents the methodologies and assumptions used to calculate impacts on greenhouse gas (GHG) emissions and water use and quality.
- Appendix D: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software (if any).
- Appendix E: Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: Infiltration Assumptions and Multifamily Building Leakage Data describes the infiltration assumptions used for the mid-rise and high-rise prototypes for the ERV/HRV measure and supporting data for those assumptions
- Appendix H: Prototype Building Description shows the prototype assumptions for the energy models, including number of floors, building dimensions, and example floor lay-outs
- Appendix I: Methodology for Testing Capture Efficiency for Sample of Range Hoods describes how range hoods were selected and tested for laboratory testing of capture efficiency
- Appendix J: Range Hood Capture Efficiency Test Results provides the full results for capture efficiency of six range hoods tested in a laboratory through this project
- Appendix K: Nominal TDV Energy Savings provides monetized energy savings in nominal dollars, without net present values applied

2. Measure Description

This Final CASE Report proposes three changes related to multifamily dwelling unit ventilation requirements, all of which either improve indoor air quality, provide energy savings, or accomplish both:

- Submeasure A: Heat Recovery Ventilator (HRV)/Energy Recovery Ventilator (ERV)
- Submeasure B: Kitchen Exhaust Minimum Capture
- Submeasure C: Central Ventilation Duct Sealing

For all submeasures, because Title 24, Part 6, Sections 120.1, 140.X, 150.0(o), and 150.1(c)X apply only to newly constructed buildings, unless where specified, the proposals would not affect alterations unless the existing ventilation equipment is replaced. The Statewide CASE Team is proposing that all submeasures affect additions, since the new construction energy, cost, and market analysis for these measures would apply to additions.

In order to compare proposed code changes to the current language, the Statewide CASE Team refers to the current sections of the 2019 Title 24, Part 6 Standards. The current standard has separate sections for low-rise and high-rise multifamily dwelling units. However, if the proposed code requirement for a unified multifamily section is accepted, the Statewide CASE Team would make one requirement for all multifamily units.

These measures are stand-alone (i.e., are separate proposals). However, a balanced ventilation system using central ventilation ducts—defined here as ventilation duct systems serving more than one dwelling unit—would be affected by the requirements in both Submeasure A (heat or energy recovery ventilation), and Submeasure C (central ventilation duct sealing).

2.1 Submeasure A: ERV/HRV

2.1.1 Measure Overview

An HRV captures outgoing energy (sensible) in exhausted air and transfers it to incoming air, thus essentially preheating or precooling incoming air. An ERV does the same thing but also transfers moisture, thereby transferring latent energy. ERVs and HRVs span a wide range of costs, and this analysis did not conduct a robust comparison of costs between HRVs and ERVs. However, ERVs tend to be slightly more expensive. The Statewide CASE Team also found that ERVs were more likely to include an option for MERV 13 filtration, which is a requirement in 2019 Title 24, Part 6.

The ERV/HRV submeasure is primarily an energy savings measure, and the proposed code change would only apply to climates zones where analysis shows it is cost effective. The submeasure would also provide comfort and air quality benefits to occupants compared to other balanced ventilation strategies that provide unconditioned supply air.

For multifamily dwelling units following the balanced ventilation path in Section 150.0(o)1E (for low-rise multifamily dwelling units) or 120.1(b)2Aivb (for high-rise dwelling units), this proposal would set the prescriptive standard for the ventilation system to an ERV or HRV in California Climate Zones 1, 2, and 11-16. The standard HRV or ERV would have a heating sensible recovery efficiency (SRE) or a heating net sensible effectiveness of 67 percent and fan efficacy of 0.6 W/cfm.

For multifamily dwelling units following the compartmentalization path in Section 120.1(b)2Aivb (for high-rise dwelling units) or Section 150.0(o)1E (for low-rise multifamily dwelling units), there is no additional requirement. The exception is, if project teams choose to install HRVs or ERVs where they are not required in the prescriptive path, the equipment must meet a minimum fan efficacy: 1.0 W/cfm for unitary ERVs / HRVs (each one serving a single dwelling unit) and the fan efficacy requirements in Title 24, Part 6 Section 140.4 for central ERVs/HRVs (one ERV or HRV serves multiple dwelling units). This mandatory fan efficacy is intended as a backstop to eliminate the least efficient ERVs or HRVs from use.

The proposal is a prescriptive measure and would affect all multifamily dwelling units that are new construction and additions. As a prescriptive measure, the Standard Design in the performance approach would include this measure. The Statewide CASE Team proposes this as a prescriptive, rather than a mandatory measure, to provide project teams with more flexibility: Project teams in the affected climate zones that use a performance approach could choose not to install this measure but would have to exceed energy efficiency requirements elsewhere in their design.

This requirement only affects alterations that replace ventilation equipment in low-rise multifamily units (under existing language in Section 150.2). Many existing multifamily buildings have no whole dwelling unit ventilation and use operable windows, but no continuous exhaust or balanced ventilation system. Adding an ERV or HRV—which may include adding ductwork if the dwelling unit does not have forced air heating or cooling—could be costly and difficult because of existing space constraints (e.g., less space for soffits for ductwork).

Any project that is not subject to this requirement, but chooses to install an ERV or HRV, would not be subject to the prescriptive minimum SRE proposed. For example, for newly constructed multifamily dwelling units in Climate Zones 3-10 or units that use compartmentalization to meet the requirements of Section 150.0(o)1E or Section

120.1(b)2Aivb, the prescriptive baseline ventilation system would not include heat recovery.

The following flow chart provides an overview of the proposed scope. To avoid confusion, a flowchart similar to below could be incorporated into the compliance manual.

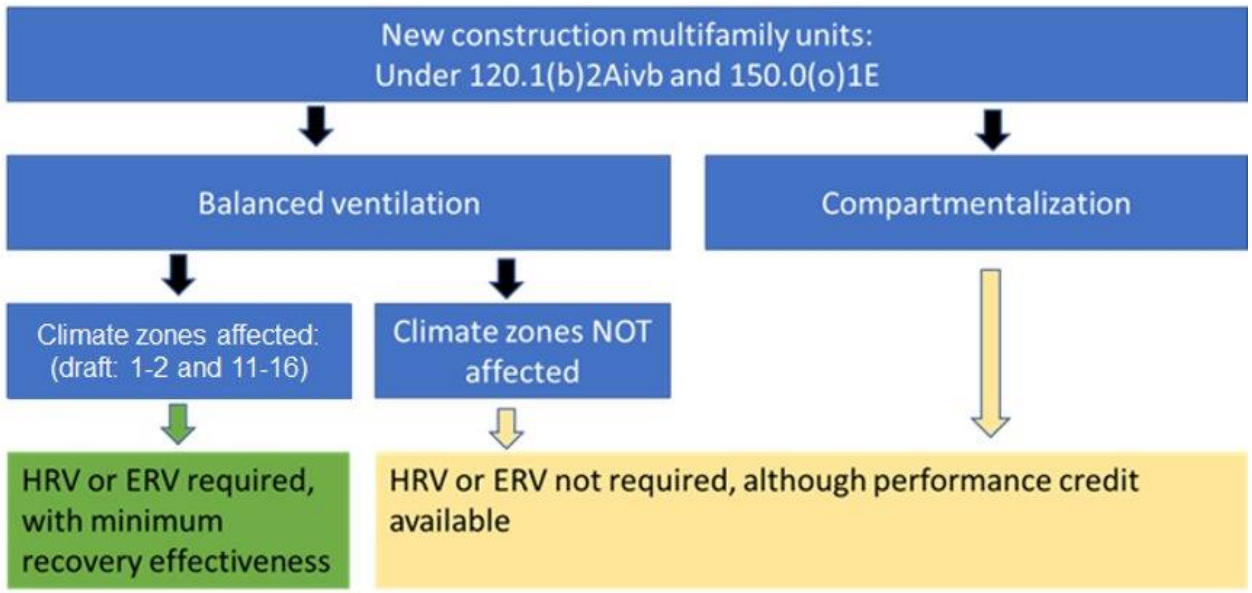

Figure 1: Overview of multifamily dwelling units affected by proposed ERV/HRV code change.

This proposal adds field verification to ensure that the HRV or ERV equipment meets the sensible heat recovery requirement. The proposal would add requirements for a technology that had been allowed under current and past requirements of Title 24, Part 6, but were not required previously.

2.1.2 Measure History

This proposal would provide cost-effective energy savings by requiring the exhaust stream of a balanced ventilation system to pass through an ERV or HRV so that incoming ventilation air is preheated or precooled.

As background, HRVs and ERVs transfer heat between exhaust and fresh intake air in order to reduce heating and cooling loads in a building. Heat can be transferred between the two air supplies using rotary wheels, fixed plate heat exchangers, heat pipes, and run-around systems. Latent heat and sensible heat can be transferred using rotary wheels (a circular honeycomb structure that is rotated within the air streams) or fixed plate heat exchangers (stacked metal plates that may be humidity permeable used to pass air through in order to transfer heat through plates). Figure 2 provides an example schematic.

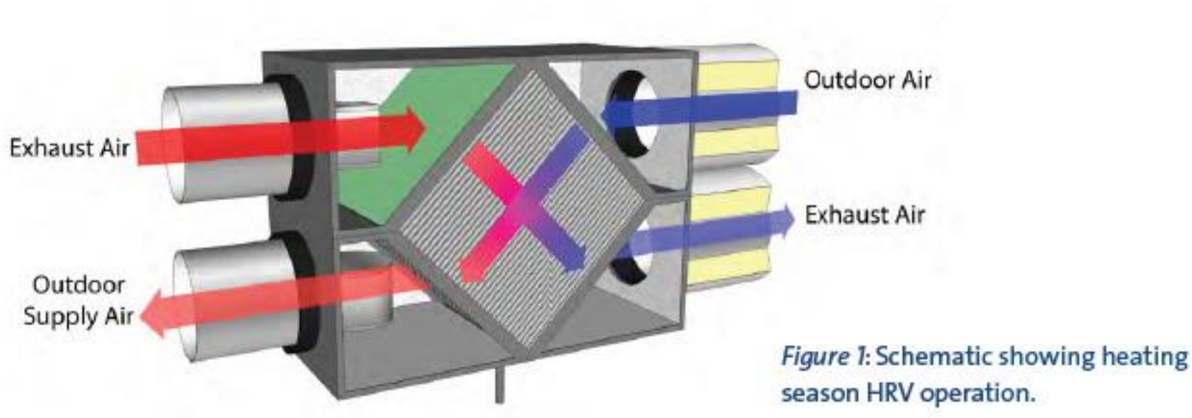

Figure 2: Example HRV diagram.

Source: BC Housing, n.d.

The difference between an HRV and ERV is that while both transfer sensible energy, an ERV transfers additional latent energy because it also transfers humidity. Sensible energy heat exchange is the difference in the dry bulb temperature between the incoming outdoor air and the exhausted indoor air. During the heating season, the ERV also transfers moisture from the outgoing air to the incoming airstream. Conversely, during the cooling season, the ERV transfers moisture to or from the outdoor airstream depending on which whether outdoor humidity is lower or higher than indoors. The proposed code change would allow project teams to choose either an HRV or ERV system.

Unitary HRV and ERV equipment have an SRE rating, which is defined as follows by the Home Ventilating Institute (HVI):

> “SRE: The net sensible energy recovered by the supply airstream as adjusted by electric consumption, case heat loss or heat gain, air leakage, airflow mass imbalance between the two airstreams and the energy used for defrost (when running the Very Low Temperature Test), as a percent of the potential sensible energy that could be recovered plus the exhaust fan energy ” (Home Ventilating Institute 2017).

Thus, the SRE signifies how much sensible energy in the outgoing airstream is transferred to the incoming airstream, and a higher SRE denotes more energy returned to the conditioned space captured. This proposal uses an SRE value, which captures sensible but not latent heat recovery because the HVI database currently lists SRE values but not an indicator of total (sensible and latent) recovery efficiency. For California’s dry summer and mild winter climates, SRE is the important metric.

As described in Section 3.1.2, the median SRE is 69 percent for both ERVs and HRVs in the HVI database, so project teams should not have difficulty meeting the proposed requirement with either an HRV or ERV.

Unitary equipment is typically packaged and rated with an SRE, which accounts for the heat transferred from the outgoing air to the incoming airstream and includes the recovery core and fan. Central equipment is typically rated with a sensible recovery *effectiveness*, which accounts for the sensible heat transferred from the outgoing air to the incoming airstream and includes only the recovery core, since it is sometimes paired with different fans. CBECC-Res and CBECC-Comm allow users to input an SRE value and a sensible recovery effectiveness value, respectively. The Statewide CASE Team proposes the same minimum value—67 percent, for both the minimum SRE (typically used for unitary equipment) and sensible recovery effectiveness (typically used for central equipment).

This is the first proposed code change that would require ERVs or HRVs for Title 24, Part 6. The 2019 Title 24, Part 6 Standards have allowed ERVs and HRVs under the performance approach, but there is no existing requirement for them in California's Energy Code.

The 2022 version of ASHRAE Standard 90.1 includes a new addendum requiring an HRV or ERV in high-rise multifamily buildings. This addendum provides an exception for International Energy Conservation Code (IECC) Climate Zone 3C, which covers almost all of California Climate Zones 3 through 6 and parts of California Climate Zones 1, 2, 6 and 9. Figure 5 in Section 2.1.4.4 provides a map comparing ASHRAE Climate Zone 3c and the California climate zones. The Statewide CASE Team based its requirements on which climate zones this analysis showed the ERV/HRV measure to be cost effective. The Statewide CASE Team may have found that the measure is cost effective for different areas of California than ASHRAE 90.1 because of several differences in methodology. This includes that the Statewide CASE Team used TDV savings, whereas ASHRAE 90.1 uses a different metric; the Statewide CASE Team modeled savings at a more granular level within California (the 16 climate zones designated by the California Energy Commission), rather than the IECC climate zones, which are coarser for California (for example, IECC Climate Zone 3C covers part of six climate zones as designated by the Energy Commission); and the Statewide CASE Team used the prototype buildings approved by the Energy Commission.

2.1.3 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 7 of this report for detailed proposed revisions to code language. The Energy Commission is planning consolidation of low-rise and high-rise multifamily requirements under a new multifamily section(s) in 2022 Title 24, Part 6. Restructuring the standards for multifamily building may also result in revisions to Reference Appendices, ACM Reference Manuals, compliance manuals, and compliance documents. Location and section numbering of the 2022 Standards and supporting documents for multifamily buildings depend on the Energy Commission's approach to and acceptance of a unified multifamily section(s). For clarity, the changes proposed in this Final CASE Report are demonstrated in terms of the 2019 structure and language.

2.1.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of Title 24, Part 6 as shown below. See Section 7.2 of this report for marked-up code language.

SECTION 120.1 – REQUIREMENTS FOR VENTILATION AND INDOOR AIR QUALITY and SECTION 150.0 – MANDATORY FEATURES AND DEVICES

Sections 120.1(b)2Aivb and **150.0(o)1E:** For systems that serve multifamily dwelling units following the balanced ventilation path for compliance, the proposed code change would add the following mandatory fan efficacy requirements: Unitary heat or energy recovery ventilation (one ERV or HRV serving each dwelling unit) must have fan efficacy of ≤ 1.0 W/cfm.

SECTION 140.0 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 140.X – PRESCRIPTIVE REQUIREMENTS FOR VENTILATION SYSTEMS:

The proposed code chance would add a new section of prescriptive requirements specifically for ventilation system. Dwelling units that follow the balanced ventilation path in 120.1(b)2Aivb in Climate Zones 1, 2, or 11-16 must include a heat or energy recovery ventilator (HRV or ERV) that meets one of the following:

- Unitary heat or energy recovery ventilation (one ERV or HRV serving each dwelling unit) with minimum sensible heat recovery efficiency of 67 percent at 32 °F (0 °C), as listed by the Home Ventilating Institute – HVI), and fan efficacy less than or equal to 0.6 W/cfm.
- A central HRV or ERV system that provides ventilation to more than one dwelling unit with have a minimum sensible heat recovery efficiency or effectiveness of 67 percent at 32 °F (0 °C), fan efficacy that meets the requirements of Section 140.4, and include a bypass function that enables it to function in an economizer mode to take advantage of free cooling. An ATT shall conduct functional testing of controls as listed under Section NA 7.5.4 Air Economizer Controls.

Section 141.0(a) Additions: The proposed code change would add ventilation systems to the list of newly installed equipment that must meet requirements.

Section 141.0(b) Alterations: Alterations would not trigger this requirement in high-rise dwelling units.

Section 150.1(c)X Prescriptive Standards/Component Package: The proposed code change would add a new subsection of prescriptive standards for ventilation systems similar to what is added to 140.X.

Dwelling units that follow the balanced ventilation path in 150.0(o)1E in Climate Zones 1, 2, or 11-16 must include a heat or energy recovery ventilator (HRV or ERV) that meets one of the following:

- Unitary heat or energy recovery ventilation (one ERV or HRV serving each dwelling unit) with minimum sensible heat recovery efficiency of 67 percent at 32°F (0°C), as listed by the Home Ventilating Institute – HVI), and fan efficacy less than or equal to 0.6 W/cfm.
- A central HRV or ERV system that provides ventilation to more than one dwelling unit with have a minimum sensible heat recovery efficiency or effectiveness of 67 percent at 32°F (0°C), fan efficacy meeting Section 140.4 requirements, and a bypass function that enables it to function in an economizer mode to take advantage of free cooling.

Table 150.1-B COMPONENT PACKAGE – Multifamily Standard Building Design would need to be updated to include ERV/HRV requirements.

2.1.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the sections of the Reference Appendices identified below. See Section 7.3 of this report for the detailed proposed revisions to the text of the reference appendices.

The Reference Appendices are currently structured to distinguish between low-rise and high-rise requirements. For this measure, the Statewide CASE Team proposes that the distinction be made based on whether the ERVs/HRVs are unitary (each serves an individual dwelling unit) or central (each serves multiple dwelling units).

NONRESIDENTIAL APPENDIX

NA2 – Nonresidential Field Verification and Diagnostic Test Procedures: The proposed change would add a Subsection: NA2.4: Rated Heat Recovery and Energy Recovery Ventilation Verification Procedures. This new subsection would specify the procedure for verifying required information for HRV and ERV equipment if these are installed to meet the requirements of Section 120.1(b)2Aivb.

1. If unitary ERVs/HRVs (each ERV/HRV serves one dwelling unit) are listed on the compliance forms, a HERS Rater would verify in the field that an ERV or HRV is installed, that airflows for the dwelling unit's balanced ventilation systems would be met, and that the prescriptive requirements are met by looking up the nominal SRE and fan efficacy for the installed model in product databases (HVI, Air

Conditioning, Heating, Refrigeration Institute [AHRI]) or from product specifications from the manufacturer.

2. If central ERVs/HRVs (each ERV/HRV serves multiple dwelling units) are listed on the compliance forms, an ATT would verify in the field that an ERV or HRV is installed, that airflows for the dwelling unit's balanced ventilation systems would be met, and that the prescriptive requirements are met by looking up the nominal SRE and fan efficacy for the installed model in product databases (HVI, AHRI) or from product specifications from the manufacturer. The ATT would also field verify that the bypass function exists and conduct functional testing as listed under Section NA 7.5.4 Air Economizer Controls.

Section 141.0(b) Alterations. Alterations would not need to follow this requirement.

RESIDENTIAL APPENDIX

RA3.4.4 HVAC System Verification Procedures (low-rise multifamily dwelling units): The proposed change would add a Subsubsection: RA3.7.4.4: Rated Heat Recovery and Energy Recovery Ventilation Verification Procedures. This new subsection would specify the procedure for verifying required information for HRV and ERV equipment if these are installed to meet the requirements of 150.0(o)1E.

For unitary ERVs/HRVs, a HERS Rater will:

1. Verify if an ERV/HRV is needed, depending on the project's compliance path—balanced ventilation or compartmentalization—and the project's climate zone.
2. If it is required, verify in the field that an ERV or HRV is installed, that airflows for the dwelling unit's balanced ventilation systems will be met, and that the prescriptive requirements are met by looking up the nominal SRE and fan efficacy for the installed model in product databases (HVI, AHRI) or from product specifications from the manufacturer.

For central ERVs/HRVs, an ATT will conduct steps 1 and 2 above for unitary ERVs/HRV. In addition, an ATT will

3. Verify that the bypass function exists from the cut-sheet, and conduct functional testing as listed under NA 7.5.4 Air Economizer Controls.

2.1.3.3 Summary of Changes to the Residential and Nonresidential ACM Reference Manuals

This proposal would modify the following sections of the Residential and Nonresidential ACM Reference Manual as shown below. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

This proposal would modify the following sections of the Residential/Nonresidential ACM Reference Manual as shown below. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

RESIDENTIAL ACM REFERENCE MANUAL

Section 2.4.9 Indoor Air Quality Ventilation: Add a reference for the Standard Design that multifamily dwelling units will be evaluated as a balanced ventilation system with a sensible heat recovery of 67 percent and minimum fan efficacy of 0.6 W/cfm in Climate Zones 1, 2, and 11 through 16.

NONRESIDENTIAL ACM REFERENCE MANUAL

Section 5.6.6.4 Outdoor Air Ventilation: Add a new box called Heat Recovery that specifies a sensible heat recovery of 67 percent to the Standard Design in Climate Zones 1, 2, and 11 through 16.

ACM Reference Manual 2.4.9: Indoor Air Quality Ventilation. Changes will be made to this section to reference new requirements for the standard design.

For multifamily dwelling units:

- Currently, if the proposed design uses exhaust-only, the model assumes exhaust-only for ventilation. There will be no change if the project uses compartmentalization.
- Currently, if the proposed design uses balanced ventilation, the model assumes balanced fans without heat recovery. This will be changed for California Climate Zones 1, 2, and 11-16 so that it includes heat recovery and the operating set points for SRE and fan efficacy of the prescriptive requirements.
- For a unitary system, for the performance path, the standard design is modeled with the same fan efficacy if the proposed design fan efficacy does not exceed 0.6 W/cfm. If the project installs a unitary ERV/HRV with a worse fan efficacy (e.g., 0.8 W/cfm), the proposed design uses 0.8 W/cm while the standard design assumes 0.6 W/cfm, so the model will show a penalty for fan energy (at least part of which will be offset by the heating and energy recovery). The Statewide CASE Team also proposes a backstop of 1.0 W/cfm; i.e., projects using the performance approach could install a unitary ERV/HRV with a fan efficacy better (less than) 0.6 W/cfm and receive energy savings, an ERV/HRV with a fan efficacy of 0.6 W/cfm for no energy savings, or an ERV/HRV with a fan efficacy between 0.6 and 1.0 W/cfm and receive an energy penalty. For central ERV/HRVs, the same approach would be used for the performance path except the assumed efficacy is the requirements in Section 140.4.

- Currently, the California Building Energy Code Compliance for commercial buildings (CBECC-Com) software, which is used for modeling multifamily buildings with more than three occupiable floors,[5] has a bypass check-box (options of yes/no). The Statewide CASE Team proposes to change the CBECC-Com software so that, for buildings using a central ventilation system in the climate zones affected by the measure, the software assumes a heat recovery system with bypass. The California Building Energy Code Compliance for residential buildings software (CBECC-Res), which is used for modeling multifamily buildings with three occupiable floors or less, does not have a bypass function or allow central systems. The Statewide CASE Team will propose to add a feature so that CBECC-Res has a bypass function.

2.1.3.4 Summary of Changes to the Residential and Nonresidential Compliance Manuals

The proposed code change would modify the following section of the Residential and Nonresidential Compliance Manuals:

RESIDENTIAL COMPLIANCE MANUAL

Section 4.6 – Indoor Air Quality and Mechanical Ventilation: The manual will include language that summarizes the requirement. The manual will provide an overview of strategies to meet the requirement, including unitary HRVs or ERVs; or central ERVs such as rooftop HRVs or ERVs serving a vertical column of units, or HRVs or ERVs serving a cluster of units (such as one on every floor). The sizing and installation of bypass ducting will be illustrated and discussed.

The manual would also include language recommending that, for all multifamily projects that install HRVs or ERVs (including in climate zones not regulated by this requirement), the HRVs or ERVs include a bypass function, or that the dwelling units have mechanical cooling, to prevent overheating. The purpose of this language is to promote energy-efficient thermal comfort for occupants.

ERV/HRVs can use multiple strategies for distributing outside air and (if interfacing with an air handling unit) integrating the supply duct into an AHU. However, the outside air distribution issues for ERV/HRVs will be similar to issues faced under the current requirements for other types of balanced ventilation systems. 2019 Title 24, Part 6 prohibits the “continuous operation of central forced air system air handlers used in central fan integrated ventilation systems”. There are no requirements in ASHRAE Standard 62.2 for distributing outside air within the dwelling unit—i.e., providing all outdoor air through one supply register is compliant, although it is best practice to

[5] Parking garages are not considered occupiable.

distribute it throughout the dwelling unit, particularly when the outside air is outside of thermostat set points. The manual should describe at least two options for how outside air can be distributed within the dwelling unit:

1. One example in which the ERV/HRV has its own duct work, and supply air is distributed to each bedroom and the living area, and
2. One example in which the ERV/HRV interfaces with the heating, ventilation, and air conditioning (HVAC) system, by ducting the supply air into the return plenum of the forced air system.

Section 4.6.1 – Compliance and Enforcement: The manual will stipulate that the HERS Rater must document the SRE or effectiveness and verify it is ≥67 and that fan efficacy is a value of 0.6 W/cfm or lower.

Section 4.6.3.3 – Multifamily Dwelling Unit Compartmentalization: The manual will describe the new requirement for an ERV or HRV in certain climate zones for projects following the balanced ventilation path.

NONRESIDENTIAL COMPLIANCE MANUAL

Sections 4.3.2 – High-Rise Residential Dwelling Unit Mechanical Ventilation: The manual will include language that summarizes the requirement. The manual will provide an overview of strategies to meet the requirement, including unitary HRVs or ERVs, and central HRVs or ERVs serving multiple dwelling units.

The manual would also include language recommending that, for all multifamily projects that install HRVs or ERVs (including in climate zones not regulated by this requirement), the HRVs or ERVs include a bypass function, or that the dwelling units have mechanical cooling, to prevent overheating. The purpose of this language is to promote thermal comfort for occupants. The manual will frame this guidance, so it is clear what is required, versus what is recommended. The current compliance manual uses this approach for other measures, such as Section 4.5.2.4 for Supply-Air Temperature Reset Control, which specifies certain set points for this measure and provides recommendations for how this can be achieved.

Section 4.3.2.5.3 – Multifamily Dwelling Unit Compartmentalization (which describes the balanced ventilation alternative to compartmentalization): The manual will describe that an ERV or HRV is required in certain climate zones for projects following the balanced ventilation path.

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 7.6.

The proposed measure would necessitate several changes to compliance forms, including for low-rise multifamily:

- Certificate of Compliance (CF1R): Ventilation Cooling section will need to be revised to include references to ERV/HRV with bypass.
- Certificate of Installation (CF2R): Several sections would need to reflect the proposed ERV/ HRV requirements, including A. Central Fan Ventilation Cooling, B. Local Mechanical Exhaust System, C. Air Moving Equipment, G., Other Requirements, and H. Air Moving Equipment.
- Certificate of Verification (CF3R): Several sections would need to reflect the proposed ERV/HRV requirements, including A. Central Fan Ventilation Cooling System, and B. Local. Mechanical Exhaust system.

Similarly, for high-rise multifamily:

- Nonresidential Certificate of Compliance (NRCC): Any new NRCI, NRCA, or NRCV forms will need to be referenced, and information on ERV/HRV systems, as well as any central shafts requiring sealing will need to be included.
- Nonresidential Certificate of Acceptance (NRCA): Section A. Construction Inspection would need to include the proposed requirements.
- Nonresidential Certificate of Verification (NRCV): Several sections would need to reflect the proposed ERV/HRV requirements, including B. Local Mechanical Exhaust System and D. Air Moving Equipment.

2.1.4 Regulatory Context

2.1.4.1 Existing Requirements in the California Energy Code

There are no relevant existing requirements in the California Energy Code for ERV or HRV. Projects may use them under the performance approach, but they are not currently mandatory or prescriptive.

One related requirement is 2019 Title 24, Part 6 Section 120.1(b)2iv (for high-rise multifamily dwelling units) and Section 150.0(o)1E (for low-rise multifamily dwelling units), which requires that multifamily dwelling units have either balanced ventilation or meet a compartmentalization requirement.

Another related requirement is 2019 Title 24, Part 6, Section 120.1(b)1C (for high-rise dwelling units) and Section 150.0(m)12C (for low-rise dwelling units) which requires Minimum Efficiency Reporting Value (MERV) 13 filtration for heating, cooling, and ventilation air.

2019 Title 24, Part 6 Section 140.4(e) Economizers includes Table 140.4(e) for High Limit Shut Off Control Requirements. The Statewide CASE Team refers to this table of requirements for economizer shut-offs for the bypass or free-cooling function proposed for the central ERV or HRV path and presents it here as Figure 3.

TABLE 140.4-E AIR ECONOMIZER HIGH LIMIT SHUT OFF CONTROL REQUIREMENTS

Device Type[a]	Climate Zones	Required High Limit (Economizer Off When):	
		Equation[b]	Description
Fixed Dry Bulb	1, 3, 5, 11-16	$T_{OA} > 75°F$	Outdoor air temperature exceeds 75°F
	2, 4, 10	$T_{OA} > 73°F$	Outdoor air temperature exceeds 73°F
	6, 8, 9	$T_{OA} > 71°F$	Outdoor air temperature exceeds 71°F
	7	$T_{OA} > 69°F$	Outdoor air temperature exceeds 69°F
Differential Dry Bulb	1, 3, 5, 11-16	$T_{OA} > T_{RA}$ °F	Outdoor air temperature exceeds return air temperature
	2, 4, 10	$T_{OA} > T_{RA}$-2°F	Outdoor air temperature exceeds return air temperature minus 2°F
	6, 8, 9	$T_{OA} > T_{RA}$-4°F	Outdoor air temperature exceeds return air temperature minus 4°F
	7	$T_{OA} > T_{RA}$-6°F	Outdoor air temperature exceeds return air temperature minus 6°F
Fixed Enthalpy[c] + Fixed Drybulb	All	$h_{OA} > 28$ Btu/lb[c] or $T_{OA} > 75°F$	Outdoor air enthalpy exceeds 28 Btu/lb of dry air[c] or Outdoor air temperature exceeds 75°F

[a] Only the high limit control devices listed are allowed to be used and at the setpoints listed. Others such as Dew Point, Fixed Enthalpy, Electronic Enthalpy, and Differential Enthalpy Controls, may not be used in any Climate Zone for compliance with Section 140.4(e)1 unless approval for use is provided by the Energy Commission Executive Director.

[b] Devices with selectable (rather than adjustable) setpoints shall be capable of being set to within 2°F and 2 Btu/lb of the setpoint listed.

[c] At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6,000 foot elevation, the fixed enthalpy limit is approximately 30.7 Btu/lb.

Figure 3: Current requirements for economizer high limit shut-off control requirements in table 140.4(e).

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

While there are no directly related requirements in other parts of the California Building Code, Title 24, Part 4 (the California Mechanical Code, or CMC), Section 311.3 requires that outside air not be taken from less than 10 feet in distance from an appliance vent outlet, or the discharge outlet of an exhaust fan, unless the outlet is three feet above the outside-air inlet. This is to reduce the risk of contaminating the incoming air with outgoing exhaust. This minimum separation distance can be challenging to achieve, particularly for multifamily projects with small dwelling units. However, the proposed requirement for an ERV/HRV should not be more difficult than the existing requirement for balanced ventilation in terms of this CMC requirement. ASHRAE Standard 62.2 also requires a minimum 10 foot (3 meter) separation distance, but allows several exceptions:

1. Ventilation openings in the wall may be as close as a stretched-string distance of 3 ft (1 m) from sources of contamination exiting through the roof or dryer exhausts.
2. No minimum separation distance shall be required between windows and local exhaust outlets in kitchens and bathrooms.
3. Vent terminations covered by and meeting the requirements of the National Fuel Gas Code (NFPA 54/ANSI Z223.1) or equivalent.
4. Where a combined exhaust/intake termination is used to separate intake air from exhaust air originating in a living space other than kitchens, no minimum separation distance between these two openings is required. For these combined terminations, the exhaust air concentration within the intake airflow shall not exceed 10 percent, as established by the manufacturer.

The Statewide CASE Team recommends that the Energy Commission coordinate across agencies to include these exceptions in the CMC requirements for separation. In particular, the fourth exception may be advantageous for "through-wall" ERVs/HRVs installed at the wall that do not require ducting.

Title 24, Part 11 (CALGreen) requires that bathroom exhaust fans be ENERGY STAR® compliant, ducted to terminate outside the building, and (unless functioning as a component of a whole house ventilation system) include a humidity controller. Based on interviews with six subject matter experts (a mix of HERS Raters and multifamily mechanical engineers), dwelling units with ERVs and HRVs typically have an intake in the bathroom that is ducted to the ERV or HRV, rather than a stand-alone bath fan. Thus, the market appears to be interpreting this requirement as not applying when a bathroom is connected to an ERV or HRV. The Statewide CASE Team also discussed the CALGreen requirement with Housing and Community Development (HCD) staff. They reported they were aware of the potential conflict between the CALGreen requirement for an ENERGY STAR bath fan and typical installation of an HRV or ERV, and reported that they will likely revise the language in the CALGreen requirement to allow for an exception to the ENERGY STAR fan requirement if an ERV or HRV is used.

The proposed exemption from the HCD is below. Changes to the CALGreen requirement are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

Section 4.506 Indoor Air Quality and Exhaust

4.506.1 Bathroom exhaust fans. Each bathroom shall be mechanically ventilated and shall comply with the following:

1. Fans shall be ENERGY STAR compliant and be ducted to terminate outside the building.

Exception to 1: Fans functioning as a component of an energy or heat recovery ventilation system do not need to comply with Section 4.506.1(1).

2. Unless functioning as a component of a whole house ventilation system, fans must be controlled by a humidity control.

a. Humidity controls shall be capable of adjustment between a relative humidity range of ≤ 50 percent to a maximum of 80 percent. A humidity control may utilize manual or automatic means of adjustment.

b. A humidity control may be a separate component to the exhaust fan and is not required to be integral (i.e., built-in).

Exception to 2: Fans functioning as a component of a whole house ventilation system do not need to comply with Section 4.506.1(2).

Notes:

1. For the purposes of this section, a bathroom is a room which contains a bathtub, shower, or tub/shower combination.
2. Lighting integral to bathroom exhaust fans shall comply with Title 24, Part 6.

The Statewide CASE Team also examined whether the Nonresidential HVAC CASE proposal for the Fan Energy Index (FEI) or fan power budget would affect this measure. The proposal affects equipment 5 horsepower (hp) or higher; unitary ERVs/HRVs typically have a lower horsepower so would not be impacted. Larger central ERVs or HRVs would be impacted. The proposed language in this report would meet the current requirements for fan efficacy in 2019, Title 24, Part 6 Section 140.4. If the FEI and fan power budget proposal is adopted, those new requirements would apply instead.

2.1.4.3 Relationship to Local, State, or Federal Laws

There are no known relevant local, state, or federal laws for any of the multifamily IAQ submeasures.

2.1.4.4 Relationship to Industry Standards

ASHRAE Standard 90.1-2019, which applies to multifamily buildings four stories and higher, has two requirements for heating and cooling energy recovery for ventilating systems in Section 6.5.6.1.

The first requirement is triggered by climate zone and fraction of outside air; this requirement was also in the previous version of the standard – ASHRAE Standard 90.1-2016. Most unitary ventilation systems (i.e., those serving individual multifamily dwelling units) are exempt from this requirement, because the requirements for ASHRAE Climate Zone 3 (which covers most of California—as shown in the map in Figure 5) start at a minimum airflow rate of 80 cfm, which is higher than typical multifamily dwelling unit ventilation rates (typically 30 to 70 cfm, with the airflow rate depending on unit size and number of bedrooms). For central supply air—i.e., for supply ventilation systems serving multiple dwelling units— heat and energy recovery is required depending on the airflow rate as shown in Figure 4: Energy recovery requirements for central systems in ASHRAE 90.1-2019 for California.

ASHRAE Climate Zone	**% Outdoor Air at Full Design Airflow Rate**							
	≥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[6]	NR	≥19,500	≥9000	≥5000	≥4000	≥3000	≥1500	≥120
0A, 1A, 2A, 3A, 4B, 5B[7]	≥2500	≥2000	≥1000	≥500	≥140	≥120	≥100	≥80
4A, 5A, 6A, 7, 8[8]	≥200	≥130	≥100	≥80	≥70	≥60	≥50	≥40

a. NR – Not required

Figure 4: Energy recovery requirements for central systems in ASHRAE 90.1-2019 for California.

Source: (ASHRAE 2019b).

The second requirement for heat or energy recovery of ventilation systems is a new requirement (i.e., adopted for the 2019 version of ASHRAE 90.1), and is specific to multifamily dwelling units. The requirement calls for heating and cooling energy recovery with an enthalpy recovery ≥50 percent at cooling & 60 percent at heating in dwelling units. The requirement has an exemption for dwelling units smaller than 500 square feet, with an exception to the proposed requirement for ASHRAE Climate Zone 3C. While there is not a direct mapping between the ASHRAE climate zones and California climate zones, ASHRAE Climate Zone 3C roughly corresponds to the southern parts of California Climate Zones 1 and 2, and parts or all of California Climate Zones 3, 4, 5, 6, and 9, as shown in Figure 5.

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[6] Roughly corresponds to parts or all of California Climate Zones 1, 11, 12, 13, 14, 15, 16.

[7] Roughly corresponds to parts or all of California Climate Zones 12, 14, 16.

[8] Does not correspond to any California climate zones.

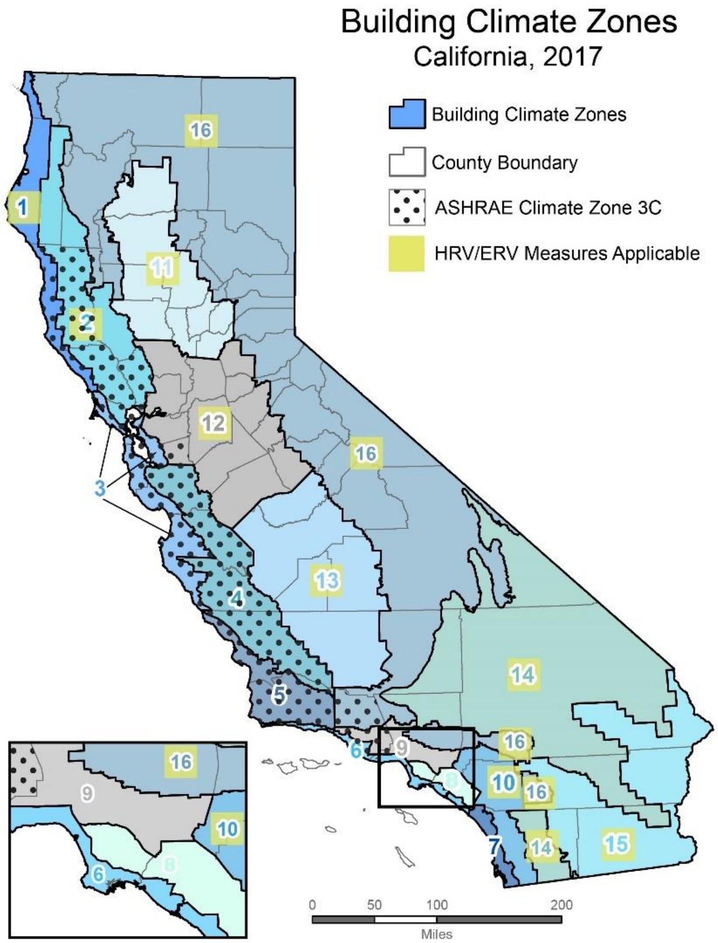

Figure 5: Map of ASHRAE Climate Zone 3C compared with California climate zones with proposed requirement.

Source: Created by Statewide CASE Team using California Energy Commission 2017 and International Code Council data, 2012.

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. In general, compared to the current compliance process which must verify installation of a balanced ventilation system for projects pursuing that path (as opposed to compartmentalization), the proposed requirement would require verification of the specific ERV/HRV equipment installed and that it meets requirements for recovery effectiveness and (if a central system) requirements for a bypass function.

- **Design Phase:** The building design team identifies if the project is in a climate zone where the requirement applies. If applicable, the building design team specifies the make and model of the ERV or HRV and ensures it meets minimum recovery efficiency via compliance documentation. The plans or specifications listing the manufacturer and model number are provided to the compliance consultant for inclusion in the NRCC or CF1R.
- **Permit Application Phase:** The project team submits design documents showing the make and model of ERV or HRV equipment supported by compliance documentation. Design of the ducts is submitted for approval. The plans examiner reviews the drawings and specifications to ensure the ERV or HRV meets the proposed requirements.
- **Construction Phase:** The project team installs the HRV or ERV equipment and ducts. The general contractor's procurement staff must ensure that the product ordered matches the model number in the plans and specifications or equivalent substitutions documented in change orders. The contractor provides a Certificate of Installation (CF2R for low-rise or NRCI for high-rise) confirming the specified ERV/HRV designed has been installed on the project. The HVAC subcontractor must ensure that the duct system is properly installed.
- **Inspection Phase:** The building inspector visually confirms that the HRV or ERV is installed and that the ducts are properly installed. To best align with current procedures, unitized equipment will be verified by HERS Raters and central equipment will be verified by ATTs, as described here:
    - For projects using unitary ERVs/HRVs (i.e., one per dwelling unit), a HERS Rater captures the make and model of equipment, verifies that the equipment's recovery efficiency or effectiveness and its fan efficacy meets the proposed requirement using the product's cut sheet or information available online. Verification procedures would be documented via applicable Certificate of Verification/ NRCV/ CF3R.
    - For projects using central ERVs/HRVs (i.e., one serves multiple dwelling units), an ATT captures the make and model of equipment, verifies that the equipment's recovery efficiency or effectiveness and its fan efficacy meets the proposed requirement using the product's cut sheet or information available online, and verifies the ERV or HRV has a bypass or free cooling function if it is a central system. The ATT would also conduct function testing of the bypass function. Verification procedures would be documented via applicable Certificate of Acceptance/NRCA.

Note that the differentiation of verification procedures by equipment type (unitized vs. central) rather than by number of stories (low-rise vs. high-rise) aligns with the movement toward multifamily unification that is proposed for 2022-Title 24, part 6. In some cases, HERS raters would verify equipment in high-rise multifamily buildings, if the projects use unitized ERVs/HRVs. Conversely, ATTs would verify equipment in low-rise multifamily buildings, if the projects use central ERVs/HRVs. Alternatively, HERS Raters and ATTs could be allowed to verify this requirement in all types of multifamily buildings, if proper training is required.

2.2 Submeasure B: Kitchen Exhaust Minimum Capture

2.2.1 Measure Overview

The purpose of this submeasure is to improve IAQ. As Title 24 evolves to require more envelope tightening, the need for adequate ventilation increases. For example, 2019 Title 24, Part 6 added the Quality Insulation Installation (QII) procedures to the prescriptive path for low-rise multifamily buildings, and proposed requirements for 2022 Title 24, Part 6 include a version of QII for the prescriptive path for high-rise multifamily buildings. Increased sealing measures in QII reduces infiltration, which provides energy savings, but also heightens the need for adequate ventilation.

Cooking-related pollution carries various health risks, and there is a growing body of research that highlights the health impacts from cooking-related pollution. Cooking over any type of cooktop (natural gas or electric) releases ultrafine and fine particles such as particulate matter 2.5 micrometers or smaller (PM2.5), as well as other irritants and potentially harmful gases including formaldehyde, acetaldehyde, acrolein, and polycyclic aromatic hydrocarbons (Singer and Chan 2018). The use of natural gas burners and ovens also releases nitrogen dioxide (NO2) and carbon monoxide (CO).

Figure 6 shows adjustments in disability-adjusted life years (DALY – which measures one year of healthy life lost due to exposure from various pollutants, several of which are associated with cooking [shown in red boxes]). As shown in this figure, PM2.5 is typically the most harmful pollutant in residences (Logue, et al. 2011). PM2.5 can travel into the lungs and bloodstream, causing respiratory and cardiovascular impacts, and NO2 is associated with respiratory problems such as chest tightness, shortness of breath, and wheezing (EPA n.d.).

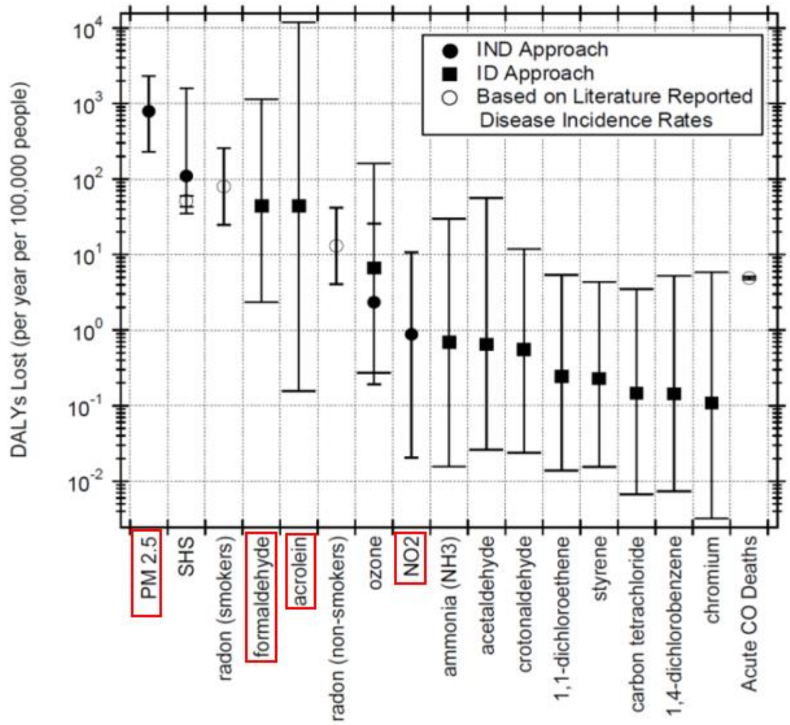

Figure 6: Estimated population averaged annual cost, in disability adjusted life years (DALYs), of pollutants with highest median DALY estimates shows PM2.5 with highest median DALY estimate.

Source: Logue, et al. 2011.

NO2 also causes other deleterious health effects. For example, a study found that asthmatic children are at higher risk for more severe asthma symptoms at low levels of NO2 and that the risk rises as levels of NO2 rise (Belanger 2013). Another study found that homes with gas stoves have 50 percent to 400 percent higher concentrations of NO2 than homes with electric stoves (EPA 2008). CO is released by natural-gas stoves and also produces deleterious health effects. However, past research found that NO2 and PM2.5 safe levels were often exceeded from cooking and cooking equipment, while CO typically was not (Singer, Pass and Delp 2017), (Logue, et al. 2014). Consequently, this analysis followed the example of Lawrence Berkeley National Laboratory (LBNL) simulations (Chan, et al. 2020) and developed requirements to maintain PM2.5 and NO2 levels at acceptable concentrations, because these should also be protective for CO.

It is particularly important that kitchen exhaust systems in multifamily dwelling units effectively remove kitchen exhaust, since these residences can have their air degraded by both their own kitchen pollution and from pollution transferred from adjacent units. The Statewide CASE Team investigated the effectiveness of kitchen range hoods in removing pollutants. Range hoods are devices that include a fan above or next to the stove or cooktop and serve to remove pollution from cooking. They may be also combined with microwave ovens. Simulation results done by LBNL (Chan, et al. 2020) have shown that for almost all California new homes, a range hood capture efficiency of at least 70 percent is required to avoid exceeding unhealthy levels of NO2 (1-h average concentration of 100 parts per billion from the U.S. Environmental Protection Agency [EPA]), and 60 percent is required to avoid unhealthy levels of PM2.5 (24-h average of 25 microgram per cubic meter from World Health Organization 2006).[9] Furthermore, LBNL recently conducted additional analysis that considered more granular size ranges of dwelling units. Based on personal communications with the LBNL authors, as shown in Table 7, at least 65 percent capture efficiency is needed to maintain PM2.5 and 75 percent capture efficiency is needed to maintain NO2 withing acceptable levels in dwelling units less than 750 ft^2.

Table 7. Minimum capture efficiency needed to maintain PM2.5 and NO2 within acceptable levels by dwelling unit floor area

Floor area of dwelling unit	Hood over electric range for PM2.5 control	Hood over natural gas range for NO2 control
≤ 750 ft^2	65% CE or 250 cfm	75% CE or 290 cfm
750 – 1,000 ft^2	55% CE or 200 cfm	65% CE or 250 cfm
1,000 - 1,500 ft^2	50% CE or 175 cfm	55% CE or 200 cfm
>1,500 ft^2	50% CE or 175 cfm	50% CE or 175 cfm

Source: Personal communication with Brett Singer and Rengie Chan, September 29, 2020

Range hoods are also typically demand controlled (user-operated). The capture efficiency evaluated under the ASTM test method corresponds to a lower field condition capture efficiency in the field (Singer, Delp and Apte 2012), because the airflow of the range hood is often lower in the field than under laboratory test conditions due to exhaust duct restrictions that increase static pressure, and because the person cooking disturbs the plume, which reduces capture efficiency. However, the proposed requirement for this code cycle balance IAQ needs with availability and pricing of compliant products.

The proposed code change would be a mandatory measure that requires a kitchen exhaust system with either a minimum capture efficiency or minimum airflow. The kitchen exhaust system must meet one of the following paths:

[9] These results were generated using models to enable variations in cooking-event time, cooking technique (e.g., boiling versus frying), size of the kitchen, and other parameters that can affect results.

1. A vented range hood with a minimum capture shown in Table 8, per ASTM Standard E3087-18 at nominal installed airflow, per HVI Publication 920, or
2. A vented range hood with a minimum airflow shown in Table 8, at a static pressure of 0.1 inches w.c. or greater,

Table 8. Minimum Range Hood Capture Efficiency or Airflow Based on Dwelling Unit Size and Fuel Type

Floor area of dwelling unit	Hood over electric range	Hood over natural gas range
<750 ft^2	65% CE or 250 cfm	75% CE or 290 cfm
750 – 999 ft^2	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500 ft^2	55% CE or 200 cfm	55% CE or 200 cfm
>1,500 ft^2		50% CE or 175 cfm

or

3. A vented downdraft exhaust with a minimum airflow of 300 cfm at a static pressure of 0.1 inches w.c. or greater, or
4. For enclosed kitchens only, continuous kitchen exhaust at a minimum of five kitchen air changes per hour at 50 Pa. An enclosed kitchen is defined as a kitchen whose permanent openings to interior adjacent spaces do not exceed a total 60 ft^2 [6 square meters]).

The first path is new. The second path increases the minimum airflow requirement. The third and fourth paths exist in the current requirements and have been retained.

For the first path, the nominal installed airflow is defined in HVI Publication 920 as a "normalized airflow rate calculated by applying the normalized airflow curve ratio to the airflow determined by the intersection of a kitchen range hood's test report airflow curve and the nominal duct system curve" (Home Ventilating Institute 2020, 8). HVI Publication 920 also defines a normalized system curve, which should be used when identifying the nominal installed airflow for consistency.

For the second path, the Statewide CASE Team considered multiple options for minimum airflow. While the correlation of airflow and capture efficiency is not well established, the Statewide CASE Team used laboratory testing of kitchen range hoods to estimate a relationship between capture efficiency and airflow, as shown in Section 3.2.2.2. The Statewide CASE Team also found that the majority of range hood products in the HVI database comply with the proposed requirement. Table 9 below shows the percentage of microwave, undercabinet and chimney range hoods in the HVI database that would comply with the proposed requirements. Note that the first path is more stringent than the second, since the static pressure at the nominal installed airflow (typically 0.2 to 0.25 inches w.c.) is almost always higher than 0.1 inches w.c., and airflow increases as static pressure decreases. Because capture efficiency generally increases as airflow increases, capture efficiency should also increase as static pressure decreases, as supported by Figure 18 in Section 3.2.2.

Table 9. Percentage of HVI Products Compliant with Proposed Requirements

Minimum Airflow (cfm)	Vertical Discharge			Horizontal Discharge		
	Microwave (n=107)	Undercabinet (n=45)	Chimney (n=61)	Microwave (n=104)	Undercabinet (n=32)	Chimney (n=4)
175	93%	98%	100%	86%	91%	100%
200	93%	98%	100%	82%	91%	100%
250	77%	84%	95%	16%	69%	100%
290	19%	67%	92%	8%	56%	100%

The third and fourth paths generally remain unchanged from current requirements. The Statewide CASE Team did not find new data on downdraft exhausts or continuous kitchen ventilation effectiveness. Consequently, the Statewide CASE Team did not alter these paths, except to specify that the airflow for the downdraft exhaust systems should be measured at 0.1 inches w.c., consistent with the second path.

Range hoods must continue to meet the current requirement for sound: no greater than three sones tested at 100 cfm or higher for demand-controlled products. Note that this study does not propose an associated sound requirement at the capture efficiency or higher airflows described above. This is because adding a sound rating at the proposed capture efficiency and proposed higher airflow would require manufacturers to retest their products for sound at the higher airflow, and because the Statewide CASE Team did not find data indicating acceptable sound levels for range hood products.

For enforcement, field verification will confirm that the range hood is vented to outdoors; recirculation type hoods shall not be allowed. The model of the kitchen range hood shall be verified and recorded on the compliance documentation for the project, and the HERS Rater or ATT shall verify that the HVI rating for this model meets the minimum capture efficiency or airflow and sound limit specified.

This proposal would be a mandatory requirement and affect all multifamily dwelling units that are new construction or additions.

This measure does not impact alterations, unless an existing vented range hood is replaced in low-rise units. In that case, under existing language in Section 150.2, the new equipment would need to meet the proposed requirement.

Because the scope of this Final CASE Report is multifamily indoor air quality, this Final CASE Report does not explicitly include recommendations for single family dwelling units. However, the Statewide CASE Team recommends that the Energy Commission provide the same range hood requirements for single family dwelling units as what is proposed here to ensure adequate kitchen ventilation. Furthermore, the proposed requirements would not significantly restrict what types of range hoods could be installed in most single family units: This analysis found that the vast majority of range hoods (including all chimney hoods) included a speed of at least 200 cfm, which is the minimum demand-control airflow proposed in dwelling units 750 to 1,000 ft^2 with electric ranges and in dwelling units 1,000 to 1,500 ft^2 with natural gas ranges. (Larger dwelling units must meet a minimum airflow of 175 cfm, which nearly all products meets.) Imposing the same requirements for single family dwelling units would have the greatest impacts on small dwelling units (smaller than 1,000 ft^2). Because these small single family units would have less dilution air to reduce pollutant levels (similar to multifamily units), they should also meet the same range hood requirements. Furthermore, this analysis found that the proposed requirements can be feasibly met, including with microwave-range hood and undercabinet products that may be common in small single family dwelling units.

2.2.2 Measure History

This proposal addresses IAQ problems resulting from inadequate exhaust of pollutants from cooking, which include PM2.5 and other hazardous pollutants, as well as pollutants from natural-gas fired cooking appliances, including NO2. As multifamily building envelopes tighten under Quality Insulation Installation (QII), increasingly stringent requirements for envelope insulation, and other requirements, it is important that cooking-related pollution is properly ventilated.

2.2.2.1 Current Requirements

Currently, 2019 Title 24, Part 6 requires by reference to ASHRAE Standard 62.2 that a local mechanical exhaust system be installed in each kitchen. In addition, 2019 Title 24, Part 6 (by reference to ASHRAE Standard 62.2) allows three kitchen exhaust systems: a range hood, a downdraft exhaust system, and (in enclosed kitchens only) continuous exhaust; all must be vented to the outdoors. The proposed language for 2022 Title 24, Part 6 would not alter the requirement that kitchen exhaust be vented, and for the purposes of this Final CASE Report, the Statewide CASE Team uses the terms “range hood” and “kitchen exhaust” to refer to vented systems only. For both low-rise and high-rise buildings, under 2019 Title 24, Part 6, the kitchen exhaust must meet one of three paths:

1. A demand-controlled range hood with an airflow of at least 100 cfm, or
2. A downdraft exhaust system with an airflow of at least 300 cfm, or

3. For enclosed kitchens only:[10] continuous exhaust with an airflow of at least five kitchen air changes per hour at 50 Pa.

Equipment must be rated by HVI (Home Ventilating Institute 2015) or AHAM to not exceed three sones at 100 cfm for demand-controlled equipment, or to not exceed one sone for continuous exhaust.

In the existing 2019 Title 24, Part 6 language, HERS Raters are required to verify that an HVI label is present on the installed range hood, and that the range hood complies with these requirements. Current Title 24, Part 6 Standards have no requirements for capture efficiency for removing pollutants.

Recirculating range hoods (which exhaust air back into the kitchen after passing through a filter) are not currently permitted in new construction. The Statewide CASE Team conducted a literature review to investigate if some types of recirculating range hoods should be permitted—particularly to explore whether a requirement should be added for alterations that would use recirculating range hoods (so would not depend on installation of exhaust duct). A 2017 literature review by Rojas et al. found there were no scientific studies available on the performance of recirculating range hoods. However, the literature review found a German consumer magazine, *Stiftung Warentest*, that tested 21 different range hoods in both extracting and recirculating configurations. Results of tests were rated on a five-level scale ranging from “very good” to “insufficient.” Although all products were rated “very good” for odor removal in extraction mode, only two models had ratings of either “very good” or “good” in recirculation mode. The rest of the models had ratings between *medium* and *insufficient* (Rojas, Walker and Singer 2017). A typical recirculating range hood has an activated carbon filter which may remove pollutants such as VOCs but the filtration efficiency over time for PM and odors are unknown (EPA n.d.; Rojas, Walker and Singer 2017). There is also little evidence of recirculating range hoods that can remove carbon monoxide or water vapor (Stratton and Singer 2014). Furthermore, if the home has gas cooking equipment, this equipment would produce NO2, which would need to be removed through a vented exhaust system.

2.2.2.2 Illustration of Capture Efficiency

Capture efficiency is measured as the mass of pollutant removed by the range hood per mass of pollutant released. A higher capture efficiency indicates that more pollutant is removed. The recently updated ASTM Standard E3087-18 provides a test method for capture efficiency, and HVI is currently developing the HVI Range Hood Capture

[10] ASHRAE Standard 62.2 defines an enclosed kitchen as a kitchen whose permanent openings to interior adjacent spaces do not exceed a total of 60 ft^2 (6 m^2).

Efficiency Testing and Rating Procedure (HVI Publication 917), which refines ASTM methods based on results from laboratory work at Texas A&M University. Figure 7 shows how capture efficiency can vary with airflow rate. This figure shows results in an airflow rate (cfm) per linear foot but capture efficiency results as described in this report are presented compared with airflow rate (cfm), since industry databases (such as HVI) list products by airflow (cfm).

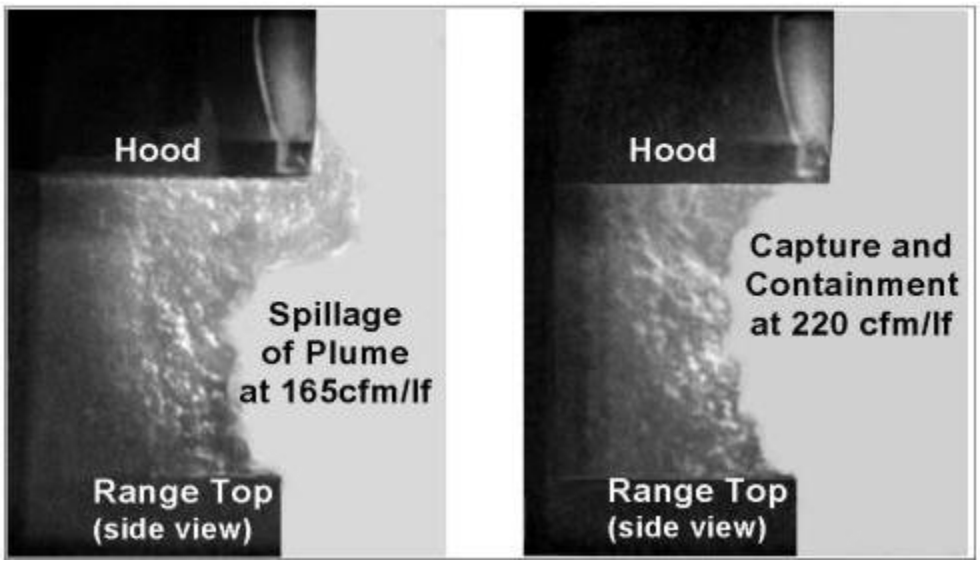

Figure 7: Illustration of range hood plume spillage at different airflow rates.

Source: (ASHRAE 2011).

Note that capture efficiency varies by distance of the hood relative to the kitchen range. However, optimal placement varies by product. Neither 2019 Title 24, Part 6 nor the California Mechanical Code (CMC) require a specific range hood installation height, but range hoods should be installed at a distance above the range according to manufacturers' instructions.

2.2.2.3 Related Progress Underway by Stakeholder Working Groups

Given the health impacts associated with kitchen pollution, several industry groups are working to incorporate a capture efficiency rating or requirement, including the ASHRAE Standard 62.2 committee. This committee established a working group in 2019 to develop recommendations for a capture efficiency requirement for future versions of the ASHRAE 62.2 Standard. The working group membership included members from the ASHRAE 62.2 committee and range hood manufacturers as well as researchers from LBNL and engineering staff from HVI and AHAM. In developing the proposed requirements, the Statewide CASE Team collaborated with these groups to coordinate development of test conditions for the proposed requirement, so that test conditions are aligned as much as possible between 2022 Title 24, Part 6 and industry testing.

2.2.2.4 Rationale for Airflow Compliance Paths for Kitchen Range Hoods

Because manufacturers are still finalizing test conditions for the capture efficiency test and are not yet publishing the capture efficiency of their equipment, the Statewide CASE Team has proposed the alternative compliance options for kitchen exhaust equipment listed in Section 2.2.1.

The first compliance option—for a minimum capture efficiency—anticipates that capture efficiency listings by HVI, AHAM, and other agencies are forthcoming within the 2022 code cycle, and requires that the ratings be verified to meet a minimum capture efficiency that varies by dwelling unit type and fuel for the range. HVI indicated that capture efficiencies would be included in listings by October 2020 on a voluntary basis and would be made mandatory in October 2021. The second, third, and fourth options allow verification based on minimum airflow rates, using data from HVI, the AHAM database, or other listings. Section 3.2.2.2 provides data from a sample of range hood products that estimates a relationship between capture efficiency and airflow.

The rationale for compliance paths based on minimum airflow is that laboratory testing shows that range hood capture efficiency generally increases airflow, as shown in data from LBNL presented in Figure 8. Note that this figure provides results using a different method (called the “pollutant method”) than the ASTM Standard E3087-18. This figure is presented because there is no equivalent data available using ASTM Standard E3087-18, and this figure illustrates how capture efficiency increases with airflow rate. Although the quantitative relationship (correlation) between capture efficiency and airflow will be different under ASTM Standard E3087-18, the qualitative finding (increased capture efficiency with increased airflow) will hold. In the figure, each range hood product is represented by a letter and number (e.g., L1, B1). The figure also illustrates that capture efficiency is higher at the same airflow for back burner cooking than front burner. For example, the regression lines indicate that at 200 cfm, back burner capture efficiency is approximately 85 percent while front burner capture efficiency is approximately 50 percent.

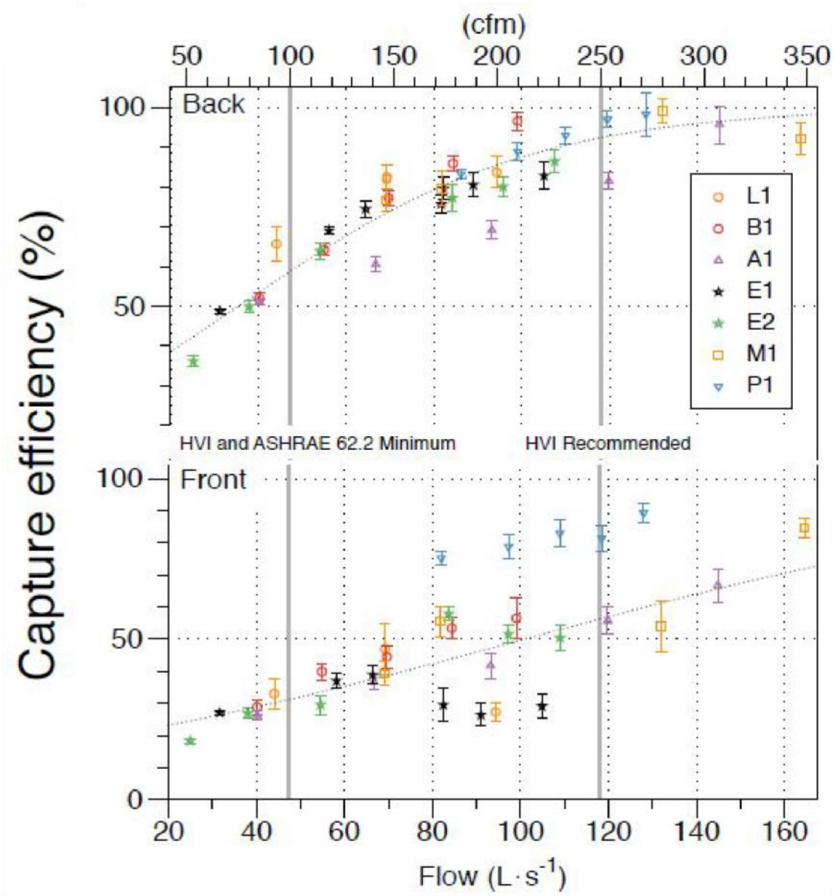

Figure 8: Capture efficiency of kitchen range hoods, as measured via "pollutant method".

Source: Performance Assessment of U.S. Residential Cooking Exhaust Hoods (Delp and Singer 2012)

2.2.2.5 Consumer Range Hood Behavior

Because range hoods typically require occupants to turn them on, the Statewide CASE Team investigated how often occupants engage their range hoods as part of its market research. Figure 9, below, provides results of a survey from LBNL in the Healthy Efficient New Gas Homes (HENGH) project of how often occupants reportedly used range hoods when they used the cooktop. As shown, most occupants reported using their range hood at least sometimes, although most do not use it all the time that they cook.

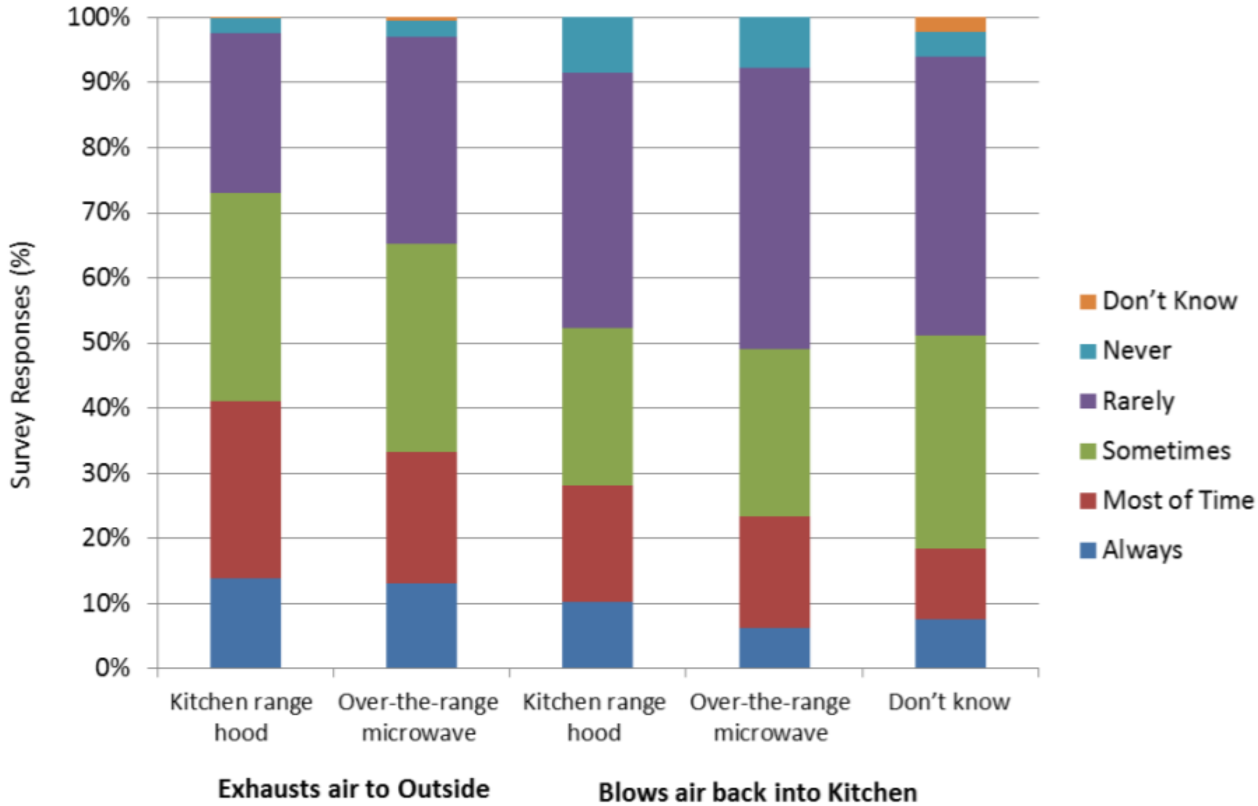

Figure 9: Frequency of the kitchen range hood usage.

Source: (Chan, et al. 2019)

Figure 10 presents the results of a survey question that asked why occupants do not use the range hood for all cooking events. As shown, consumer selected “not needed” most often, followed by “too noisy”.

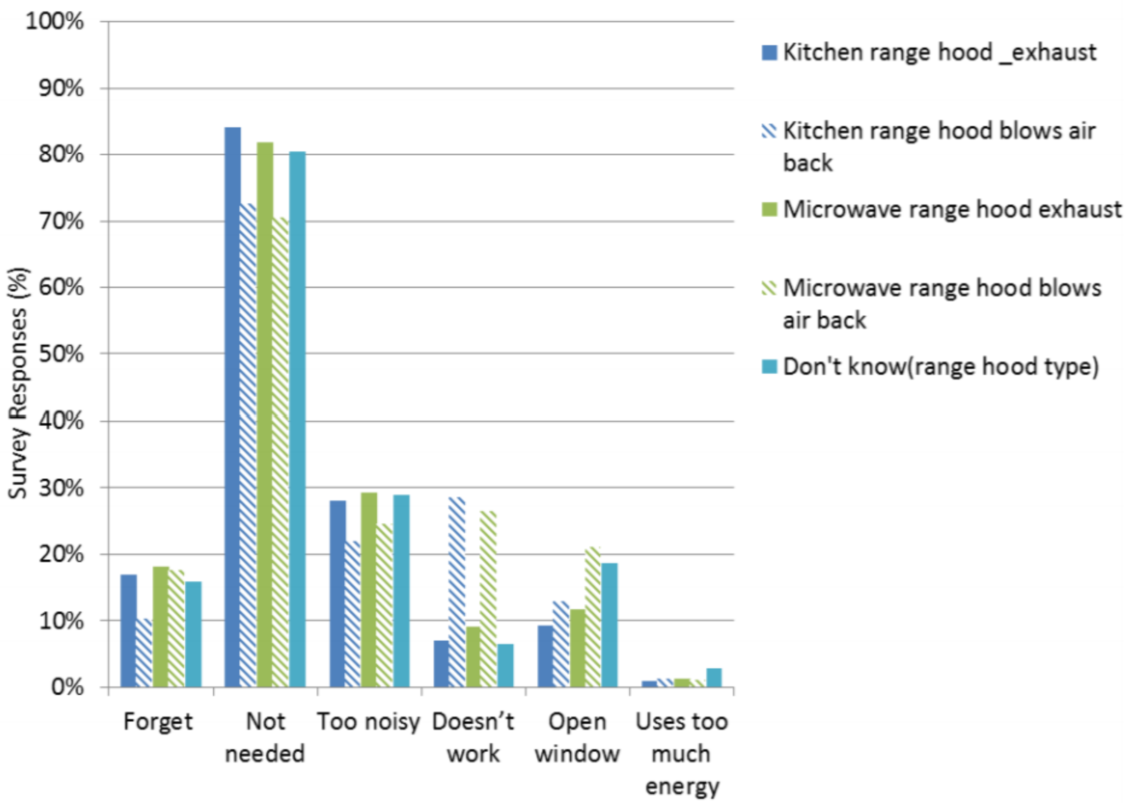

Figure 10: Reasons for not using kitchen exhaust.

Source: (Chan, et al. 2019)

Overall, results indicate that most consumers sometimes do use their range hood – specifically when they believe it is needed. The airflow-based compliance path aligns with this market research finding, because it will provide users with range hoods that are effective at removing pollution when they choose to operate them.

During the standard development process, several stakeholders recommended requiring automated range hoods, since many consumers do not always operate their hoods when cooking. The concept of requiring the hood to turn on automatically whenever temperature sensors show that cooking is occurring, or when pollutant sensors indicate ventilation is needed, is an exciting idea that should be explored in future code cycles as a means of increasing the IAQ benefits to occupants. Energy impacts, pollutant impacts, and user acceptability of automated kitchen ventilation (e.g. whether there are risks of occupants tampering with automated functions if they do not like them) should also be considered.

The survey responses also highlight the importance of tightening the sound requirement. The new requirement may still not be stringent enough to encourage consumer range hood use during all cooking events, particularly because range hoods will have a higher sone rating at the higher airflow or capture efficiency required in this proposal. Since adding a sound rating requirement at a higher airflow would require product retesting, the Statewide CASE Team considered dropping the allowable sound requirement at 100 cfm from three sones to two sones. However, the Statewide CASE Team could not find a strong correlation showing that lower sound levels at lower airflow corresponded to higher sound levels at higher airflow. Figure 11 shows a comparison of predicted sone levels at 250 cfm for compliant (has sone rating of less than or equal to two sones at working speed) and noncompliant (has sone rating of greater than two sones at working speed). The sone levels at 250 cfm are predicted through interpolation or extrapolation of the provided sound and airflow ratings from the HVI database. Although on average compliant products had a lower sound rating, sound ratings at the higher airflow ratings were highly variable, and only resulted in a reduction of about 0.5 sones compared to the noncompliant group. Future code cycles should consider a sound requirement at a higher airflow.

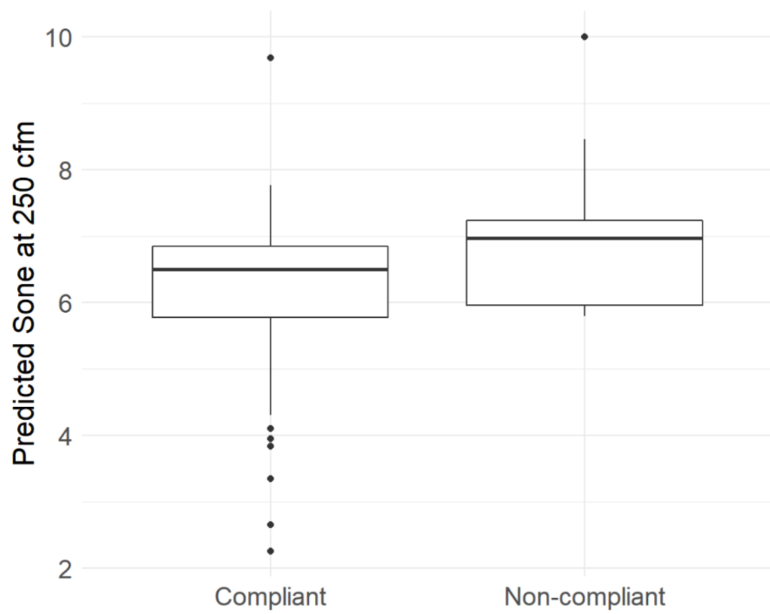

Figure 11. Sound comparison at 250 cfm for lower sone and current sone requirements.

Finally, the data above highlight a need for consumer education. For this proposal, the Statewide CASE Team has recommended adding language in Section 10-103. It would require that builders provide instructions to tenants on the operation and maintenance of local exhaust systems, including when they should be operated. For buildings with multiple tenants, these instructions will be provided to the owner, with additional instructions to provide them to each tenant at the beginning of their occupancy. Shortly before the Final CASE Report due date, based on stakeholder feedback, the Statewide CASE Team considered requiring a label in the kitchen for range hoods to educate the resident of when the hood should operate and health consequences if this is not followed. However, a consumer-facing label requires careful and precise wording with stakeholder input and (if possible) testing with a sample of consumers, which was not possible at that point in the cycle. A future code cycle could consider requiring labels to educate residents about range hood use.

2.2.2.6 Relationship of Airflow to Static Pressure and Expected Performance under Installed Conditions

The proposed requirement calls for capture efficiency or airflow measured at a minimum static pressure, since higher static pressure generally leads to lower airflow, and lower airflow generally leads to lower capture efficiency.

Each unique kitchen range hood responds differently to static pressure as defined by its "fan curve." Each field installation will have a unique "system curve" that is determined by the size and length of the duct and the number and type of fittings. As shown in Figure 12, the intersection of the two curves determines the volume of air a fan will deliver. Most range hoods are currently rated at 0.1 inches w.c., but under actual installed conditions, the static pressure may be much higher. As shown in the figure below, the airflow decreases with increasing static pressure. Because capture efficiency decreases as airflow decreases, a range hood with a capture efficiency of 70 percent at 0.1 inches w.c. (as tested in the laboratory) will have a lower capture efficiency when installed in the field.

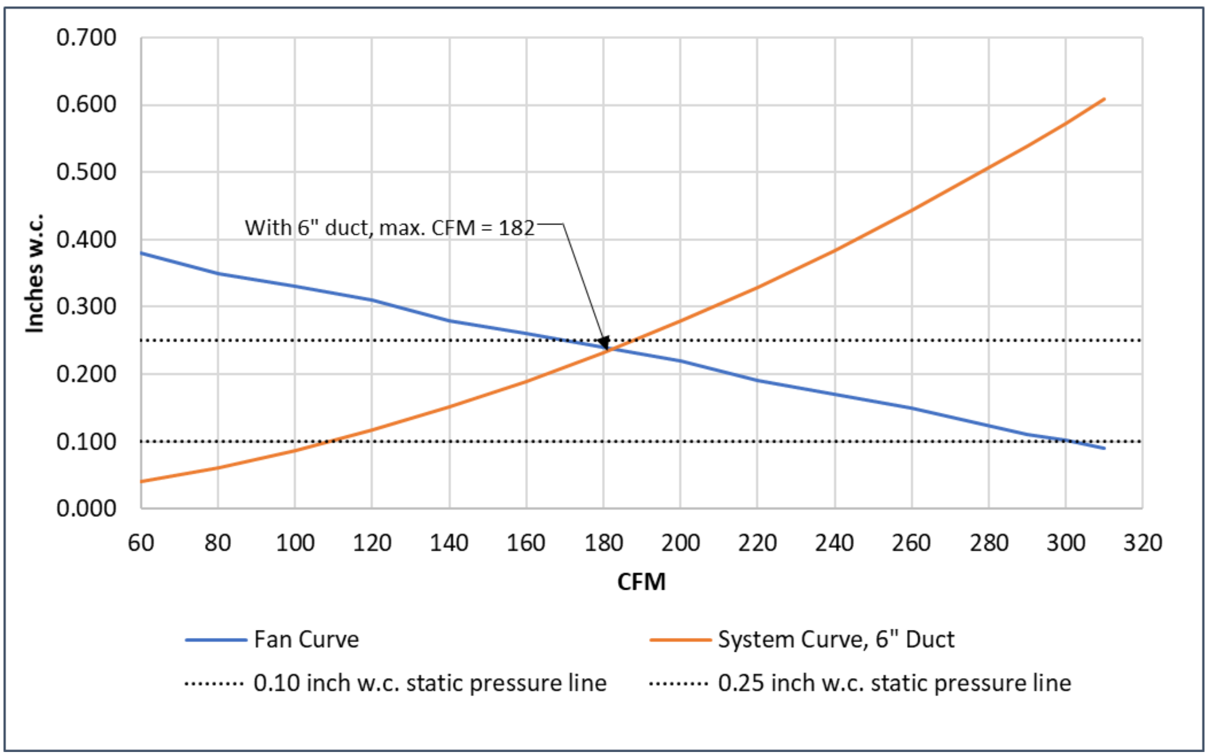

Figure 12: Typical kitchen range hood system and fan curves.

The method for measuring airflow prescribed by the Home Ventilating Airflow Test Procedure (HVI Publication 916) is to take measurements at ten or more static pressures. Airflow is reported at high speed at a static pressure of 0.1 inches w.c. (or higher at the manufacturers' option), and at a lower "working speed" setting for which the static pressure is determined from the high speed system curve. The February 2020 HVI 920 publication establishes another rating point at the nominal installed airflow. The nominal installed airflow is calculated from the intersection of the airflow curve and a nominal system curve (as in Figure 12). The nominal system curve is calculated using 10 feet of duct with the same dimensions as the hood connection, two elbows, and a vent termination fitting. This new HVI 920 requirement agrees with the approach proposed by the ASHRAE Standard 62.2 Capture Efficiency Working Group.

Because of the additional static pressure in the field, and the resulting decrease in capture efficiency and air flow, range hood products that comply with the proposed airflow requirements will likely provide lower results than the laboratory test. For example, a range hood that is shown in laboratory testing to achieve 290 cfm at 0.1 inches w.c., corresponding to 75 percent capture efficiency, will likely achieve lower airflow and therefore lower capture efficiency as installed. Consequently, it may not maintain PM2.5 and NO_2 concentrations at acceptable values. Future code proposals should consider adjusting the proposed requirement to address the higher static pressure of installed conditions, preferably in alignment with the direction of industry.

2.2.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the Standards, Reference Appendices, ACM Reference Manuals, and compliance documents will be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.2.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of Title 24, Part 6 as shown below. See Section 7.2 of this report for marked-up code language.

SECTION 10-103 PERMIT, CERTIFICATE, INFORMATIONAL, AND ENFORCEMENT REQUIREMENTS FOR DESIGNERS, INSTALLERS, BUILDERS, MANUFACTURERS, AND SUPPLIERS

The proposed change would add language in the "Ventilation information" section for builders to provide at the time of permitting. The proposed language would:

- Add a requirement for the builder to provide instructions for proper operation and maintenance of local exhaust systems, including instructions for when any user-controlled systems should be used.
- Provide uniform language in this section for low-rise and high-rise multifamily buildings.

- Require that, for systems in buildings or tenant spaces that are not individually owned and operated, the instructions shall state that the building's owner or their representative shall provide copies of instructions for these systems to all tenants at the start of their occupancy. For systems in buildings or tenant spaces that are centrally operated, the information shall be provided to the person(s) responsible for operating and maintaining the feature, material, component or mechanical ventilation device installed in the building.

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

The proposed change would define "ASTM Standard E3087-18," used in the first compliance pathway below.

The proposed change would also add "kitchen, enclosed" to the definitions, using the existing definition in ASHRAE Standard 62.2.

SECTION 120.1 – REQUIREMENTS FOR VENTILATION AND INDOOR AIR QUALITY and SECTION 150.0 – MANDATORY FEATURES AND DEVICES

Section 120.1(b)2A (for high-rise dwelling units): Language should be added to the beginning of this section to state that the ventilation requirements of CMC Chapter 7 (to ensure sufficient combustion air for combustion appliances) and the informational requirements of 10-103 (requiring the builder to provide instructions on ventilation systems) be met.

Section 120.1(b)2Avi (for high-rise dwelling units): The proposed change modifies requirements for kitchen exhaust systems in multifamily dwelling units that are new construction or additions, or in existing kitchen ventilation systems that are replaced as part of an alteration to an existing building. The exhaust system must comply with at least one of the following:

1. A vented kitchen range hood with a minimum capture efficiency shown in Table 10, as measured according to ASTM Standard E3087-18 at nominal installed airflow described in HVI Publication 920, or
2. A vented kitchen range with at least one speed setting with a minimum airflow shown in Table 10, at 25 Pa (0.1 inches w.c.) static pressure as measured according to HVI Publication 916

Table 10. Minimum Range Hood Capture Efficiency (CE) or Airflow Requirements by Dwelling Unit Floor Area and Range Fuel, for Demand-Controlled Range Hoods

Floor area of dwelling unit	Hood over electric range	Hood over natural gas range
<750 ft^2	65% CE or 250 cfm	75% CE or 290 cfm
751 – 999 ft^2	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500 ft^2	50% CE or 175 cfm	55% CE or 200 cfm
>1,500 ft^2		50% CE or 175 cfm

or

3. A vented downdraft kitchen exhaust fan with at least one speed setting with a minimum airflow of 300 cfm at 25 Pa (0.1. inches w.c.) or higher, or
4. For enclosed kitchens only: A continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour at 50 Pa.

Section 150.0(o) (for low-rise multifamily): Language should be added to the beginning of this section to state that the ventilation requirements of CMC Chapter 7 (to ensure sufficient combustion air for combustion appliances) and the informational requirements of 10-103 (requiring the builder to provide instructions on ventilation systems) shall be met. Language should also be added referencing the requirements in ASHRAE Standard 62.2 Section 6.4.2 for atmospherically vented combustion appliances or solid-fuel-burning appliances. Given the kitchen range hood airflow requirements, this will prohibit the installation of atmospherically vented combustion appliances or solid-fuel-burning appliances in multifamily units smaller than 1,000 square feet, and require a calculation of minimum floor area compared with the two largest exhaust fans for larger dwelling units.

Section 150.0(o)1G (for low-rise multifamily): The language above would be repeated in Section 150.0(o)1G for low-rise multifamily:

The proposed change modifies requirements for kitchen exhaust systems in multifamily dwelling units that are new construction or additions. The exhaust system must comply with one of the following:

1. A vented kitchen range hood with a minimum capture efficiency shown in Table 10, as measured according to ASTM Standard E3087-18 at nominal installed airflow described in HVI Publication 920, or
2. A vented kitchen range with at least one speed setting with a minimum airflow shown in Table 10, at 25 Pa (0.1 inches w.c.) static pressure as measured according to HVI Publication 916, or
3. A vented downdraft kitchen exhaust fan with at least one speed setting with a minimum airflow of 300 cfm at 25 Pa (0.1. inches w.c.) or higher, or

4. For enclosed kitchens only: A continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour at 50 Pa.

Section 141.0(a) Additions

Additions would need to follow proposed language for new construction. The Statewide CASE Teams proposes to add “or ventilation” system in the new multifamily chapter to the list of newly installed equipment that meets requirements.

Section 141.0(b) Alterations

Current language in Section 141.0(b) do not require alterations in high-rise dwelling units to meet ventilation requirements. Under the Mandatory requirements for Alterations, the Statewide CASE Team proposes to add a new section, 141.0(b)1D for “Ventilation in high-rise residential”, where the altered kitchen ventilation component and any newly installed equipment serving the ventilation alteration shall meet the applicable requirements of 120.1(b)Avi. The proposed language is based on the language for alterations in low-rise multifamily units in Section 150.2.

Section 150.2 Additions and Alterations

Low-rise additions and alterations are already required to meet requirements of Section 150.0(o) in altered components or replaced equipment of the alteration, so no changes are needed.

2.2.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the sections of the Reference Appendices identified below. See Section 7.3 of this report for the detailed proposed revisions to the text of the reference appendices.

NONRESIDENTIAL APPENDIX

NA2.2.4.1.3 – Kitchen Range Hood Verification (high-rise dwelling units). The proposed change would add a requirement that verification of the range hood include the rated capture efficiency as listed by HVI or AHAM, or verification of the manufacturer’s rating of the airflow, which is similar to the verification method in NA2.2.4.1.3.

RESIDENTIAL APPENDIX

RA3.7.4.3 – Kitchen Range Hood Verification (low-rise dwelling units). The proposed change would add a requirement that verification of the range hood include the rated capture efficiency as listed by HVI or AHAM, or verification of the manufacturer’s rating of the airflow, which is similar to the verification method in RA3.7.4.3.

In the verification section, the Statewide CASE Team proposes to replace “installed kitchen range hood” with “installed kitchen exhaust system” so it more broadly covers range hoods as well as downdraft exhaust and continuous exhaust systems.

2.2.3.3 Summary of Changes to the Residential and Nonresidential ACM Reference Manuals

The proposed code change would not modify the ACM Reference Manual.

2.2.3.4 Summary of Changes to the Residential and Nonresidential Compliance Manuals

The proposed code change would modify the following sections of the Nonresidential and Residential Compliance Manuals:

NONRESIDENTIAL COMPLIANCE MANUAL

Section 4.3.2 – High-Rise Residential Dwelling Unit Mechanical Ventilation, and Section 4.3.2.3 – Air-Moving Equipment Requirements: Would add a description of the new requirements proposed by this submeasure.

Section 4.3.2.4 – Compliance and Enforcement: Would add capture efficiency to the certificate of compliance enforcement requirements.

Section 4.3.2.7.3 – Ventilation Rate for Demand-Controlled Local Exhaust: Will add a description of the new requirements.

RESIDENTIAL COMPLIANCE MANUAL

Section 4.6.1 – Compliance and Enforcement: Would summarize the requirement and add capture efficiency to certificate of compliance enforcement requirements and CF2R-MCH-01 listings.

Section 4.6.7 – Local Exhaust: Would modify the section describing the ASHRAE Standard 62.2 requirements to clarify that multifamily dwelling units that are new construction or additions must use one of the kitchen exhaust compliance paths in Title 24, Part 6 Section 150.0(o)1G.

Section 4.6.7.1 – Demand Controlled (Intermittent) Exhaust: Would add a description of the new requirement.

Section 4.6.7.2 – Continuous Local Exhaust: Would add language describing that continuous kitchen exhaust is not a code-compliant strategy for multifamily dwelling units with non-enclosed kitchens.

2.2.3.5 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 7.6.

The proposed measure would necessitate several changes to compliance forms, including:

- CF2R: Several sections would need to reflect the proposed kitchen exhaust system requirements, including B. Local Mechanical Exhaust System and C. Kitchen Exhaust System.
- CF3R: Several sections would need to reflect the proposed kitchen exhaust system requirements, including B. Local Mechanical Exhaust system, to document the ERV/HRV and bypass (if required).
- NRCA: Section A. Construction Inspection would need to include the proposed requirements.
- NRCV: Several sections would need to reflect the proposed kitchen exhaust system, including B. Local Mechanical Exhaust System and C. Kitchen Exhaust System.
- NRCC: Any new NRCI or NRCA forms will need to be referenced, and information on new kitchen exhaust requirements would have to be added.

2.2.4 Regulatory Context

2.2.4.1 Existing Requirements in the California Energy Code

Section 150.0(o) and Section 120.1(b)2 specify that all attached dwelling units must meet all sections of ASHRAE 62.2, except where specified. ASHRAE 62.2 Section 5 includes language that all non-enclosed kitchens have a vented demand-controlled range hood with an airflow of at least 100 cfm; enclosed kitchens can either meet that intermittent range hood requirement or use continuous exhaust of at least five kitchen air changes per hour. Because most new construction multifamily kitchens are non-enclosed, most multifamily units must follow the vented range hood requirement under current regulations.

There are no relevant existing requirements in Title 24, Part 6 for minimum capture efficiency for kitchen range hoods. 2019 Title 24, Part 6, Section 150.0(o)1G requires that kitchen range hoods be rated for sound in accordance with Section 7.2 of ASHRAE 62.2. 2019 Title 24, Part 6 Section 120.1(b)2Avi provides the same language for dwelling units in high-rise buildings.

Section 7.2 of ASHRAE 62.2 requires that demand-controlled local exhaust fans in kitchens be rated for sound at a maximum of three sones at one or more airflow settings greater than or equal to 100 cfm and a maximum of one sone for continuous exhaust fans. These measurements are to be done in accordance with the HVI Loudness Testing and Rating Procedure (HVI Publication 915) and HVI Publication 916.

2019 Title 24, Part 6, Section 150.0(o)2B (for low-rise dwelling units) and 120.1(b)2Bii (for high-rise dwelling units) require field verification that the kitchen range hood is HVI-rated.

The current standards also require—through reference to ASHRAE Standard 62.2—that local exhaust airflow rates be tested or that projects follow prescriptive duct sizing requirements provided in a table in ASHRAE Standard 62.2. The table in ASHRAE Standard 62.2 provides duct sizing at the static pressure of 0.25 inches w.c. The proposed language for 2022 Title 24, Part 6 calls for range hoods that meet a minimum airflow measured at 0.1 inches w.c. (to align with current listings in the HVI database) or that meet a minimum capture efficiency measured at a nominal installed airflow. This proposal does not make any change to the prescriptive duct sizing requirement. Project teams can meet the minimum airflow requirement specified in the proposed requirement for 2022 Title 24, Part 6 (at least 250 cfm at 0.1 inches w.c. as one compliance path) and use the range hood's fan curve to identify the minimum duct size to meet the prescriptive duct sizing requirements in ASHRAE Standard 62.2 (based on the static pressure of 0.25 inches w.c.). Note that the Statewide CASE Team does not recommend that a table (similar to the prescriptive duct sizing table in ASHRAE Standard 62.2) be developed at 0.1 inches w.c., because static pressures in the field typically exceed this value.

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

There are multiple parts of the Building Code related to kitchen exhaust system requirements. CMC Table 403.7 requires a minimum exhaust rate of 100 cfm or 50 cfm if exhaust is continuous. CMC Section 311.3 prohibits outside air from being taken less than 10 foot horizontally from an exhaust discharge unless the outlet is three feet above the outside air inlet. This minimum separation distance can be challenging to achieve, particularly for multifamily projects with small dwelling units. However, the proposed requirement for range hoods should not be more difficult than the existing requirement, since 2019 Title 24, Part 6 already requires vented kitchen exhaust to outdoors through its reference to ASHRAE Standard 62.2.

CMC Section 504.3 requires that ducts used for domestic kitchen ranges be of metal with smooth interior surfaces but allows Schedule 40 PVC for downdraft grill ranges where the duct is under a slab floor. CMC Section 701.3 requires makeup air where kitchen ventilation systems interfere with the operation of appliances, such as gas furnaces or water heaters that draw combustion air from within the space. Neither Title 24, Part 2 (California Building Code) nor Part 11 (CALGreen) include requirements for domestic kitchen range hoods.

CMC Chapter 7 includes Section 701.4, which includes language specifying the required volume of indoor air for each vented combustion appliance. The importance of the CMC requirement will increase under the proposal to increase the range hood airflow because more air will be exhausted. The Statewide CASE Team recommends that language be added to the beginning of Section 120.1(b)2A for high-rise and the beginning of 150.0(o) for low-rise multifamily dwelling units to state that the ventilation requirements of CMC Chapter 7 be met.

In addition, ASHRAE Standard 62.2 Section 6.4 for Combustion and Solid-Fuel-Burning Appliances requires the following: “Where atmospherically vented combustion appliances or solid-fuel-burning appliances are located inside the pressure boundary, the total net exhaust flow of the two largest exhaust fans (not including a summer cooling fan intended to be operated only when windows or other air inlets are open) shall not exceed 15 cfm per 100 ft^2 (75 L/s per 100 m2) of occupiable space when in operation at full capacity.” To meet this requirement and the proposed range hood airflows, atmospherically vented and solid-fuel appliances may not be installed in dwelling units smaller than 1,000 ft^2. They may be installed in units larger than 1,000 ft^2, depending on the airflows of other exhaust fans in the unit, as shown in Table 11.

Table 11. Minimum Dwelling Unit Floor Area to Meet ASHRAE Standard 62.2 Combustion Requirements for Atmospherically-vented and Solid-fuel Appliances

	Minimum hood airflow (cfm) in this proposal		Minimum dwelling unit size required by ASHRAE 62.2 for atmospherically-vented or solid-fuel appliance to meet range hood cfm		Atmospherically-vented or solid-fuel appliance allowed?	
Dwelling unit size range	**Over electric range**	**Over natural gas range**	**In unit with electric range**	**In unit with natural gas range**	**In unit with electric range**	**In unit with natural gas range**
< 750 ft^2	250	290	1,667	1,933	No	No
751-999 ft^2	200	250	1,333	1,667	No	No
1,000 – 1,500 ft^2	175	200	1,167	1,333	Maybe, depending on other exhaust fan airflows in unit	
> 1,500 ft^2	175	175	1,167	1,167		

The Statewide CASE Team investigated whether the FEI proposal would affect this equipment. Because that requirement is for equipment of 5 hp or greater, and range hoods are less than 1 hp, the FEI proposal would not impact this equipment.

2.2.4.3 Relationship to Local, State, or Federal Laws

There are no known relevant local, state, or federal laws for this submeasure.

2.2.4.4 Relationship to Industry Standards

There are no relevant industry requirements for kitchen range hood capture efficiency. The ASHRAE 62.2 committee convened a working group of industry stakeholders to develop testing conditions—including a representative system curve—for measuring capture efficiency using ASTM Standard E3087-18, and to recommend a minimum capture efficiency based on this method. The Statewide CASE Team collaborated with this working group during the development of this proposal.

2.2.5 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:** The building design team selects a kitchen exhaust system that complies with either the Title 24, Part 6 capture efficiency or airflow requirements using listings from HVI, AHAM, or other listing agencies and product information (cut sheet, online database), and specifies the manufacturer, model number, and airflow or capture efficiency on the plans and/or specifications. Bid documents must indicate that the substitutions shall meet the proposed requirements. The design team member may be the architect, mechanical engineer/contractor, or kitchen consultant. The plans or specifications listing the manufacturer and model number are provided to the compliance consultant for inclusion in the NRCC or CF1R. Duct systems will need to be designed and specified that allow the chosen fan to meet air flow requirements.
- **Permit Application Phase:** The project team submits design documents showing proposed kitchen hood equipment via compliance documentation. The plans examiner reviews the drawings and specifications to ensure the exhaust system complies with either the capture efficiency or airflow requirements, as documented in the applicable Certificate of Compliance NRCC/CF1R form.
- **Construction Phase:** The project team installs the compliant kitchen hood. The general contractor's procurement staff must ensure that the product ordered matches the model number in the plans and specifications or equivalent substitutions documented in change orders. The Certificate of Installation

(CF2R/NRCI) provided by the installing contractor should confirm that the specified kitchen hood designed has been installed on the project.

- **Inspection Phase:** The ATT or HERS Rater would be required to verify through visual inspection that the kitchen exhaust equipment carries an HVI label and verify that the airflow or capture efficiency for the HVI-listed product matches the value entered in the Certificate of Installation and Certificate of Acceptance/ Verification documents (NRCI and NRCA for mid/high-rise or CF2R and CF3R for low-rise multifamily). The HERS Rater or ATT follows verification procedures and documents them via the applicable Certificate of Verification/Acceptance NRCV/NRCA/CF3R. The building inspector will confirm that applicable Installation/Verification/Acceptance documentation, along with ventilation system instructions, have been made available to the building owner.

Title 24, Part 6, Sections 120.1(b) and 150.0(o) require that dwelling unit exhaust systems meet sound and airflow ratings in accordance with ASHRAE Standard 62.2-2016. Field verification that is already required to verify that the HVI-listed performance is consistent with these requirements will continue with the new rating requirements. HVI will add listings for capture efficiency as tests are completed. There will be no change needed to product listings for the second compliance path (minimum airflow). Modifications to forms will be needed to capture efficiency ratings.

2.3 Submeasure C: Central Ventilation Duct Sealing

2.3.1 Measure Overview

This measure is primarily for energy savings but would also result in IAQ benefits.

The measure would require duct sealing for ventilation ductwork serving multiple dwelling units (referred to as “central ventilation ducts” in this report), and field verification that a sample of ducts meets a maximum leakage requirement. The central ventilation ductwork is typically comprised of a central fan (often located at the rooftop), a central ventilation duct (“shaft”) that runs between floors, horizontal branches to connect the dwelling units to the shaft, and in-unit connection points such as grilles to deliver (for supply) or remove (for exhaust) air from each dwelling unit. The figure below illustrates an example; in this example, there are no horizontal branches.

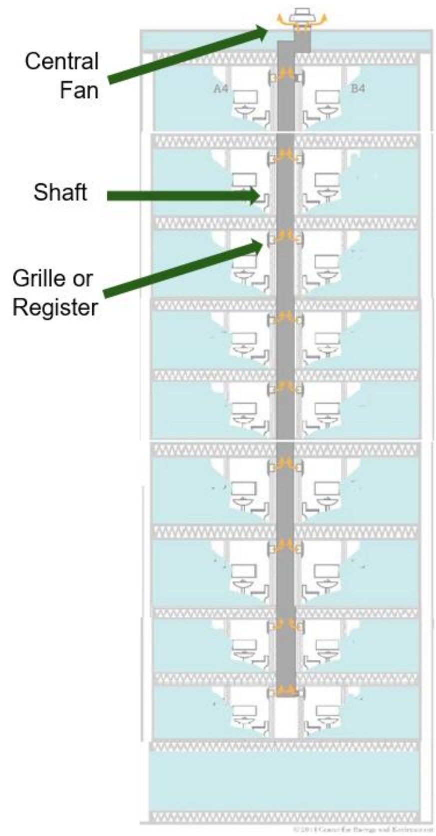

Figure 13: Diagram of central ventilation duct system components.

Source: Center for Energy and Environment 2016.

The requirement would affect central ventilation ducts providing continuous airflow or airflows used to meet the balanced ventilation path (as opposed to compartmentalization, in Section 120.1(b)2Aivb1 for high-rise and 150.0(o)1Ei for low-rise multifamily dwelling units), because those airflows continuously or near continuously. Intermittent flows, such as demand-controlled exhaust from kitchens, bathrooms, or driers, would be exempt because these operate less often and therefore have lower annual airflows, resulting in less energy savings from duct sealing.

Based on energy modeling and cost analysis completed by the Statewide CASE Team, the proposed measure provides positive energy savings that is cost effective in all climate zones. Energy savings comes from both reduced fan energy use and reduced heating and cooling. For supply ventilation ducts, the reduction in heating and cooling is due to reduced infiltration from supply ventilation ducts into the dwelling units; for exhaust ventilation ducts, the reduction in heating and cooling is due to reduced leakage of conditioned air from dwelling units to exhaust ducts.

There are also IAQ benefits from sealing both central supply and central ventilation ducts. Tighter central supply ducts ensure that all multifamily units—particularly those at the bottom or end of the central shaft—receive adequate ventilation airflow. Tighter central exhaust ducts ensure that exhausted air does not leak into other dwelling units, degrading their air quality by introducing pollutants. Bathroom exhaust is often a continuous airflow, and it can contain high humidity from bathing activities and volatile organic compounds (VOCs) from personal-care products. Humid air can cause mold on interior surfaces such as walls and ceiling. Mold leads to respiratory problems, can exacerbate asthma, and can also damage the structural integrity of the building. Finally, tighter central ventilation ducts reduce the risk of air transfer, including reducing the risk of airborne viral disease transmission.

Figure 14 illustrates duct leakage in a central ventilation duct with hypothetical airflow rates. In this example, the central fan provides 166 cfm of airflow, but only 117 cfm passes through the registers; the remaining 49 cfm (or 30 percent) is wasted, and not all dwelling units receive equal or adequate ventilation.

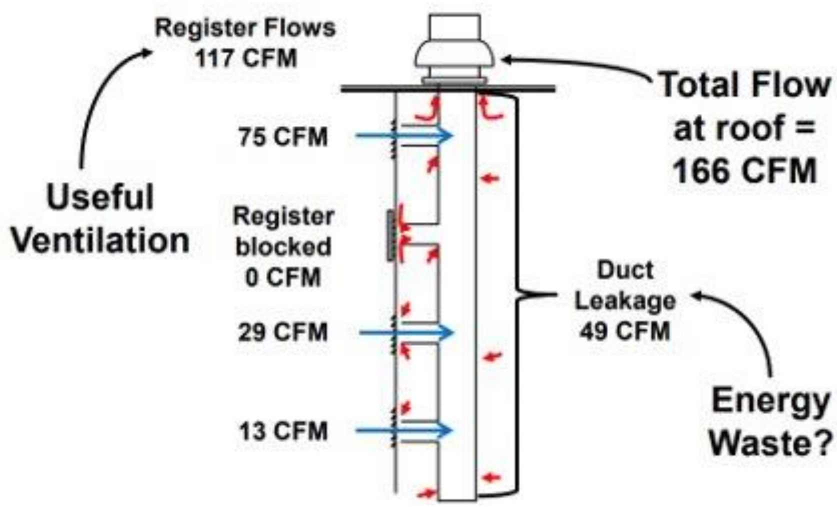

Figure 14: Ventilation duct leakage, with hypothetical flow rates.

Source: Steven Winter and Associates 2013.

This proposal would be a mandatory code requirement and affect all new construction multifamily buildings with central ventilation ducts. The proposed measure does not impact alterations but would apply to additions.

Under the proposed code change, an ATT would conduct a fan pressurization test to show that duct leakage is no greater than 6 percent leakage compared to a nominal airflow rate at 0.2 inches water column (inch w.c.) (50 Pa) for ducts serving more than six dwelling units and at 0.1 inches w.c. (25 Pa) for ducts serving six or fewer dwelling units. The Statewide CASE Team proposes a more stringent requirement for ducts serving more than six dwelling units because they will typically be under higher static pressure, which results in greater leakage, which represents additional wasted energy.

In addition, SMACNA staff reported that sealing to SMACNA Seal Class C (which applies to ducts up to 3 inches w.c.) corresponds to roughly 5 to 6 percent leakage.

The Statewide CASE Team proposes to use a fan pressurization test, which is already referenced in 2019 Title 24, Part 6 Standards, with one modification: the test will be conducted at a higher pressure (50 Pa, or 0.2 inches w.c.) for ducts serving more than six dwelling units, to better represent operating conditions in large multifamily central ventilation ducts. The ATT can use sampling for the fan pressurization test using the sampling protocols, with a higher sampling rate for this measure, presented in Section 7.3.3. In addition, the ATT can conduct the fan pressurization test at rough-in, so that leaks can be more easily sealed.

The airflow in these central ventilation ducts will vary by project, but overall airflow rates are expected to be fairly low—e.g., 1,000 cfm or lower—and can typically be tested using a duct blaster. This is because the proposed requirement is for ventilation air only, so the airflow per unit will be approximately 30 to 60 cfm per dwelling unit (depending on the unit size and number of bedrooms, and whether the central ventilation duct is providing supply or exhaust air). As an example calculation, for a ten-story building with a central ventilation duct providing continuous supply air to two dwelling units per floor—each of which is two-bedrooms and 1,080 ft^2, 55 cfm is needed per dwelling unit so total airflow needed for the twenty units served by the central duct system is 1,100 cfm. This is on par with the airflow needed for some space conditioning systems in single family homes, which is also tested with a duct blaster.

2.3.2 Measure History

The current requirements in 2019 Title 24, Part 6 require duct sealing requirements for conditioned air, but not ventilation air.

As was required in previous version of Title 24, Part 6, the current requirements in 2019 Title 24, Part 6 Section 140.4(l) stipulates duct sealing and duct leakage testing in commercial buildings for ductwork that provides conditioned air to a single zone less than 5,000 square feet. Similarly, 2019 Title 24, Part 6 Section 150.0(m)11 provides requirements for sealing and testing duct systems in low-rise residential buildings (including low-rise multifamily dwelling units) connected to space conditioning systems. Although "conditioned air" could refer to ventilation air, in addition to heated and cooled air, Energy Commission staff reported to the Statewide CASE Team that the requirements in Section 140.4(l) and 150.0(m)11 are intended to cover heated and cooled air only.

Consequently, ventilation ducts are not covered by the current requirements. Continuous or near ventilation airflows—often used for bathroom exhaust or as part of a balanced ventilation strategy—represent a significant energy use, both because of fan energy and loss of conditioned air. Central ventilation ducts represent a particularly important source of leakage to address, because a central fan (often located at the roof) must provide significantly more air through leaky ductwork to ensure that the bottom dwelling units receive adequate ventilation. 2019 Title 24, Part 6, Section 120.1(b)2B for high-rise and Section 150.0(o)2A for low-rise dwelling units require field verification to confirm that dwelling unit airflow meets the specified rate. If a supply ventilation duct is excessively leaky, the ventilation fan will need to provide more supply air to meet the dwelling unit ventilation rates—wasting energy.

In addition to the energy savings, the measure provides IAQ benefits. The proposed code change works synergistically with the Section 120.1(b)2Av requirement that central ventilation systems (i.e., those serving multiple dwelling units) be "balanced to provide ventilation airflow to each dwelling-unit served at a rate equal to or greater than the rate specified by Equation 120.1-B, but not more than 20 percent greater than the specified rate." A tight exhaust duct helps maintain the desired pressure in the duct. A product description for a constant air regulator (CAR), which is one method for balancing central duct systems, states that "Constant Airflow Regulators shall be installed in tight ducting systems" (American Aldes 2014, 3). Regarding leakage of exhausted air, while exhaust ducts should be negatively pressurized, these systems could theoretically include areas of positive pressure due to stack effect—i.e., the phenomenon of a tall building acting like a chimney, with warm air rising from floors below causing a positive pressure at top floors; the proposed measure helps ensure that exhaust air does not flow from the shaft to dwelling units.

Although there would be energy savings from intermittent exhaust flowrates—such as those from demand-controlled exhaust in kitchens, bathrooms, and dryers, or other areas, the proposed measure only covers continuous airflows or those used for balanced ventilation, because they represent the highest energy savings. However, future CASE Reports should investigate energy savings from intermittent ventilation. For example, demand-controlled kitchen exhaust could have cost-effective savings, because occupants most frequently use these exhaust systems during peak demand times (early evening for dinner preparation).

Also, the requirements for duct sealing in commercial buildings are in Section 140.4(l) - prescriptive section. Because the Statewide Multifamily IAQ CASE Team recommends this as a mandatory requirement, this Final CASE Report recommends adding the language in Section 120.4(g). The Statewide Nonresidential HVAC CASE Team recommends that the previous language on duct testing for commercial buildings also shift to 120.4(g). Consequently, the Multifamily IAQ CASE Report recommends that this proposed requirement be included as 120.4(g)2, with commercial building duct leakage requirements in 120.4(g)1 and 120.4(g)3.

2.3.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the standards, Reference Appendices, ACM Reference Manuals, and compliance documents will be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.3.1 Summary of Changes to the Standards

This proposal would modify the following sections of Title 24, Part 6 as shown below. See Section 7.2 of this report for marked-up code language.

SECTION 120.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

Section 120.4(g)2: Adds a requirement that ventilation ducts serving multiple dwelling units and that are used for continuous airflows or airflows that are part of a balanced ventilation strategy be sealed. Field verification shall confirm that leakage is no greater than 6 percent of the central fan design airflow rate at a test pressure of 25 Pa (0.1 inches w.c.) if the duct serves six or fewer dwelling units and at 50 Pa (0.2 inches w.c.) for ducts serving more than six dwelling units, as conducted using ASTM Standard E1554.

Section 150.0(m)11: Adds a requirement that ventilation ducts serving multiple dwelling units and that are used for continuous airflows or airflows that are part of a balanced ventilation strategy be sealed. Field verification shall confirm that leakage is no greater than 6 percent of the central fan design airflow rate at a test pressure of 25 Pa (0.1 inches w.c.) if the duct serves six or fewer dwelling units and at 50 Pa (0.2 inches w.c.) for ducts serving more than six dwelling units, as conducted using ASTM Standard E1554.

Section 141.0

Additions would need to follow proposed language for new construction. Alterations would not need to follow the proposed requirement.

2.3.3.2 Summary of Changes to the Reference Appendices

NONRESIDENTIAL APPENDIX

NA1.6.3 – HERS Procedures – Group Sample Field Verification and Diagnostic Testing: The proposed code language requires an ATT to test at least one in three central ventilation duct systems for verifying the requirements in Section 120.4(g)2.

The Statewide CASE Team also proposes to change the name of this subsection to "HERS *and ATT* Procedures – Group Sample Field Verification and Diagnostic Testing", to include ATT procedures.

NA1.9.1 – Duct Leakage Field Verification by the Acceptance Test Technician:

This section already states that duct leakage may be verified by an Acceptance Test Technician (ATTs) instead of a HERS Rater. Language should specify that only ATTs should conduct the duct leakage test in Section 120.4(g).

This section also states that duct leakage systems are not eligible for sampling. The proposed code language would add an exception to allow sampling for the requirements in Section 120.4(g)2.

NA2.1.4.2 – Diagnostic Duct Leakage:

The proposed code change will add the requirements of Section 140.4(1)3 to the compliance criteria in Table NA2.1-1-1.

NA2.1.4.2.2: Diagnostic Ventilation Duct Leakage from Fan Pressurization of Ducts, and subsequent subsections will be renumbered. The language in the new subsection will be similar to that in the existing Subsection NA2.1.4.2.1: Diagnostic Duct Leakage from Fan Pressurization of Ducts, which applies to testing of ducts providing conditioned air at 25 Pa (0.1 inches w.c.). However, the new subsection will revise language so that it applies to ventilation duct systems as opposed to space conditioning duct systems, and specify that the test be conducted at 50 Pa (0.2 inches w.c.) for ducts serving more than six dwelling units.

The revised language will also state that sampling can be used for duct testing following NA1.6 procedures, but that a minimum of one in three central ventilation duct systems must be tested. Language will be added stating that the leakage test can be conducted at rough-in. Language will be added (similar to the language in RA3.1.4.3) stating if the leakage test is conduct at rough-in, spaces between the supply or register boots and the wallboard shall be sealed, and at least one supply and one return register must be removed to verify proper sealing.

RESIDENTIAL APPENDIX

RA2.6.2 HERS Procedures - Initial Model Field Verification and Diagnostic Testing

Due to requests from the Energy Commission to limit any new testing requirements by HERS raters, the Statewide CASE Team proposes that this measure be verified by ATTs. While ATTs have historically conducted testing in nonresidential buildings (including high-rise residential) but not low-rise residential buildings, the delineation of low vs. high-rise multifamily buildings is decreasing with multifamily unification within 2022-Title 24, Part 6. To accommodate the utilization of ATTs for this measure, the Statewide CASE Team recommends that the title of Subsection 2.6.2 be modified to “HERS and ATT Procedures - Initial Model Field Verification and Diagnostic Testing ”, and that this section state that this test be conducted by ATTs. In the future, if the Energy Commission allows additional testing from HERS Raters, the Statewide CASE

Team recommends that both ATTs and HERS Raters be allowed to conduct this test in both low-rise and high-rise multifamily buildings.

In addition, the revised language will state that sampling can be used for duct testing following RA2.6.2 procedures. However the sampling group is up to three duct systems, which is more stringent than the seven that is required for other measures.

RA3.1.4.3 Diagnostic Duct Leakage

The revised language will add this measure to the Table RA3.1-2 – Duct Leakage Verification and Diagnostic Test Protocols and Compliance Criteria. The language will include a new subsection stating how the test will be conducted. It will be based on the current language in RA3.1.4.3.1 Diagnostic Duct Leakage from Fan Pressurization of Ducts, but will revise language so that it applies to ventilation duct systems as opposed to space conditioning duct systems, and specify a test pressure of 25 Pa (0.1 inches w.c.) for ducts six or fewer units, and 50 Pa (0.2 inches w.c.) for ducts serving more than six units.

Note that Section RA3.1.4.3 allows duct leakage testing at rough-in, and states that after the finishing wall is installed, spaces between the register boots and the wallboard shall be sealed, and at least one randomly chosen supply and one return register must be removed to verify that the spaces between the register boot and the interior finishing wall are properly sealed.

2.3.3.3 Summary of Changes to the Residential and Nonresidential ACM Reference Manuals

No changes are needed for this measure. While changes to the prototype model were necessary for calculating energy savings for this measure, changes to the ACM reference manuals are not required due to this measure being a mandatory requirement and not performance based. No additional savings for reducing duct leakage below the requirement is proposed so no specific guidance on how to appropriately model the impact of duct leakage is provided.

2.3.3.4 Summary of Changes to the Residential and Nonresidential Compliance Manuals

NONRESIDENTIAL COMPLIANCE MANUAL

Section 2.2.8 – HERS and ATT Verification – Certificate of Field Verification and Diagnostic Testing: The proposed requirement will expand the language in this section—which currently describes the leakage test for ducts carrying conditioned air in commercial buildings under Section 140.4(l)—to include the central ventilation duct leakage test, and to update the section reference to 120.4(g).

RESIDENTIAL COMPLIANCE MANUAL

Section 2.5.1 – Measures Requiring HERS or ATT Field Verification and Diagnostic Testing: The proposed requirement will expand the language in this section—which currently describes the leakage test for ducts carrying conditioned air in low-rise multifamily buildings under Section 150.0(m)11—to include the central ventilation duct leakage test. Language will be added clarifying this test must be conducted by an ATT.

See Section 7.5 of this report for the detailed proposed revisions to the text of the Compliance Manuals.

2.3.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify several compliance documents, including those listed below. Note that the proposed requirements trigger some minor changes in existing HERS measures, and some significant changes to NRCV forms to accommodate some new testing procedures. Changes include:

- CF1R: This form would need to be revised to include the proposed requirements.
- CF2R: Several sections would need to reflect the proposed requirements, including C. Air Moving Equipment and H. Air Moving Equipment
- CF3R: Several sections would need to reflect the proposed requirements, including C. Air Moving Equipment and H. Air Moving Equipment
- NRCA: Several sections would need to reflect the proposed requirements, including A. Construction Inspection and B. Functional Testing
- NRCV: Several sections would need to reflect the proposed requirements, including D. Air Moving Equipment, and I. Air Moving Equipment
- NRCC: Any new NRCI, NRCA, or NRCV forms will need to be referenced, and information on central shafts requiring sealing will need to be included.

Examples of the revised documents are presented in Section 7.6.

2.3.4 Regulatory Context

2.3.4.1 Existing Requirements in Title 24, Part 6

2019 Title 24, Part 6, Section 140.4(l) provides duct sealing requirements in high-rise residential and nonresidential buildings for ducts carrying conditioned air. This requirement was first added in the 2005 version of Title 24, Part 6, and it specifies a maximum leakage rate of 6 percent of the nominal air handler airflow rate based on field verification and diagnostic testing, in accordance with Reference Nonresidential Appendix NA2. NA2 states duct leakage testing is done at 0.1 inch w.c. (25 Pa), which is the same test pressure as for a residential duct leakage test. The leakage test in Section 140.4(l)1 includes leakage of the entire system, including the air handling unit, central shaft and horizontal branches, and grilles/fans within the conditioned space.

In addition to being limited to providing conditioned air, Section 140.4(l) is limited to systems serving a single zone less than 5,000 ft^2 of conditioned floor area. Based on interviews with a subject matter expert, this was because the original research was conducted on smaller buildings. The feasibility of conducting a leakage test in a shaft serving a larger area is discussed in Section 3.3.2.

As described in Section 2.3.2, 2019 Title 24, Part 6 Section 150.0(m)11 provides requirements for sealing and testing duct systems in low-rise residential buildings (including low-rise multifamily dwelling units) connected to space conditioning systems. Thus, 2019 Title 24, Part 6 includes requirements for duct sealing and testing of conditioned air (interpreted by Energy Commission staff as air that is heated or cooled) but not ventilation air.

In addition to expanding duct sealing requirements to ventilation air, the proposed code change works synergistically with the Section 120.1(b)2Av requirement that central ventilation systems (i.e., those serving multiple dwelling units) be "balanced to provide ventilation airflow to each dwelling-unit served at a rate equal to or greater than the rate specified by Equation 120.1-B, but not more than twenty percent greater than the specified rate." A tight exhaust duct helps maintain the desired pressure in the duct, which helps maintain balance. Furthermore, for supply air ventilation ducts, 2019 Title 24, Part 6, Section 120.1(b)2B (for high-rise dwelling units) and Section 150.0(o)2A (for low-rise dwelling units) require that field verification confirms that dwelling unit airflow meets the specified rate. The proposed code measure will help enable dwelling unit airflow to remain close to the specified rate.

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

While the California Mechanical Code (CMC) has complementary requirements for duct sealing, it does not include duct leakage testing for ventilation ducts in multifamily buildings.

CMC Section 602.1 has requirements for duct construction for heating, cooling, or evaporative cooling duct systems. But this section does not specify requirements for ducts carrying only ventilation air. CMC Section 603.10 provides language on sealing joints and seams of ducts, as excerpted below. This sealing language applies to ventilation ducts in multifamily buildings.

603.10 Joints and Seams of Ducts: Joints and seams for duct systems shall comply with Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) HVAC Duct Construction Standards-Metal and Flexible. Joints of duct systems shall be made substantially airtight by means of tapes, mastics, gasketing, or other means. Crimp joints for round ducts shall have a contact lap of not less than 11/2 inches (38 mm) and shall be mechanically fastened by means of not less than three sheet-metal screws equally spaced around the joint, or an equivalent fastening method. Joints and seams and reinforcements for factory-made air ducts and plenums shall comply with the conditions of prior approval in accordance with the installation instructions that shall accompany the product. Closure systems for rigid air ducts and plenums shall be listed in accordance with UL 181A. Closure systems for flexible air ducts shall be listed in accordance with UL 181B.

CMC includes Section 603.10.1 for Duct leakage Tests, which was not adopted by California Housing and Community Development (HCD), so does not apply to low-rise residential ductwork. Furthermore, CMC Section 603.10.1.1 Duct Leakage Tests for Residential Buildings [HCD1 and HCD2] explicitly references Title 24, Part 6 for duct leakage test requirements in all single and multifamily buildings by stating, "See California Energy Code Section 150.0(m)(11) for low-rise residential; and Section 140.4(l) for duct leakage tests for other residential buildings." The Energy Commission should work with HCD staff to update the reference to 120.4(g).

2.3.4.3 Relationship to Local, State, or Federal Laws

There are no known relevant local, state, or federal laws for any of the multifamily IAQ submeasures.

2.3.4.4 Relationship to Industry Standards

SMACNA is the industry practice leader for duct construction and testing. The SMACNA HVAC Air Duct Leakage Test Manual 2nd edition states in Section 2.5.1 Leakage Tests, "It is not required that duct systems constructed to 3 in. wg class or lower be tested."[11] Because central ventilation ducts in multifamily buildings typically have a static pressure of 1 inch w.c. or less, this type of ductwork would not require testing under this manual. However, SMACNA representatives reported to the Statewide CASE Team that they support leakage testing for low pressure classes of ductwork, at a meeting held on October 16, 2019.

2.3.5 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

[11] Note that "in. wg" is inches water gauge, which is the same as inches w.c.

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:** The project team identifies the location of central ventilation shafts, specifies sealing materials and strategies, and develops details and specifications supporting a tight air barrier. The project team shall include in the design documents duct sealing specifications including acceptable materials and minimum site conditions, and outline oversight responsibilities.
- **Permit Application Phase:** The project team submits design documents showing the location of central ventilation shafts and sealing materials. Verification requirements are included in energy compliance documentation. Building inspectors confirm these elements during plan review.
- **Construction Phase:** As the ducts are assembled, sheet metal workers shall apply duct sealant to the seams and joints of the assembly, taking care to cover the seams with sealant of a thickness and width as prescribed by the sealant manufacturer, and ensuring that manufacturer's recommendations for application conditions (such as minimum temperature and moisture) are met.
- **Inspection Phase:** The ATT shall perform the duct pressurization test and document results per the requirements of the Certificate of Acceptance /Verification NRCV/NRCA/CF3R. The verifier shall select a sample of shafts for testing. For this sample, the verifier shall temporarily seal the connection to (or the opening to) each register, grille, or other connection with an airtight covering. The verifier shall remove the existing central fan and mount a calibrated test fan and seal it to the fan curb. The duct system shall be pressurized to 25 Pascals (0.1 inch w.c.) for ducts serving six or fewer dwelling units and to 50 Pascals (0.2 inches w.c.) for ducts serving more than six dwelling units, and the flow rate recorded. A passing flow rate equals 6 percent or less of the nominal flow rater of the fan for the tested duct. The verifier then removes the test fan, reinstalls the central fan, and removes any temporarily sealing materials from the registers.

3. Market Analysis

For each submeasure, 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 various industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during public stakeholder meetings that the Statewide CASE Team held on August 22, 2019 and on March 25, 2020. The Statewide CASE Team also held meetings with various industry stakeholders, as described in Appendix F.

3.1 Submeasure A: ERV/HRV

3.1.1 Market Structure

The market can meet the proposed requirements for this measure, and some multifamily projects have already installed HRVs or ERVs. It is the role of general contractors and developers, in consultation with mechanical engineers, to identify whether they will use ERVs or HRVs, or another ventilation strategy, in each project. For projects where ERVs or HRVs are used, mechanical engineers identify an ERV or HRV approach—both the overall strategy, such as unitary equipment (one ERV or HRV per dwelling unit), or a central system serving multiple units, as well as the selection of specific equipment. Various manufacturers or commercial and residential HVAC equipment produce HRV and ERV products (e.g., Aldes, Broan, Panasonic, Zehnder, Swegon, Greenheck, Annexair, and more) and rate them for recovery efficiency in a certified laboratory.

3.1.2 Technical Feasibility, Market Availability, and Current Practices

3.1.2.1 Current Practices

While not a common practice, all types of multifamily projects are installing ERVs or HRVs. Based on interviews conducted in 2016 with 12 HERS Raters and mechanical engineers for the 2019 Title 24, Part 6 Residential Indoor Air Quality Final CASE Report, ERVs and HRVs were not standard practice at the time, but they were sometimes used in multifamily projects—particularly projects with high energy efficiency goals. Various types of ERVs and HRVs are available for all types of multifamily projects (Springer and Goebes 2017).

Interviewees also reported to the Statewide CASE Team that some projects are installing ERVs or HRVs to meet the requirements of San Francisco Health Code Article 38. This requirement is unique to San Francisco, and requires mechanically supplied dwelling unit ventilation air (i.e., exhaust-only ventilation cannot be used) with MERV 13 filtration in areas of the city with high ambient PM2.5 (San Francisco Department of Public Health n.d.).

Based on a survey of plans for 12 multifamily projects in the 2016 to 2018 California Multifamily New Homes (CMFNH) program, one high-rise project, which was subject to San Francisco Article 38, showed unitary ERVs in the building plans. Based on a survey of 29 multifamily buildings constructed since 2013, Evergreen Economics found that three buildings have an HRV and one building has an ERV, all of which were central equipment. Several manufacturers sell ERV and HRV equipment. While there are about 300 HRV and ERV in the HVI database, a much smaller subset use (or include an option to use) MERV 13 filtration. The Statewide CASE Team conducted internet research to identify HRV and ERV products that could provide unitary ventilation with MERV 13 filtration. Table 12: Example Products of HRVs and ERVs with MERV 13 or HEPA Filter Options lists examples, focusing on products with MERV 13 filtration that could provide unitary (individual dwelling unit) ventilation. The required cfm/dwelling ranges (e.g., from 31 cfm for the 540 ft^2 studios to 72 cfm for the 3-bedroom, 1,410 ft^2 units in the multifamily prototype buildings). Some of the equipment listed below could serve one or multiple units.

Table 12: Example Products of HRVs and ERVs with MERV 13 or HEPA Filter Options

Manufacturer	Product	Product Name	Flowrate (cfm)	Cost ($)	SRE (%)	Bypass filter?
American Aldes	HRV	H280-SRG	Up to 284 cfm	$979	75% at 64 cfm*	No
Venmar	HRV	EVO5 700 HRV HEPA	50-104	$999	65% at 51 cfm*	No
Panasonic	ERV	Panasonic Intellibalance 100	50-100	$940[12]	81% at 53 cfm*	No
Fantech	HRV	HERO 120H Fresh Air Appliance	56-136	$1,025	80% at 70 cfm*	No

12 Cost includes $900 for ERV and $40 for a MERV 13 filter replacement.

Zehnder	HRV	Q-600	25-353	$3,800	93% at 59 cfm**	Modulating Bypass
Zehnder	ERV	Q-600	25-353	$3,800	89% at 59 cfm**	Modulating Bypass

a. *SRE tested at supply air temperature of 0°C.

b. **Supply air temperature not found.

Sources: Zehnder 2019; American Aldes 2018; Venmar 2019; Panasonic 2019; fantech 2019. The Statewide CASE Team also called respective manufacturers for additional information. Costs are based on calls with manufacturers sales representative or prices found on Amazon, Home Depot, or Whole Sale Radon Distributors.

In addition to the unitary ERV and HRV equipment shown above, project teams can also install larger ERV or HRV equipment to serve multiple dwelling units. Table 13 provides an overview of ERV and HRV strategies, and design considerations for each approach, based on interviews with three subject matter experts.

Table 13: Overview of HRV and ERV Strategies for Multifamily Buildings

Approach	Description	Pro	Con
Unitary	One ERV or HRV is provided per dwelling unit	Simple strategy that does not require central ventilation ducts or fire smoke dampers	More exterior penetrations, more units to maintain, accessibility to the equipment is more difficult
Centralized	ERV(s) or HRV(s) serves multiple dwelling units. Examples include rooftop equipment serving a vertical column of units; or equipment located throughout the building and serving a cluster of dwelling units	Reduces the number of penetrations and typically does not require penetrations on the façade; provides some economies of scale for bypass function	More penetrations between units which require fire smoke dampers; can be more complicated to design

As another design consideration, project teams could install an ERV or HRV with MERV 13 filtration, or an ERV or HRV with lower MERV with an in-line MERV 13 filter.

The proposed requirement provides flexibility and allows project teams to choose an ERV or HRV solution that works best for their project, including unitary, rooftop centralized, or horizontal centralized; and an ERV or HRV with MERV 13 filtration or with a stand-alone filter.

3.1.2.2 Sensible Recovery of Available Products

The Statewide CASE Team also analyzed SRE values of HRVs (Figure 15) and ERVs (Figure 16: Net sensible recovery effectiveness of ERV/HRVs in AHRI database (Courtesy Red Car Analytics).) in the HVI database and found that the majority of product in the HVI database met or exceeded an SRE of 67 percent, as shown by the products to the right of the dashed line in the figures below.

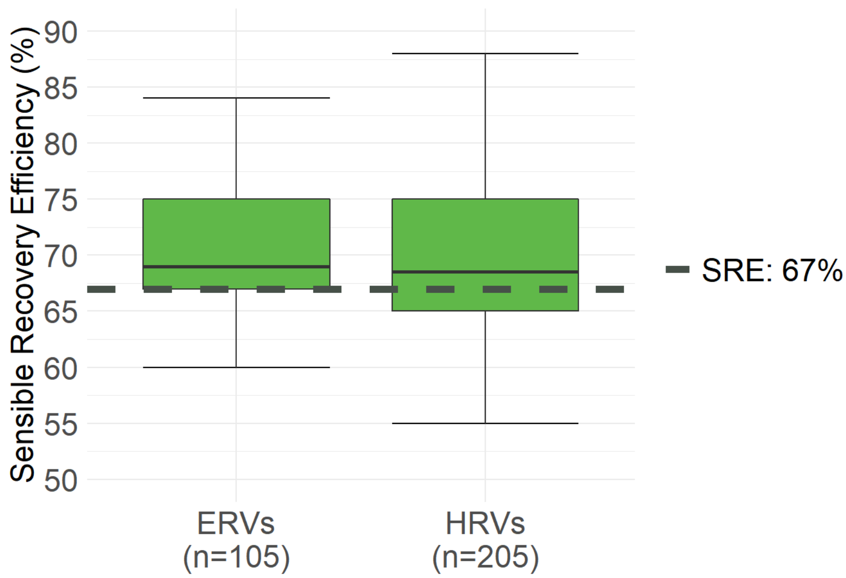

Figure 15: Boxplot of SRE of ERVs and HRVs (30-100cfm) from the HVI Certified Products database.

Source: Created by Statewide CASE Team using data from Home Ventilating Institute 2019.

Figure 16 was developed by the Nonresidential HVAC CASE Team for a heat recovery ventilation proposal for nonresidential buildings. The data show the net sensible recovery effectiveness for HRV and ERV systems in the AHRI database for airflows up to 92,000 cfm. Products that would serve as a central ERV or HRV for multifamily buildings may be listed in AHRI. SRE refers to recovery effectiveness of the entire ERV/HRV product (heat recovery core and fan), while sensible recovery *effectiveness* refers to the recovery efficiency of only the recovery core. The Statewide CASE Team did not find a quantitative comparison of SRE and sensible recovery effectiveness but proposes to use the same minimum value for each. As shown in the market availability data in the figure below, most ERV and HRV products meet the proposed prescriptive requirement of 67 percent net sensible recovery effectiveness.

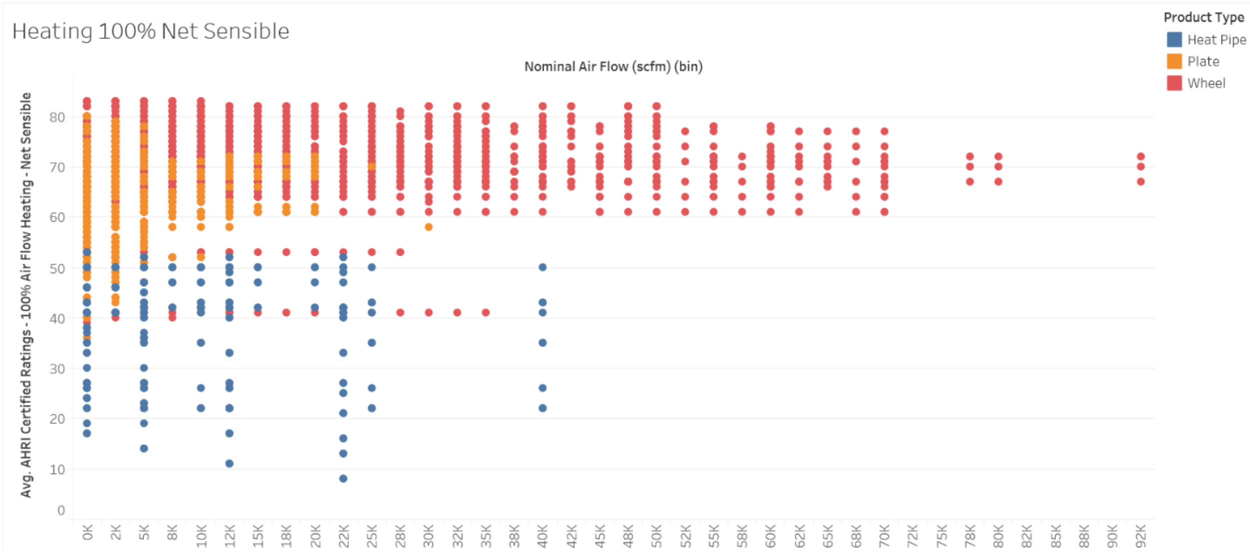

Figure 16: Net sensible recovery effectiveness of ERV/HRVs in AHRI database (Courtesy Red Car Analytics).

3.1.2.3 Fan Efficacy Requirements

The Statewide CASE Team proposes fan efficacy requirements—with a more stringent requirement in the prescriptive path and a “backstop” (more lenient allowance) in the mandatory requirements.

Minimum fan efficacy requirements for unitary ERVs/HRVs are proposed as 0.6 W/cfm in the prescriptive path and 1.0 W/cfm for mandatory requirements (i.e., for all unitary ERVs and HRVs). The Statewide CASE Team found that 21 percent of ERVs and HRVs in the HVI database meet the prescriptive requirement of 0.6 W/cfm but most (79 percent) meet the mandatory minimum efficacy requirement of 1.0 W/cfm. While only one-fifth of products meet the prescriptive requirement, project teams using the performance approach could install a product with a worse fan efficacy but trade this off for a different measure.

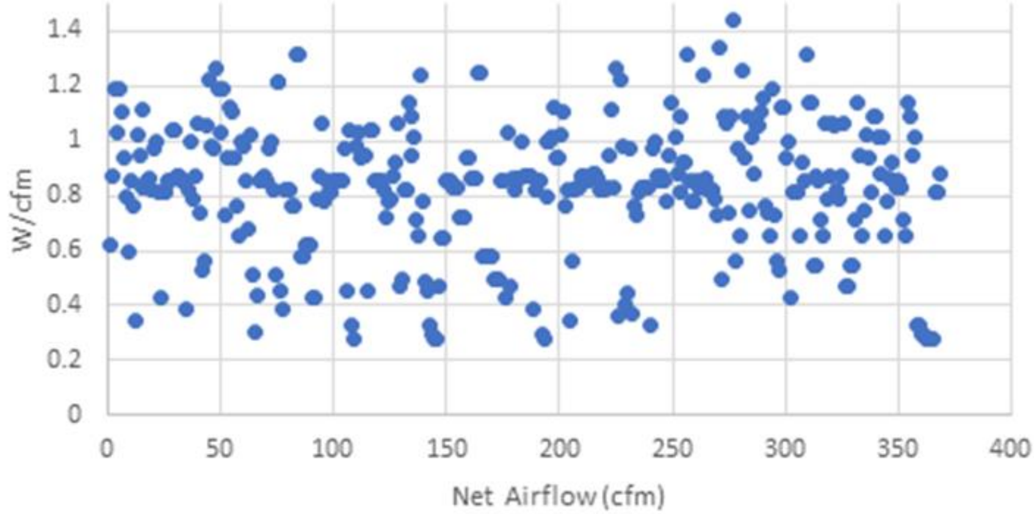

Figure 17: Fan efficacy of HRVs and ERVs in HVI database.

For central ERV/HRV, the fan efficacy requirement would follow the current language in 2019 Title 24, Part 6 Section 140.4.

3.1.3 Market Impacts and Economic Assessments

During the March 25, 2020 multifamily IAQ stakeholder meeting, the Statewide CASE Team asked participants how they would likely meet the proposed requirement in the climate zones affected by this proposal: through installing unitary ERVs/HRVs, installing central ERVs/HRVs (serving multiple dwelling units), or by meeting the compartmentalization requirement that is the current alternative to balanced ventilation in 2019 Title 24, Part 6.

Six of the twelve respondents reported they would use HRV or ERV (typically unitary) in garden-style multifamily projects, and seven of eleven respondents reported they would use HRV or ERV (typically central) in multifamily projects with common corridors. The remainder (six of twelve for garden-style and four of eleven for buildings with common corridors) reported they would use compartmentalization. These responses, though a small sample size, indicate that the market may view ERV/HRV as roughly the same or less onerous than compartmentalization.

3.1.3.1 Impact on Builders

Builders will need to incorporate ERV or HRV equipment into their multifamily projects in the climate zones affected by this proposal. There are many off-the-shelf ERV and HRV products that builders can choose from. Builders and developers of multifamily projects with common corridors can also choose to install central ERV or HRV equipment. Because the industry has been installing ERV and HRV in high efficiency projects or as one solution to meeting San Francisco Article 38, various case studies exist that show ERV and HRV in multifamily buildings. Furthermore, there are energy consultants and mechanical engineers who can support builders and developers in identifying solutions to their individual project needs. The revised compliance manuals along with compliance improvement classes will provide instruction to the industry.

3.1.3.2 Impact on Building Designers and Energy Consultants

Building designers and energy consultants will need to identify an ERV or HRV strategy for multifamily projects in climate zones in which this requirement applies. As discussed above, they can choose between various strategies, including ERV or HRV equipment serving individual dwelling units with MERV 13 filtration, ERV or HRV with low MERV (e.g., MERV 8) with an in-line MERV 13 filter, and centralized equipment with MERV 13 filtration and bypass. Designers will need to consider specifics of the project, including the necessary wall penetrations for each scenario, fire code requirements, first costs, code limitations that specify minimum distances between intake and exhaust outlets, and maintenance impacts.

3.1.3.3 Impact on Occupational Safety and Health

The proposed measure will not have a significant impact on occupational safety and health.

3.1.3.4 Impact on Building Owners and Occupants

Owners will need to ensure that the ERV/HRV equipment is maintained, including regular replacement of filters. Facility managers or third-party maintenance contractors will most likely provide maintenance. The owner could potentially train tenants or condominium owners for the filter replacement task. However, other types of balanced ventilation systems that do not include heat or energy recovery ventilators must also use MERV 13 filtration, so would also need to be replaced. Consequently, the Statewide CASE Team does not anticipate a significant incremental difference to the owner from the proposed measure compared to existing requirements.

This measure will provide improved occupant thermal comfort compared with other balanced ventilation strategies that provide unconditioned outdoor air.

3.1.3.5 Impact on Building Component Retailers

For ERV/HRV, the “retailer” would most often be HVAC distributors who stock and sell HVAC equipment for multiple manufacturers. A selection of models, types, and brands of equipment would be available. Distributors compete for business with other suppliers, which results in discounted prices for large projects. Online retailers, such as Amazon.com, and brick-and-mortar retailers, such as Home Depot, also sell ERV and HRV equipment.

HVAC distributors are likely to have slightly higher sales revenue because of this measure. Distributors will sell more ERV and HRV, but less equipment to support other balanced ventilation systems, including separate exhaust and supply fans. But because the price of ERV and HRV equipment is higher than the price of separate exhaust and supply fans, sales revenues should be higher.

3.1.3.6 Impact on Building Inspectors

The total amount of time needed to verify the ventilation system will be approximately the same as now due to this measure. During the permit application phase, building department plans examiners will need to confirm that the design includes HRV or ERV for projects where it is required (i.e., for multifamily projects that follow the balanced ventilation path in California Climate Zones 1, 2, and 11 through 16), and that the HRV or ERV equipment specified meets the minimum sensible recovery requirements and fan efficacy (if following the prescriptive path). During the inspection phase, the HERS Rater or ATT will verify that the HRV or ERV equipment was installed, document the model number, and check that it meets the prescriptive requirements for sensible recovery and fan efficacy.

However, under the base case, a building inspector would need to verify that the ventilation system meets the 2019 Title 24, Part 6 Standards definition of balanced ventilation.

Because a building inspector would be identifying different elements of the ventilation system for the proposed measure compared with the base case the total compliance enforcement time should be roughly equal.

3.1.3.7 Impact on Statewide Employment

The proposed measure is not expected to have a significant impact on employment. Instead of installing a different type of balanced system, project teams will install an ERV or HRV. Labor hours may increase or decrease depending on the balanced system installed in the base case, and the ERV or HRV strategy installed in the proposed case. In general, because both the base case and proposed case include supply and exhaust airflows, total labor is not expected to change significantly.

3.1.4 Economic Impacts

The Statewide CASE Team does not anticipate a significant change expected due to this proposal, as the proposal recommends switching from one type of balanced system (without heat or energy recovery) to one with heat or energy recovery. Therefore, the Statewide CASE Team anticipates no significant change in full time employment or businesses.

3.1.4.1 Creation or Elimination of Jobs

There is no expected change to the creation or elimination of jobs.

3.1.4.2 Creation or Elimination of Businesses in California

There is no expected change to the creation or elimination of businesses in California.

3.1.4.3 Competitive Advantages or Disadvantages for Businesses in California

There is no expected change to competitive advantage or disadvantages for businesses in California.

3.1.4.4 Increase or Decrease of Investments in the State of California

There is no expected change to investments in California.

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

There is no expected change to funds or local governments.

3.1.4.6 Impacts on Specific Persons

There is no expected change to specific persons.

3.2 Submeasure B: Kitchen Exhaust Minimum Capture

3.2.1 Market Structure

Depending on the size and type of project, kitchen exhaust systems and associated equipment may be selected by the architect, mechanical engineer, or kitchen consultant; in the case of small projects and design-build projects, the general or mechanical contractor may make the selection. Whether the exhaust is vented through the wall or to a common shaft (i.e., a central, vertical duct) will not likely affect the selection of the hood.

Manufacturers have products rated in a certified laboratory for characteristics such as airflow and sound. Few products have been tested for capture efficiency and HVI had not begun providing listings as of February 28, 2020. The option of a certified capture efficiency will not occur until 2022 Title 24, Part 6 goes into effect, giving manufacturers two years to respond to the demands of their customers.

The proposed requirement for minimum range hood airflow is based on simulations from LBNL that indicate what capture efficiency is needed to maintain acceptable levels of PM2.5 in all dwelling units and NO_2 in dwelling units with natural gas ranges. The Statewide CASE Team estimated a correlation between airflow and capture efficiency through laboratory testing. In addition, market data indicates that the majority of range hoods could meet the requirements for electric ranges in units greater than 750 ft^2 or for natural gas ranges in units greater than 1,000 ft^2—i.e., an airflow of at least 200 cfm. A significant proportion of products could meet the requirements for electric ranges for units less than 750 ft^2 or natural gas ranges in units greater than 750 ft^2 but less than

1,000 ft^2– i.e., an airflow of at least 250 cfm. There were fewer products meeting the requirement for natural gas ranges in units less than 750 ft^2—i.e., an airflow of at least 290 cfm. Table 14 shows the percentage of products in the HVI database compliant under the proposed requirements. The data shows undercabinet and microwave-range hood combination products, since they are most commonly installed in multifamily units. This indicates that the market is equipped to meet this measure.

Table 14. Percentage of HVI Products Compliant with Proposed Requirements

Minimum Airflow (cfm)	Vertical Discharge		Horizontal Discharge		Electric Range Unit Floor Area (ft^2)	Natural Gas Range Unit Floor Area (ft^2)
	Microwave (n = 107)	Under-cabinet (n = 45)	Microwave (n=104)	Under-cabinet (n=32)		
175	93%	98%	86%	91%	>1,000	>1,500
200	93%	98%	82%	91%	750-1,000	1,000 – 1,500
250	77%	84%	16%	69%	<750	750-1,000
290	19%	67%	8%	56%	NA	<750

3.2.2 Technical Feasibility, Market Availability, and Current Practices

3.2.2.1 Industry Standard Practice

As described in this subsection, typical industry practice is to install kitchen exhaust in each dwelling unit—either using a range hood or using a continuous exhaust fan.

To date, no kitchen range hood products are listed for capture efficiency, but a laboratory at Texas A&M University has been applying the ASTM Standard E3087-18 and the HVI membership have approved HVI Publication HVI 917, which prescribes detailed laboratory test procedures to improve consistency of test results. HVI 917 has been published but, as of August 2020, has not been publicly released. However, HVI plans to begin listing capture efficiencies in late 2020 and to make the listing mandatory in October 2021. Thus, capture efficiency data will be available when the 2022 Title 24, Part 6 code goes into effect.

The proposed alternative option for range hoods based on a minimum airflow does not require additional testing or listings. The HVI database already includes airflow measurements for products at the proposed minimum static pressure of 0.1 inches w.c.

As further market analysis, the Statewide CASE Team reviewed plans for 11 multifamily projects in the 2016 to 2018 CMFNH program. These projects were permitted under 2013 or 2016 Title 24, Part 6, which did not require the kitchen exhaust requirements in ASHRAE Standard 62.2. All eleven projects included at least some details of their kitchen exhaust strategy. Based on this review:

- Almost all (ten of eleven) exhausted kitchen pollution to the outdoors. The primary strategy for the projects that vented to the outdoors was unitary exhaust (i.e., each unit's kitchen was vented separately) through an exterior wall. One project used central kitchen exhaust (i.e., kitchen exhaust from multiple dwelling units are combined into one vertical duct) that was vented to the roof. Under the proposed requirement, either unitary or central exhaust would be permitted.
- Most projects did not have complete mechanical plans available for review and did not specify the kitchen ventilation equipment that would be used. Of the five projects that did, the Statewide CASE Team found that:
    - Two projects used a range hood exhausted to the outdoors, and would comply with the proposed requirement.
    - Two projects did not use a range hood for kitchen ventilation but instead specified a bath fan operating continuously. One of these projects appeared to meet the ASHRAE Standard 62.2 definition of an enclosed kitchen (would comply with the proposed requirement), while the other did not (not compliant).
    - One project used a recirculating range hood (would not comply with the proposed requirement or existing requirements).

Because the projects reviewed were permitted under 2013 or 2016 (rather than 2019) Title 24, Part 6, the Statewide CASE Team cannot tell from this review how much practices will change now that the 2019 Title 2, Part 6 requirements for kitchen exhaust are in effect.

Based on a survey of 42 multifamily units in 29 buildings constructed since 2014, Evergreen Economics found the following:

- 20 had range hoods that vented to the outdoors
- 3 had recirculating range hoods
- 19 had no mechanical exhaust (operable windows)

3.2.2.2 Capture Efficiency Results for a Sample of Range Hoods

Because capture efficiency results are not available from manufacturers at this time, the Statewide CASE Team contracted with a certified range hood testing laboratory—the Texas A&M RELLIS Energy Efficiency Laboratory (REEL)—to measure capture efficiency for a sample of range hood products. Five undercabinet range hoods representative of what would be installed in multifamily buildings were selected from HVI listings, two of which were microwave range hood combinations (OTRs). All were 18 inches deep and were from five different manufacturers. Undercounter range hoods were tested at a height of 24 inches above the cooktop surface, and microwave combination hoods were tested at a height of 18 inches, which is typical for those product types.

It is beyond the scope of this analysis to investigate degradation factors for range hoods, such as whether capture efficiency drops over time. However, range hood degradation is possible given grease buildup, wear and tear, or other factors.

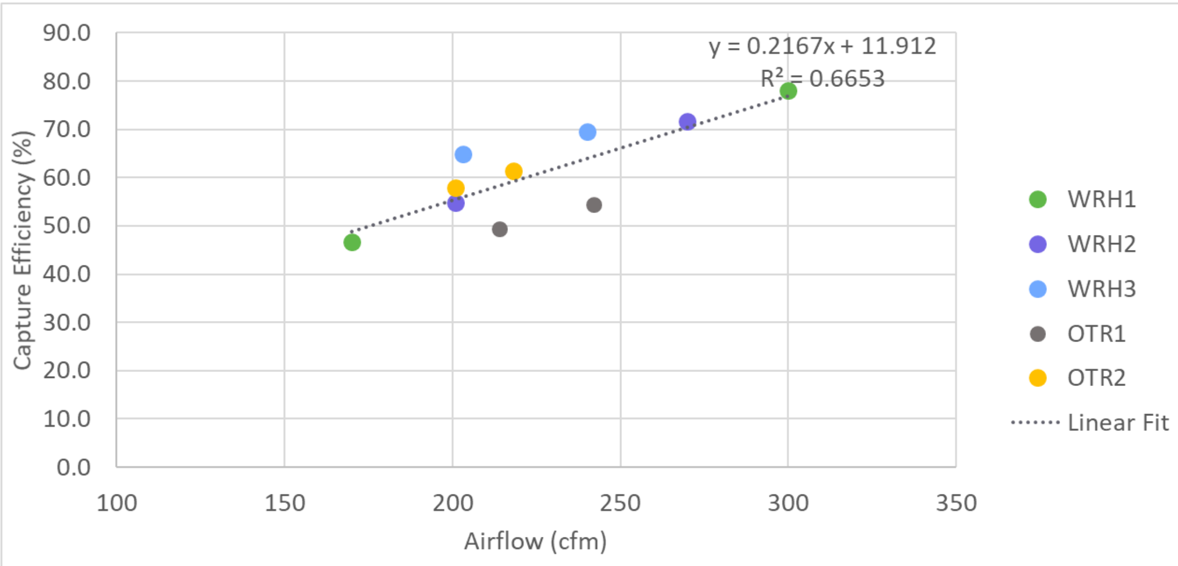

Figure 18: Capture efficiencies of example undercabinet and microwave range hoods.

Figure 18 shows capture efficiency and airflow results for each product under two static pressures: 0.1 inches w.c. and 0.25 inches w.c. The lower static pressure (0.1 inches w.c.) is used for high speed ratings, and the higher static pressure (0.25 inches w.c.) is a more accurate representation of installed conditions. Manufacturers have the option to list their products at higher pressures (usually 0.25 inches w.c.) but the selected products only have airflow listings at 0.1 inches w.c. The Statewide CASE Team selected range hood products for testing and requested that manufacturers provide airflow results (from previous testing done by third-party laboratories for HVI certification) for a range of pressures. The Statewide CASE Team used second order polynomial curve fits to develop the fan curve equations which were then solved for airflow at 0.25 inches w.c. pressure. Further information on the methodology of the capture efficiency testing is provided in Appendix I, and full results are shown in Appendix J.

The Statewide CASE Team fit a line (R-squared value of 0.67) to the capture efficiency and airflow results. For example, this analysis found that a capture efficiency of 75 percent corresponded to an airflow of 290 cfm, rounded to the nearest 5 cfm, and that 70 percent capture efficiency corresponded to 270 cfm.

While these values are based on a small sample of products, the general findings are supported by past studies:

- LBNL testing (conducted using a different capture efficiency method) found that "200 to 300 cfm are needed to achieve 70 percent capture efficiency for front burner cooking" (Chan, et al. 2020). The ASTM Standard E3087-18 method used to develop the results shown in Figure 18 simulates capture efficiency over front-burner cooking. Thus, the Statewide CASE Team's finding that an airflow of approximately 270 cfm is needed for a capture efficiency of 70 percent using ASTM Standard E3087-18 aligns with Chan, et al. 2020.
- The REEL testing conducted for the Statewide CASE Team included one product—OR2—that had been tested by LBNL previously (Zhao, et al. 2020). For front burner cooking, LBNL determined a capture efficiency of 63 percent for this product at 210 cfm. The REEL testing measured 61.4 percent at 218 cfm and 58.0 at 201 cfm; interpolating results to 210 cfm would be 59.8 percent. This is only a 3 percent difference in capture efficiency with LBNL results, indicating that results from different laboratories are similar.

The LBNL simulations (Chan, et al. 2020) also show that a slightly higher capture efficiency (and thus higher airflows) is needed to address NO2 from natural-gas equipment than the capture efficiency needed to address PM2.5 generated from all types of cooking equipment.

Figure 18 also highlights the need for an updated requirement. The 2019 Title 24, Part 6 requirement is a minimum airflow of 100 cfm. While the correlation between airflow and capture efficiency may not be linear below the tested values, capture efficiency is likely below 40 percent at 100 cfm. This is much lower than the 50 to 75 percent capture efficiency (depending on dwelling unit size and range fuel) needed to maintain pollutants within acceptable levels for IAQ.

The scatter of data indicates that, while there is clearly a correlation between increased capture efficiency with increased airflow, the exact correlation in this function varies by product (see Figure 8 in Section 2.2.2.4). This has been demonstrated through LBNL correlations of capture efficiency (measured using the "pollutant-method" for capture efficiency rather than ASTM Standard E3087-18). These variances highlight the importance of providing a capture efficiency path as one option for compliance. While there is more precision in measuring airflow than the newly developed capture efficiency metric, capture efficiency is what impacts IAQ; airflow is only a proxy to capture efficiency. Consequently, it is preferable to measure capture efficiency rather than airflow, as it more directly measures a product's ability to remove pollutants.

3.2.2.3 Market Availability of Products Meeting Compliance Path 2 (Minimum Airflow)

As described in Section 3.2.2.2, research conducted for this analysis and by LBNL shows that capture efficiency generally increases with airflow. The REEL testing found airflows that corresponded with the minimum capture efficiency needed based on LBNL simulations that varied dwelling unit size and range fuel. The Statewide CASE Team used market availability data to investigate availability of products with these minimum airflows.

The following tables show results based on HVI database analysis. To look at kitchen range hood products most likely to be used in a multifamily setting, the Statewide CASE Team filtered the HVI database for products that were rated at a static pressure of at least 0.1 inches w.c., were either a microwave or undercabinet range hood, and had ducting sizes of either 3-inch by 10-inch, 3.25-inch by 10-inch, 6-inch diameter (round or square ducting) or 7-inch diameter (round or square ducting). In addition, when analyzing the HVI database, the Statewide CASE Team attempted to combine models with nearly identical model numbers and performance characteristics (but which differed by only aesthetic characteristics, such as color) based on unique sets of model number/letters. Range hood products which were not explicitly categorized with a subcategory (e.g., microwave range hood, undercabinet range hood) in the HVI database were excluded from the analysis.

Table 15, Table 16 and Table 17 show products in the HVI database that have a maximum sone rating of three sones at a working speed of at least 100 cfm and a minimum airflow rating of 175, 200, 250 or 290 cfm at a static pressure of 0.1 inches w.c. or higher. They also shows how many manufacturers have at least one product that meets the proposed requirement. For most manufacturers, there was at least one product that complied with the proposed requirements. The tables show products in the configuration with lower percentage of products meeting proposed requirements to show more conservative estimates.

Most (82 percent of microwave, 91 percent of undercabinet and all chimney) range hoods would comply with the proposed 200 cfm minimum airflow requirement for units greater than 750 ft^2 for electric or 1,000 ft^2 for natural gas ranges. Some (30 percent of microwave, 69 percent of undercabinet and all chimney) range hoods would comply with the proposed 250 cfm minimum airflow requirement for units less than 750 ft^2 for electric and between 750 and 1,000 ft^2 for natural gas ranges. There would be less (8 percent microwave, 56 percent undercabinet, 92 percent chimney) range hoods that meet the proposed 290 cfm minimum airflow requirement for units less than 750 ft^2 with natural gas ranges.

Table 15: Count of Microwave Range Hoods That Could Meet Proposed Requirement (Horizontal Discharge)

Rated CFM	Models (n=104)		Manufacturers (n=17)
	Count	Percentage	Count
>=175	89	86%	17
>=200	85	82%	17
>=250	31	30%	14
>=290	8	8%	4

Table 16: Count of Undercabinet Range Hoods That Could Meet Proposed Requirement (Horizontal Discharge)

Rated CFM	Models (n=32)		Manufacturers (n=7)
	Count	Percentage	Count
>=175	29	91%	7
>=200	29	91%	7
>=250	22	69%	7
>=290	18	56%	5

Table 17. Count of Chimney Range Hoods That Could Meet Proposed Requirement (Vertical Discharge)

Rated CFM	Models (n=61)		Manufacturers (n=9)
	Count	Percentage	Count
>=175	61	100%	9
>=200	61	100%	9
>=250	61	100%	9
>=290	56	92%	9

3.2.3 Market Impacts and Economic Assessments

3.2.3.1 Impact on Builders

To meet 2019 Title 24, Part 6 requirements, and as shown in our market research, most builders are installing some type of kitchen exhaust fan. Builders will need to identify kitchen exhaust equipment that meets the proposed requirement. At this time, manufacturers have not yet published capture efficiency, so builders cannot yet tell if certain range hoods meet the capture efficiency compliance path. However, builders can use HVI and AHAM database listings to see which range hoods meet the airflow compliance path. Because the compliance paths for downdraft exhaust systems and continuous kitchen exhaust (in enclosed kitchens) remain unchanged, builders can continue to use product databases (in addition to dwelling unit dimensions, for the continuous airflow method) to identify products to meet either of those paths. As shown in Section 5.2, the Statewide CASE Team compared prices for a sample of products that would and would not comply with the proposed requirements. On average, compliant products were more expensive than noncompliant products at 250 cfm or higher. The Statewide CASE Team found products that comply with the proposed requirement of 250 cfm were on average more expensive than noncompliant products by approximately 40 to 50 percent. For products that comply with the proposed requirement of 290 cfm, compliant products were on average more expensive than noncompliant products by approximately 60 percent for microwave and 50 percent for undercabinet range hoods. There were not enough non-compliant products at the proposed 175 cfm and 200 cfm minimum airflow requirements to compare costs.

Table 18. Cost Impacts of Proposed Range Hood Requirements

Minimum Airflow Requirement	Dwelling Unit Square Footage	Microwave-Range Hood Incremental Cost	Undercabinet Incremental Cost
250 cfm	<750 ft$_2$ with electric range, <1,000 ft$_2$ with natural gas	$147	$200
290 cfm	<750 ft$_2$ with natural gas range	$226	$208

Because the capture efficiency and airflow are rated by manufacturers, builders do not need to conduct any testing for this proposed measure.

3.2.3.2 Impact on Building Designers and Energy Consultants

Building designers and energy consultants will need to identify exhaust system equipment that meets the proposed requirements, based on product specifications or other information (e.g., cut-sheets).

3.2.3.3 Impact on Occupational Safety and Health

The proposed measure will not have a significant impact on occupational safety and health.

3.2.3.4 Impact on Building Owners and Occupants

This measure would provide improved IAQ to occupants, because it increases the amount of pollutants removed through the kitchen range hood. Section 2.2.2 describes pollution from cooking and gas ranges, and Section 2.2.1 describes related health impacts. The proposed requirements for Title 24, Part 1 Section 10-103 specify that builders provide information to building operators and occupants for the operation of any local exhaust fans, including range hoods.

3.2.3.5 Impact on Building Component Retailers

It is normal practice to sell range hoods as part of a coordinated kitchen appliance package by equipment distributors that specialize in appliances. A bid request sheet goes to the distributor from the project purchasing agent specifying model and number. This supports a competitive situation, which will help lower prices compared to those found in retail stores. Online retailers, such as Amazon.com, and brick-and-mortar retailers, such as Home Depot, also sell range hood equipment.

The Statewide CASE Team does not anticipate that this measure will impact the total volume of sales or their revenue. Most multifamily projects would need to install a range hood to meet the 2019 Title 24, Part 6 Standards (including the requirements in ASHRAE Standard 62.2-2016), which requires intermittent exhaust for non-enclosed kitchens, and a maximum of three sones at an airflow of 100 cfm. The measure will narrow the range of products that would comply.

3.2.3.6 Impact on Building Inspectors

The total amount of time needed to verify the range hood should not increase significantly. HERS Raters or ATTs will conduct most of the verification. The 2019 Title 24, Part 6 Standards require that range hoods be HVI listed, so HERS Raters or ATTs already need to collect range hood model information, compare it to the HVI or AHAM database to verify it is listed, and confirm that it meets the airflow and sound requirements. The proposed requirement will require them to check that the range hood also meets the proposed capture efficiency or minimum airflow requirement in the same HVI or AHAM listing by reviewing a few more fields in the HVI or AHAM database.

3.2.3.7 Impact on Statewide Employment

The proposed measure will not have a significant impact in employment. The majority of multifamily units are installing some type of kitchen exhaust equipment already. This requirement will affect the type of range hoods that project teams can install, but this should not affect employment.

3.2.4 Economic Impacts

The Statewide CASE Team does not anticipate a significant change expected due to this proposal, as the proposal recommends switching from one type of kitchen exhaust system (one with lower capture efficiency or lower airflow) to a product that meets proposal requirements (higher capture efficiency or higher airflow). Therefore, the Statewide CASE Team anticipates no significant change in full-time employment or businesses.

3.2.4.1 Creation or Elimination of Jobs

There is no expected change to jobs.

3.2.4.2 Creation or Elimination of Businesses in California

There is no expected change to creation or elimination of businesses.

3.2.4.3 Competitive Advantages or Disadvantages for Businesses in California

There is no expected change to advantages or disadvantages to businesses in California.

3.2.4.4 Increase or Decrease of Investments in the State of California

There is no expected change to investments in California.

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

There is no expected change to funds or local governments.

3.2.4.6 Impacts on Specific Persons

There is no expected change to specific persons.

3.3 Submeasure C: Central Ventilation Duct Sealing

3.3.1 Market Structure

Title 24, Part 6 requires ventilation for dwelling units, but does not specify how it must be provided. For multifamily projects, mechanical engineers, general contractors, and developers identify an overall ventilation strategy. These ventilation strategies could include central ventilation ductwork that serves multiple dwelling units each with its own unitary equipment or unitized ventilation systems for each unit. The ventilation strategy decision may vary by airstream: supply air, bathroom exhaust, kitchen exhaust, etc. Airflows in these central ventilation ducts may also be continuous or intermittent. Many multifamily buildings use central ventilation ducts. For example, based on a survey from Evergreen Economics of 29 buildings constructed since 2014, ten buildings had central ventilation ducts with continuous airflow.

Ducts are composed of formed sheet metal components that fit together along seams, and joints for exhaust systems[13]. Central duct shafts are typically made of ducts with a rectangular cross section. The components are two “L” shaped sections that fit together to form the rectangular duct, as shown in Figure 19.

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[13] In older multifamily buildings, ventilation systems sometimes use drywall cavities as ducts. However, this is not typical practice in new construction (Springer and Goebes 2017), and projects would need to use hard ducted systems to meet the proposed sealing requirement.

Figure 19: Half (1/2) section rectangle duct.

Source: (Home Depot n.d.)

Sealant is applied along the long axis (where the two “L”s attach) and along the joints where two assembled duct sections meet.

Horizontal branches that connect the dwelling unit to the shaft are typically round ductwork, as shown in Figure 20. Sealant is also applied where branch ducts attach to the shaft and along seams in elbows and round duct seams as shown in Figure 21.

Figure 20: Round duct with seam showing.

Source: (Ferguson n.d.)

Figure 21: Duct with mastic applied.

Source: (Richardson 2014)

The market is equipped to meet this requirement, since duct sealing is required for some commercial duct systems under 2019 Title 24, Part 6, Section 140.4(l), and for industry standard practice (such as recommendations from SMACNA).

Mechanical engineers specify details for central ventilation ducts, including the number of central ventilation ducts, location and sizing of ductwork, central fan model and capacity, and balancing method. Testing and balancing contractors conduct balancing to ensure each dwelling receives the required amount of ventilation.

To meet the proposed code change, mechanical engineers will also specify how and where ducts will be sealed. General contractors will be responsible for ensuring that subcontractors seal ducts according to the specifications. An ATT will conduct the leakage test to measure leakage.

3.3.2 Technical Feasibility, Market Availability, and Current Practices

Based on Title 24, Part 6 requirements for sealing ducts carrying conditioned air and SMACNA requirements for sealing higher pressure ducts, the industry often seals ductwork. However, industry standard practice is to not seal ventilation ducts, because they are low pressure and carry unconditioned air, or ventilation air with moderate conditioning (from an ERV, HRV, or from a Dedicated Outdoor Air Supply [DOAS] with moderate tempering).

The proposed measure is similar to the existing requirement in 2019 Title 24, Part 6, Section 140.4(l), which requires a leakage test for commercial heating and cooling ducts serving single-zone areas 5,000 square feet or less. The Statewide CASE Team discussed the feasibility of conducting the leakage test in shafts serving larger areas with staff from Association for Energy Affordability (AEA), which has conducted central ventilation shaft leakage testing on many ducts in multifamily buildings that serve larger areas, including shafts serving up to 14 stories. In almost all cases, AEA staff reported they are able to conduct leakage measurements with a standard duct blaster test; occasionally, they use a blower door fan to achieve the required pressure.

To increase the chance of passing the proposed requirement, the project team could conduct qualitative inspections using visual observations or smoke pencil tests to identify leakage paths and improve sealing.

One major reason why the Statewide CASE Team proposed this measure for new construction and additions is because once construction is complete, most of the duct system will be behind drywall, so visual inspection of the seams will be impractical, and sealing becomes more difficult. Visual inspection will be possible where exposed in mechanical rooms and other unfinished spaces. If supply or exhaust registers are removed for cleaning or replacement, the seam between the register boot and drywall assembly can be checked for cracks or separation and resealed as needed.

3.3.3 Market Impacts and Economic Assessments

3.3.3.1 Impact on Builders

Builders will need to seal ventilation ducts serving multiple dwelling units as required by the CMC. Builders will also need to contract with an ATT to conduct leakage testing for all or a sample of central ventilation ducts. Builders are accustomed to meeting field verification requirements for duct leakage of space conditioning systems in residential buildings, per 2019 Title 24, Part 6 Section 150.0(m)11. Although commercial projects sometimes trigger the duct leakage testing requirement in Title 24, Part 6, Section 140.4(l), it is often not triggered because many duct systems are exempt (e.g., those serving multiple zones, more than 5,000 square feet, or with less than 25 percent of ducts in unconditioned spaces, outdoors or directly under a roof). Project teams may need training to seal multifamily ventilation ductwork to the level needed to pass the proposed requirements.

3.3.3.2 Impact on Building Designers and Energy Consultants

Building designers will need to identify sealing materials and sealing locations (e.g., joints, seams, connection points) in design specifications.

3.3.3.3 Impact on Occupational Safety and Health

The proposed measure will not have a significant impact on occupational safety and health.

3.3.3.4 Impact on Building Owners and Occupants

This measure will provide energy savings to the building owner through reduced fan energy, and to the occupants through reduced heating and cooling needs. In addition, the measure will provide improved IAQ to occupants, because it helps ensure that (for supply ventilation ducts) the ductwork provide sufficient fresh air to all units, and (for exhaust ducts) it reduces the risk that exhausted air can leaks from the shaft to other areas of the building. Exhausted air from bathrooms (which are often served by continuous fans) can include VOCs and humid air. VOCs and humid air can lead to mold, which can cause allergic reactions particularly in asthmatics, and can damage the structure of the building. The measure will improve comfort because it will reduce odor transfer between dwelling units.

3.3.3.5 Impact on Building Component Retailers

Retailers that provide sealing material, such as mastic and gasketing, will see an increase in sales of these products.

3.3.3.6 Impact on Building Inspectors

Because the Statewide CASE Team proposes that an ATT conduct the duct leakage testing, there will be little impact on building inspectors. Although ATTs conduct duct leakage testing on some types of commercial and low-rise residential ductwork systems, there may be a learning curve for ATTs to perform this test in large multifamily buildings.

3.3.3.7 Impact on Statewide Employment

The proposed measure will slightly increase employment, because it will require a small amount of additional sealing and leakage verification.

3.3.4 Economic Impacts

3.3.4.1 Creation or Elimination of Jobs

There is no expected significant change in jobs from this measure. There may be a minor increase in jobs for verifying duct leakage.

3.3.4.2 Creation or Elimination of Businesses in California

There is no expected significant change in the number of businesses from this measure. There may be a minor increase in business for verifying duct leakage.

3.3.4.3 Competitive Advantages or Disadvantages for Businesses in California

There is no expected change to advantages or disadvantages for businesses in California.

3.3.4.4 Increase or Decrease of Investments in the State of California

There is no expected change to investments.

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

There is no expected change to funds or local governments.

3.3.4.6 Impacts on Specific Persons

There is no expected change to specific persons.

4. Energy Savings

4.1 Submeasure A: ERV/HRV

4.1.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented for the ERV/HRV measure used the TDV factors that were released in the 2022 CBECC-Res research versions released in December 2019 for the low-rise prototypes, and the finalized 2022 TDV factors released in June 2020 for the midrise and high-rise prototypes. The TDV factors released in December 2019 and used in the low-rise prototypes were consistent with the TDV factors that the Energy Commission presented during their public workshop on compliance metrics held October 17, 2019 (California Energy Commission 2019). The electricity TDV factors did not include the 15 percent retail adder and the natural gas TDV factors did not include the impact of methane leakage on the building site, updates that the Energy Commission presented during their workshop on March 27, 2020. Presentations from Bruce Wilcox and NORESCO during the March 27, 2020 workshop indicated that the 15 percent retail adder and methane leakage would result in most energy efficiency measures having slightly higher TDV energy and energy cost savings than using the TDV factors without these refinements. As a result, the TDV energy savings presented in this report for the low-rise prototypes are lower than the values that would have been obtained using TDV with the 15 percent retail adder and methane leakage, and the proposed code changes will be more cost effective using the revised TDV. The Energy Commission notified the Statewide CASE Team on April 21, 2020 that they were investigating further refinements to TDV factors using 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. It is anticipated that the 20-year GWP values may increase the TDV factors slightly making proposed changes that improve energy efficiency more cost effective. Energy savings presented in kWh and therms are not affected by TDV or demand factors. In short: the cost-effectiveness calculations for the low-rise prototypes are slightly underestimated.

Project teams could meet the proposed ERV/HRV requirement using different strategies, including unitary ERV or HRV (i.e., one ERV or HRV for each dwelling unit) or central ERV or HRV (i.e., each ERV or HRV serves multiple dwelling units.) As described in the subsections below, the Statewide CASE Team assumed a unitary ERV for the low-rise and midrise prototypes and central ERV for the high-rise prototype.

One benefit that the Statewide CASE Team considered was equipment downsizing of heating and cooling equipment due to the ERV/HRV. Based on the Statewide CASE Team's modeling for the low-rise garden style prototype in Climate Zone 12, heating and cooling loads would drop by approximately 10 percent due to an HRV, which could enable smaller capacity heating and cooling systems to be installed. The 10 percent sizing reduction is estimated as a market average, because equipment typically comes in increments of one-quarter or one-half ton. Consequently, some projects would not downsize equipment because the loads would remain in the same size class, while others would be able to drop down an entire size class (i.e., by more than 10 percent). However, the heating and cooling loads for these multifamily units (which assumed unitary heating and cooling equipment) were already smaller than most available equipment, so the equipment could not be further downsized. Consequently, this analysis did not include equipment downsizing in incremental cost calculations.

4.1.1.1 Unitary ERV for Low-rise Prototypes

For energy savings analysis, the Statewide CASE Team assumed one ERV/HRV per dwelling unit (a "unitary ERV/HRV" approach) for the low-rise prototypes. Through email communications and interviews, five HERS Raters and mechanical engineers reported that this is the most common approach for low-rise projects. During the August 22, 2019, utility-sponsored stakeholder meeting, most stakeholders reported in a poll they would use a unitary ERV or HRV approach to meet the requirement, instead of a central ERV/HRV or compartmentalization. In addition, this aligns with the assumption in the proposal that added the ERV/HRV requirement for multifamily dwelling units into the 2022 version of ASHRAE Standard 90.1.

For all calculations, the Statewide CASE Team assumed an ERV instead of an HRV, based on product availability. Several unitary ERVs (but not HRVs) include MERV 13 filtration. Another strategy that project teams could use would be an HRV or ERV with a lower filtration value (such as MERV 6) with an in-line filter that is MERV 13. The Statewide CASE Team predicts that more project teams will install a product with built-in MERV 13 filtration, to ensure the fan can overcome any additional static pressure of this filter.

The Statewide CASE Team assumed a sensible heat recovery efficiency of 67 percent, because most HRVs and ERVs (including those with MERV 13 filtration) meet this requirement. Ventilation airflow was modeled to match the minimum code requirements and fan power was assumed to be 0.60 watts per cfm. This fan power matches the Energy Commission's proposed changes to the ACM Reference Manual for multifamily buildings for unitary systems. It also is representative of the unitary products with MERV 13 filtration that the Statewide CASE Team reviewed.

The low-rise analysis does not assume bypass because most unitary ERV products do not include a bypass function. The Statewide CASE Team identified only one such product, but its cost ranges from $2,650 to $3,350 (for maximum flow rates of 118 cfm and 324 cfm, respectively), while other ERVs or HRVs with MERV 13 filtration cost but without bypass cost $900 to $1,145 (for maximum flow rates of 100 to 269, cfm respectively).

4.1.1.2 Central ERV Strategy in High-rise

For the high-rise multifamily building, the Statewide CASE Team assumed a central ERV strategy—i.e., one rooftop ERV with rooftop ductwork that then branches into seven ventilation shafts, each serving dwelling units in a vertical column. This aligns with the high-rise multifamily prototype, which uses a central DOAS ventilation strategy.

This analysis assumed 67 percent sensible recovery effectiveness. For the high-rise prototype, the Statewide CASE Team assumed that the ERV included a bypass function which reduces the cooling penalty by bringing in outdoor air directly (without passing it through the heat exchanger) when the outdoors is cooler than the cooling design temperature. Ventilation airflow was modeled to match the minimum code requirements and the CBECC-Com default fan power of 0.764 watts per cfm was used for each the supply and return fan. Note that the Statewide CASE Team used a different fan efficacy assumption for the unitary ERV modeling (0.6 W/cfm) than central ERV modeling (0.764 W/cfm), because they interpreted the recent guidance from the Energy Commission on fan efficacy assumptions to apply to unitary ventilation systems only.

For both ERV strategies, the Statewide CASE Team assumed a 30-year measure life. The Statewide CASE Team treats this multifamily measure similar to residential measures with a 30-year lifetime, since this requirement exclusively covers residential units. Furthermore, building owners are unlikely to install a completely different ventilation approach within 30 years, because this may require different wall penetrations, ductwork, mechanical closets, or other infrastructure. This is particularly true for a central ERV, where the system has ductwork specific to its use. While the project owner may install a different type of HRV or ERV, the Statewide CASE Team believes it is unlikely they will install a different ventilation strategy without conducting a major renovation.

4.1.2 Energy Savings Methodology

4.1.2.1 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 Energy Commission introduced four multifamily prototypes for the 2022 code cycle. These prototypes are defined in the Multifamily Protype report funded by SCE (TRC 2019).

The prototype buildings that the Statewide CASE Team used in the analysis are described in Appendix H.

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

Prototype Name	Number of Stories	Floor Area (ft^2)	Description
Low-Rise Garden	2	7,680	2-story, 8-unit apartment building. Average dwelling unit size: 960 ft2. Individual gas instantaneous DHW.
Low-Rise Loaded Corridor	3	40,000	3-story, 36-unit apartment building. Average dwelling unit size: 960 ft2. Individual gas instantaneous DHW.
Mid-Rise Mixed Use	5	113,100	5-story (4-story residential, 1-story commercial), 88-unit building. Avg dwelling unit size: 870 ft2. Central gas storage DHW.
High-Rise Mixed Use	10	125,400	10-story (9-story residential, 1-story commercial), 117-unit building. Avg dwelling unit size: 850 ft2. Central gas storage DHW.

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of the California Building Energy Code Compliance (CBECC) software for low-rise residential buildings (CBECC-Res) and the EnergyPlus software for high-rise residential buildings, using CBECC-Com assumptions where possible. The following subsections provide detail on why EnergyPlus was used instead of CBECC-Com.

CBECC-Res, CBECC-Com, and EnergyPlus generate two models based on user inputs: the Standard Design and the Proposed Design.[14] The Standard Design represents the geometry of the design that the builder will 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 Residential 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

[14] CBECC-Res creates a third model, the Reference Design, that represents a building similar to the Proposed Design, but with construction and equipment parameters that are minimally compliant with the 2006 International Energy Conservation Code (IECC). The Statewide CASE Team did not use the Reference Design for energy impacts evaluations.

applies to both new construction and alterations, so the Standard Design is minimally compliant with the 2019 Title 24, Part 6 requirements, which is a balanced ventilation system without heat recovery.

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 21 presents which parameters were modified and what values were used in the Standard Design and Proposed Design. The proposed conditions assume energy recovery for all ventilation air. For the low-rise and mid-rise models, a unitary HRV or ERV was modeled; for the high-rise model a central ventilation system with an ERV was assumed. The existing functionality within CBECC-Com for modeling bypass of heat exchangers was used. The only values updated was the sensible heat exchange effectiveness on the heating and cooling conditions. Table 21 also provides details on modifications that were made within EnergyPlus for the mid-rise and high-rise prototype modeling. In general, the Statewide CASE Team used EnergyPlus for modeling the mid-rise and high-rise prototypes, because this software enabled an adjustment to the infiltration assumption. As described in Appendix G, investigations indicated that the infiltration assumption in CBECC-Comm for multifamily buildings is much lower (i.e., assumes a much tighter building) than what actual leakage data indicates, and this low infiltration assumption significantly reduced energy savings from the ERV/HRV measure. Consequently, this analysis used the higher (field-based) infiltration rates.

The measure was modeled for these prototypes by modifying the baseline EnergyPlus input file generated by CBECC-Com and running the modified input file by specifying an alternative proposed design in CBECC-Com. This process was completed for both the Standard Design and the Proposed Design runs. Review of initial analysis results showed a drastic difference in energy savings and ultimately cost effectiveness between the low-rise and mid-rise prototypes even though both were applied a unitary ERV/HRV with the same specifications. Specifically, the heating savings were much higher and the cooling penalty much smaller for the low-rise. Review of the ACM Reference Manuals identified very different assumptions for infiltration and natural ventilation across CBECC-Res and CBECC-Com. CBECC-Res assumes 7 ACH50 for multifamily buildings. CBECC-Com assumes a leakage of 0.0448 cfm per square feet of exterior wall area. While a metric based on “cfm per square foot” is more appropriate to characterize leakage for large buildings than an air exchange rate, for comparison, this translates to 0.68 ACH50 for the midrise prototype. CBECC-Com also reduces this by 75 percent at all hours to account for building pressurization when the HVAC system is operational, which is not realistic for residential buildings.

The Statewide CASE Team conducted analysis of HRV savings for Climate Zone 12 using the midrise prototype under improved infiltration assumptions. All runs assumed a natural gas furnace and split air conditioning system, per Energy Commission request.

As shown in the table below, the energy savings from the ERV/HRV measure varies significantly based on the infiltration assumption—with only $246 TDV savings under the default assumptions in CBECC-Com (which translate to an infiltration rate of 0.68 ACH50 and infiltration schedule of 0.25). If infiltration is increased to the CBECC-Res assumption of 7 ACH50 and an infiltration schedule of 1.0, savings in CBECC-Com are $1,223, which is much closer to the savings found for the low-rise garden style building of $1,652 per dwelling unit.

Table 20: Savings (in TDV $) From ERV/HRV Proposal Under Different Infiltration Assumptions in CBECC-Comm

			TDV NPV 30-yr Savings per Unit		
CBECC-Software	**Prototype**	**Assumed Infiltration rate (in ACH50), Infiltration schedule**	**Electricity**	**Gas**	**Total**
Com	Mid-rise	Base run: 0.68 ACH50, 0.25	$(334)	$581	$246
Com	Mid-rise	1.6 ACH50, 0.25	$(240)	$652	$412
Com	Mid-rise	1.6 ACH50 + schedule 1.0	$(39)	$816	$777
Com	Mid-rise	7 ACH50 + schedule of 1.0	$160	$1,063	$1,223
Com	High-rise	Base run (with bypass): 1.6 ACH50, 1.0	$443	$860	$1,303
Com	High-rise	Base run (no bypass): 1.6 ACH50, 1.0	$(318)	$1,085	$767
Res	Low-rise	Base run: 7 ACH50, 1.0	$237	$1,415	$1,652

To better reflect measured building characteristics (and secondarily to align with ASHRAE 90.1 assumptions), the leakage rate in CBECC-Com was adjusted according to the ratio of the building envelope area to exterior wall area. This ratio is 2.4 for the mid-rise prototype and 1.5 for the high-rise prototype. In addition, the 75 percent reduction to account for building pressurization was eliminated.

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 21: Modifications Made to Standard Design in Each Prototype to Simulate ERV/HRV Code Change

Prototype ID	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value	ACM value (if Different)
Low-Rise Garden & Low-Rise Loaded Corridor	IAQ Fan: IAQ Fan Type	Balanced	Balanced	N/A
	IAQ Fan: W/ CFM IAQ Vent	0.6	0.6	N/A
	IAQ Fan: IAQ Recovery Effectiveness	N/A	67%	N/A
Mid-Rise	Zone System: Exh. Type	Balanced	Heat Recovery	N/A
	Zone System: Rated Heat Recovery Eff.	N/A	67%	N/A
	Zone System: Rated Power	Adjusted to meet 0.6 W/cfm	Adjusted to meet 0.6 W/cfm	N/A
	ZoneInfiltration:DesignFlowRate Flow per Exterior Surface Area (EnergyPlus object)	0.106 CFM/ ft_2-ext-wall (0.000536 m3/s-m2-ext-wall)	0.106 CFM/ ft_2-ext-wall (0.000536 m3/s-m2-ext-wall)	0.0448 CFM/ ft_2-ext-wall (0.00022758 m3/s-m2-ext-wall)
	ResidentialLivingInfiltration Schedule (EnergyPlus object)	1.0 fraction for all hours	1.0 fraction for all hours	0.25 fraction for all hours
High-Rise	Heat Recovery: Type	N/A	Plate	N/A
	Heat Recovery: Recovery Type	N/A	Total	N/A
	Heat Recovery: 100% Flow Heating Sensible	N/A	67%	N/A
	Heat Recovery: 100% Flow Cooling Sensible	N/A	67%	N/A
	Heat Recovery: Has Bypass	N/A	Yes	N/A

Prototype ID	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value	ACM value (if Different)
	ZoneInfiltration:DesignFlowRate Flow per Exterior Surface Area (EnergyPlus object)	0.0665 CFM/ft2-ext-wall (0.000338 m3/s-m2-ext-wall)	0.0665 CFM/ft2-ext-wall (0.000338 m3/s-m2-ext-wall)	0.0448 CFM/ft2-ext-wall (0.00022758 m3/s-m2-ext-wall)
	ResidentialLivingInfiltration Schedule (EnergyPlus object)	1.0 fraction for all hours	1.0 fraction for all hours	0.25 fraction for all hours

CBECC-Res and CBECC-Com calculate 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 software then applies the 2022 time dependent valuation (TDV) factors to calculate annual energy use in thousands of British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Res and CBECC-Com also generate TDV energy cost savings values measured in 2023 present value dollars (2023 PV$) and nominal dollars.

The energy impacts of the proposed code changes 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 multifamily buildings are presented in savings per dwelling unit. Annual energy and peak demand impacts for each prototype building were translated into impacts per dwelling unit by dividing by the number of dwelling units in the prototype building. This step enables a calculation of statewide savings using the construction forecast that is published in terms of number of multifamily dwelling units by climate zone.

4.1.2.2 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 Commission n.d.). The Statewide Construction Forecasts estimate new construction that will 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 and CBECC-Res, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Appendix H 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 22: Residential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Multifamily	Low-riseGarden	4%
	LoadedCorridor	33%
	MidRiseMixedUse	58%
	HighRiseMixedUse	5%

4.1.3 Per-Unit Energy Impacts Results

First-year energy savings and peak demand reductions per dwelling unit are presented in the following tables, which are organized by prototype, and show savings from new construction. Per CASE modeling guidance from the Energy Commission, this analysis assumes that low-rise buildings are constructed as a mix of all-electric and mixed fuel buildings (assumed here as 21 percent all-electric and 79 percent mixed fuel), while the mid-rise and high-rise prototypes are assumed as 100 percent mixed fuel because there is not currently an all-electric prescriptive baseline for high-rise residential buildings. Consequently, electricity savings are higher (and natural gas savings are lower) for the low-rise buildings.

Table 23: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Garden-Style

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	100	2	34	16,084
2	54	1	19	9,444
3	19	1	11	5,251
4	13	1	11	5,380
5	16	1	10	4,519
6	(24)	0	3	457
7	(37)	0	2	(933)
8	(52)	0	1	71
9	(22)	0	4	2,224

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
10	4	1	7	4,167
11	85	1	17	11,083
12	43	1	16	9,097
13	78	1	14	9,562
14	91	1	16	10,709
15	131	1	0	6,470
16	88	2	32	15,463

Table 24: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Loaded Corridor

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	74	0	30	12,916
2	(5)	0	19	6,460
3	(37)	0	11	2,787
4	(28)	0	13	3,944
5	(49)	0	11	2,602
6	(110)	0	3	(2,372)
7	(133)	0	0	(3,991)
8	(126)	0	1	(2,670)
9	(87)	0	3	(1,425)
10	(57)	0	4	699
11	61	0	18	9,086
12	(1)	0	17	6,524
13	46	0	16	8,252
14	66	0	18	9,002
15	106	0	0	4,958
16	75	0	35	14,823

Energy savings may be lower for the mid-rise mixed-use building compared to low-rise due to the higher infiltration rates assumed in CBECC-Res than CBECC-Com, differences between the prototype buildings, or other reasons.

Table 25: First-Year Energy Impacts Per Dwelling Unit – Mid-Rise Mixed Use

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	1	0	41	12,546
2	(71)	0	23	6,786
3	(64)	0	19	4,643
4	(82)	0	14	3,737
5	(105)	0	16	2,349
6	(125)	0	6	(658)
7	(161)	0	4	(2,621)
8	(135)	0	5	(772)
9	(101)	0	7	1,160
10	(74)	0	10	2,471
11	33	0	23	10,135
12	(36)	0	21	7,351
13	11	0	18	7,921
14	27	0	21	8,912
15	99	0	4	5,543
16	(22)	0	40	12,510

Below are results for the high-rise mixed-use prototype. Comparing results between the low-rise garden-style and high-rise mixed-use, savings are about twice as high for the same climate zone for the low-rise garden style. The differences between software (including different infiltration assumptions) likely account for much of the discrepancy. However, the high-rise mixed-use results include savings from the ERV/HRV bypass function, which takes advantage of free cooling when the outdoor air is below the cooling set point during cooling season; this significantly increases net electricity savings.

Table 26: First-Year Energy Impacts Per Dwelling Unit – High-rise Mixed-Use

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	3	0	36	10,926
2	14	0	26	9,589
3	1	0	13	4,364
4	18	0	13	5,701
5	(1)	0	16	4,988
6	5	0	4	1,903

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
7	2	0	2	815
8	25	0	4	3,001
9	35	0	7	4,384
10	48	0	12	5,946
11	77	0	24	11,362
12	45	0	21	9,539
13	91	0	19	10,618
14	68	0	27	11,682
15	225	0	4	9,478
16	3	0	53	16,371

As expected, TDV energy savings varies by climate zone, with the highest savings in the more extreme climate zones.

4.2 Submeasure B: Kitchen Exhaust Minimum Capture

4.2.1 Key Assumptions and Methodology for Energy Savings Analysis

As explained in Section 2.2.1, this measure is required to ensure IAQ, rather than energy savings. However, the Statewide CASE Team investigated energy impacts of the proposal.

Kitchen exhaust is already required under 2019 Title, Part 6 through its reference to ASHRAE Standard 62.2. The code change proposal will not modify the energy stringency of the requirement, but rather impose additional requirements on capture efficiency or minimum airflow that will impact IAQ. Consequently, there will be no significant energy savings from the measure. Section 4 of this Final CASE Report, which typically presents the methodology, assumptions, and results of the per-unit energy impacts, has been truncated for this measure. However, the Statewide CASE Team did conduct investigations of energy impacts and results generally support the assumption that the proposed will not significantly impact energy use.

To conduct analysis, the Statewide CASE Team compared Watts per cfm of airflow for products that would and would not comply with the proposed requirement. A 2013 survey found that a minority of respondents always used their kitchen exhaust systems when cooking, and when used, it was to remove smoke, odors, steam and moisture. Reasons for not using their kitchen exhaust included that it was not needed, too noisy or that they did not think of using it (Stratton and Singer 2014). Since survey results indicated that occupants use their kitchen exhaust mostly when felt needed, the Statewide CASE Team assumed that occupants would run range hoods until about the same level of pollutants are cleared. Consequently, Watts per cfm, rather than just cfm (airflow) is the relevant comparison, because range hoods with lower capture efficiencies or lower airflow rates must run for a longer period of time in order to remove the same amount of pollutants compared to range hoods with higher capture efficiencies or higher airflow rates.

4.2.2 Per-Unit Energy Impacts Results

This analysis considered the power consumptions (Watts per cfm of airflow) for range hoods that would and would not comply with the airflow compliance path, using products in the HVI database.

Figure 22 below shows that all range hoods from the HVI database are compliant under current requirement (sone rating of less than 3 sones at an airflow rate of 100 cfm or higher). To look at kitchen range hood products most likely to be used in a multifamily setting, the Statewide CASE Team filtered the HVI database for products that were rated at a static pressure of at least 0.1 inches w.c., were either a microwave or undercabinet range hood, and had ducting sizes of either 3-inch by 10-inch, 3.25-inch by 10-inch, 6-inch diameter (round or square ducting) or 7-inch diameter (round or square ducting). In addition, when analyzing the HVI database, the Statewide CASE Team attempted to combine models with nearly identical model numbers and performance characteristics (but which differed by only aesthetic characteristics, such as color) based on unique sets of model number/letters.

For range hoods with airflow rates between 100 and 400 cfm, there was no statistically significant correlation of power per unit of flow (watts/cfm) to the rated airflow (cfm). For airflow rates between 100 and 600 cfm, there was a statistically significant positive correlation at the 1 percent significance level (watts/cfm increases as cfm increases indicating worse performance at higher airflow rates). While there was a statistically significant difference for the wider range of airflows (100 to 600 cfm) the Statewide CASE Team assumes that most products installed in multifamily units will be less than 400 cfm.

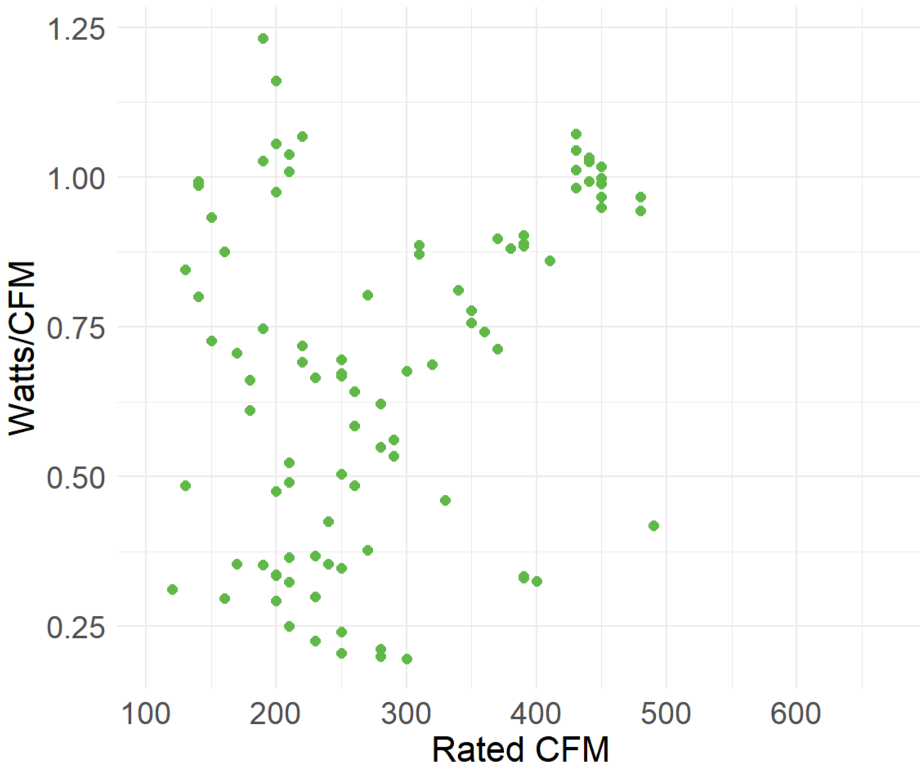


Figure 22: Kitchen range hood power per unit of flow.

Source: HVI Database

The Statewide CASE Team also used Welch's t-test to compare the watts/cfm of range hoods with airflow of 100 to 250 cfm and products with air flow of 250 to 400 cfm, since 250 cfm is the upper end of the required airflows. The analysis found a statistically significant difference (p-value < 0.1) in the watts/cfm of the compliant and noncompliant products. The range hoods with airflow of 100 to 250 cfm (noncompliant) had a *higher* average W/cfm than range hoods with an airflow of 250 to 400 cfm (compliant) indicating worse average fan performance of noncompliant range hoods. This indicates that the proposed requirement should not significantly impact energy.

4.3 Submeasure C: Central Ventilation Duct Sealing

4.3.1 Key Assumptions for Energy Savings Analysis

The energy and cost analysis presented in this report used the TDV factors that were released in the 2022 CBECC-Com and 2022 CBECC-Res research versions released in December 2019. These TDV factors were consistent with the TDV factors that the Energy Commission presented during their public workshop on compliance metrics held October 17, 2019 (California Energy Commission 2019). The electricity TDV factors did not include the 15 percent retail adder and the natural gas TDV factors did not include the impact of methane leakage on the building site, updates that the Energy Commission presented during their workshop on March 27, 2020. Presentations from Bruce Wilcox and NORESCO during the March 27, 2020 workshop indicated that the 15 percent retail adder and methane leakage would result in most energy efficiency measures having slightly higher TDV energy and energy cost savings than using the TDV factors without these refinements. As a result, the TDV energy savings presented in this report are lower than the values that would have been obtained using TDV with the 15 percent retail adder and methane leakage, and the proposed code changes will be more cost effective using the revised TDV. The Energy Commission notified the Statewide CASE Team on April 21, 2020 that they were investigating further refinements to TDV factors using 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. It is anticipated that the 20-year GWP values may increase the TDV factors slightly making proposed changes that improve energy efficiency more cost effective. Energy savings presented in kWh and therms are not affected by TDV or demand factors. In short: the cost-effectiveness calculations in this Final CASE Report are slightly underestimated.

Overall, this analysis used simulations in EnergyPlus to compare energy use in the high-rise prototype under two different levels of duct leakage. The simulations used the same ventilation fan object in EnergyPlus which supplies and exhausts air from the units. In order to model the impact of central ventilation system sealing, the fan pressure was adjusted based on estimates from four subject matter experts and corroborated through feedback from attendees at the March 25, 2020 stakeholder meeting for this topic, and the fan flow rate was adjusted based on the assumed starting leakage value for a typical central ventilation duct system. The values for fan pressure and ventilation flow rate were then adjusted again for the sealed condition based on the reduced effective leakage area in the duct system. One key assumption is that the fan is pressure and flow are adjustable and operate at the same efficiency. Energy savings come from both reduced fan energy of the rooftop supply fan and reduced heating and cooling energy from reduced loss of conditioned air. Because of the heating and cooling impacts, energy savings vary by climate zone. However, the measure was found to be cost effective in all climate zones.

The following subsections provides more detail on the energy savings methodology and results.

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 Appendix H.

The Statewide CASE Team only modeled this measure in the high-rise prototype because this is the only prototype with central ventilations systems.

Table 27: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (ft^2)	Description
High-Rise Mixed Use	10	125,400	10-story (9-story residential, 1-story commercial), 117-unit building. Avg dwelling unit size: 850 ft^2.

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of the EnergyPlus software for high-rise residential buildings, using CBECC-Com assumptions where possible. The following subsections provide detail on why EnergyPlus was used instead of CBECC-Com.

EnergyPlus generate two models based on user inputs: the Standard Design and the Proposed Design.[15] The Standard Design represents the geometry of the design that the builder will 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 Residential 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, which is a balanced ventilation system without heat recovery.

The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes to the code.

15 CBECC-Res creates a third model, the Reference Design, that represents a building similar to the Proposed Design, but with construction and equipment parameters that are minimally compliant with the 2006 International Energy Conservation Code (IECC). The Statewide CASE Team did not use the Reference Design for energy impacts evaluations.

The Statewide CASE Team made the following assumptions for energy modeling. All modeling was done in the high-rise prototype, because this is the only prototype that assumes central ventilation systems. However, the per-dwelling unit modeling results would apply to any central ventilation system including mid-rise and low-rise buildings, with the energy savings scaling with the number of dwelling units if those systems operate with similar fan pressures and leakage. Because the Statewide CASE Team assumed a fairly low pressure for the central ventilation ducts in the modeling (125 Pa, or 0.5 inches w.c.), results should be applicable to shorter buildings, such as the midrise and low-rise common corridor prototypes.

This analysis assumed that the building had central supply ventilation, but unitized exhaust (i.e., each individual dwelling unit had its own exhaust system). This was based on data from Gabel Energy indicating that—of 38 midrise and high-rise new construction projects—18 had central supply ventilation and unitized exhaust, 1 had central supply and central exhaust, and the remainder had unitized ventilation and exhaust or were exhaust-only projects. Note that, if this analysis had assumed central supply ventilation *and* central exhaust, energy savings would roughly double. This is because the supply and exhaust[16] airflows would be the same for a balanced system, so the fan energy savings would be the same. In addition, the Statewide CASE Team assumed that the air lost through leakage would be conditioned. For supply air, the leaked air represents additional air provided to dwelling units that would need to be conditioned; for exhaust air, the leaked air represents additional air removed from the dwelling units that was conditioned. Thus, energy saved for heating and cooling would be the same for sealing either a supply or exhaust duct system.

The savings analysis for this report was also conducted assuming the requirement would be 10 percent leakage at 50 Pa (0.2 inches w.c.) for all central ventilation ducts. This is equivalent to the proposed requirement for ducts servings six or fewer dwelling units maximum of 6 percent leakage at 25 Pa (0.1 inch w.c.), since 6 percent at 50 Pa equates to 9.4 percent at 25 Pa. However, it is less stringent than the proposed requirement for central ventilation ducts serving more than six units: no more than 6 percent leakage at 50 Pa (0.2 inches w.c.). Consequently, the modeled energy savings underestimate savings. Since this is a worst-case assumption for savings, the Statewide CASE Team did not repeat analysis under the proposal of 6 percent leakage at 50 Pa. Table 28 summarizes key modeling assumptions used for this measure.

[16] Recall that the proposed requirement only applies to continuous airflows or airflows that are part of a balanced ventilation strategy.

Table 28: Modifications Made to Standard Design in Each Prototype to Simulate Central Ventilation Duct Sealing Code Change

Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value	NR ACM value	Rationale for Different Assumption
Static Pressure at Fan	125 Pa	125 Pa	950 Pa	Based on review of six central ventilation ducts in two projects within the CMFNH program, the average pressure at the fan is 280 Pa. However, this resulted in very high leakage (64% in the base case, since leakage increases with static pressure).To ensure a conservative savings estimate and to make the results more applicable to the low-rise and mid-rise prototypes, this analysis assumed 125 Pa
Leakage assumption	39% at 50 Pa	10% at 50 Pa	Unknown	39% at 50 Pa corresponds to 25% at 25 Pa, which was estimated as the baseline leakage value in the Title 24-2019 Residential IAQ CASE report
Actual operating leakage	50%	10%	Unknown	Based on operating pressure of fan and evenly distributed leaks[17] located at each floor. To deliver the required ventilation rate to the lower dwelling units, and because leakage increases with pressure, fan flow must be increased by approximately 50% in the base case
Infiltration	Same as NR ACM value	Same as NR ACM value	0.0448 cfm/ft2, infiltra-tion schedule of 25%	Based on comparison of runs at different infiltration schedules, different assumptions do not significantly impact savings from this measure, so no adjustments made (although data indicates infiltration is much lower than actual multifamily leakage)
Source of leakage	From/to conditioned space	N/A	N/A	Based on assumption that duct leakage in a building chase is drawn from interior spaces

[17] Although stack effect may lead to different operating pressures by floor, stack effect changes seasonally. Since it is simpler to model even distribution, and because total leakage results should be the same if pressures vary by floor compared to even of leaks distribution, analysis assumed even distribution. In addition, the analysis assumed 50 Pa across the grill due to the balancing effort, and the magnitude of stack pressure will be small relative to the grill pressure.

The Statewide CASE Team modeled energy savings using the high-rise prototype using EnergyPlus software, since the California Building Energy Code Compliance for Commercial buildings (CBECC-Com) does not provide the user with the options to adjust ventilation duct leakage.

The Statewide CASE Team assumed a base leakage of 39 percent of central fan airflow rate at 50 Pa, since this corresponds to 25 percent leakage at 25 Pa, which was found in interviews and a literature review in the 2019 Title 24 Residential IAQ CASE research. While this is significant leakage, interviewees reported in the research conducted for the last code cycle (2019 Title 24 Residential IAQ CASE research) that, because there is no current requirement for leakage testing for these duct systems, they are often sealed poorly. The Statewide CASE Team assumed proposed leakage of 6 percent of central fan airflow, at 25 Pa (0.1 inch w.c.) for ducts serving six or fewer dwelling units, which aligns with the current requirement for 6 percent at 25 Pa for ducts carrying conditioned air in Section 140.4(l), and with requirements in 150.0(m)11C.

The proposed requirement calls for a maximum leakage of 6 percent at 50 Pa (0.2 inches w.c.) for ducts serving more than six dwelling units. Because leakage increases with static pressure, 6 percent at 50 Pa is equivalent to 9.4 at 25 Pa as shown in the calculation below:

The duct leakage curve is defined by the following equation:

$Q = C \times P^n$

Source: (The Energy Conservatory 2014)

Where Q is the leakage into or out of the system (in cfm), C is a coefficient that is building specific (and determined through the field test), P is the pressure difference inside and outside the duct system (in Pascals), and n is the coefficient that is curve-fit based using empirical data if a multi-point duct blaster door test is conducted, or typically assumed as 0.65 for a single-point test. Thus, for the same duct system, the ratio of leakage at 50 Pascals (Q_{50}) to leakage at 25 Pascals (Q_{25}) equals the ratio of pressure at 50 Pascals (P_{50}) to pressure at 25 Pascals (P_{25}), raised to the power of the exponent (n = 0.65). Because this is the same duct system, the coefficient, C, is constant so falls out of the equation.

$Q_{50} / Q_{25} = (P_{50} / P_{25})^{0.65} = 2^{0.65} = 1.57$, and therefore $Q_{50} = 1.57 \times Q_{25} = 1.57 \times 6\% = 9.42\% = Q_{50}$

4.3.2.3 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 Commission n.d.). The Statewide Construction Forecasts estimate new construction that will 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 and CBECC-Res, so the Energy Commission provided guidance on which prototypical buildings to use for each Building Type ID when calculating statewide energy impacts. Table 29 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 29: Residential Building Types and Associated Prototype Weighting

Building Type ID from Statewide Construction Forecast	Building Prototype for Energy Modeling	Weighting Factors for Statewide Impacts Analysis
Multifamily	Low-riseGarden	4%
	LoadedCorridor	33%
	MidRiseMixedUse	58%
	HighRiseMixedUse	5%

4.3.3 Per-Unit Energy Impacts Results

4.3.3.1 Results for High-rise Mixed Use Building and Comparison with Field Measurements and Engineering Calculation

Table 30 shows energy impacts by climate for the central ventilation duct sealing measure for the high-rise mixed-use building. Results are for new construction projects at the per dwelling unit level. As shown, the measure does have significantly different energy savings by climate zone, but has strong energy savings in all climate zones.

Table 30: First-Year Energy Impacts Per Dwelling Unit – High-Rise Mixed Use

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	43	(0.02)	34	8,228
2	22	0.05	23	14,437
3	(4)	0.01	17	3,683
4	12	0.04	17	5,108
5	(5)	(0.01)	19	3,791
6	(23)	0.04	8	1,492
7	(45)	0.02	3	(325)
8	(4)	0.08	6	2,088
9	26	0.08	9	4,067
10	35	0.09	10	4,602
11	83	0.10	21	8,729
12	55	0.10	21	7,847
13	82	0.08	19	8,221
14	74	0.11	20	8,131
15	176	0.15	5	7,846
16	19	0.03	37	9,229

Because these results indicate high energy savings, the Statewide CASE Team compared results using a case study from Association for Energy Affordability (AEA).

Field measurements from retrofitted buildings illustrate that this measure can significantly reduce fan flow rate, which in turn results in significant energy savings. The AEA shared a case study for this report of a nine-story multifamily building for which it had conducted a retrofit project to seal its central exhaust shafts and install constant air regulator (CAR) dampers.[18] The leakage reduction ranged from 7 percent to 94 percent, with an average reduction of 76 percent. Because of the reduced leakage, AEA was able to reduce the central fan flow rates for these shafts by an order of magnitude for some duct systems, as shown in the figure below, which shows central fan flow rates (in cfm) pre- and post- retrofit. In addition, prior to the retrofit, the upper floors were over-ventilated, and the middle and lower floors were under-ventilated, with almost no exhaust flow recorded on the lower floors. Consequently, the project delivered both energy savings and IAQ benefits in Figure 23.

[18] CAR dampers are modulating orifices that automatically adjust airflows in duct systems to maintain constant levels. Projects can use CAR dampers as one means of balancing airflow between units in a central ventilation shaft.

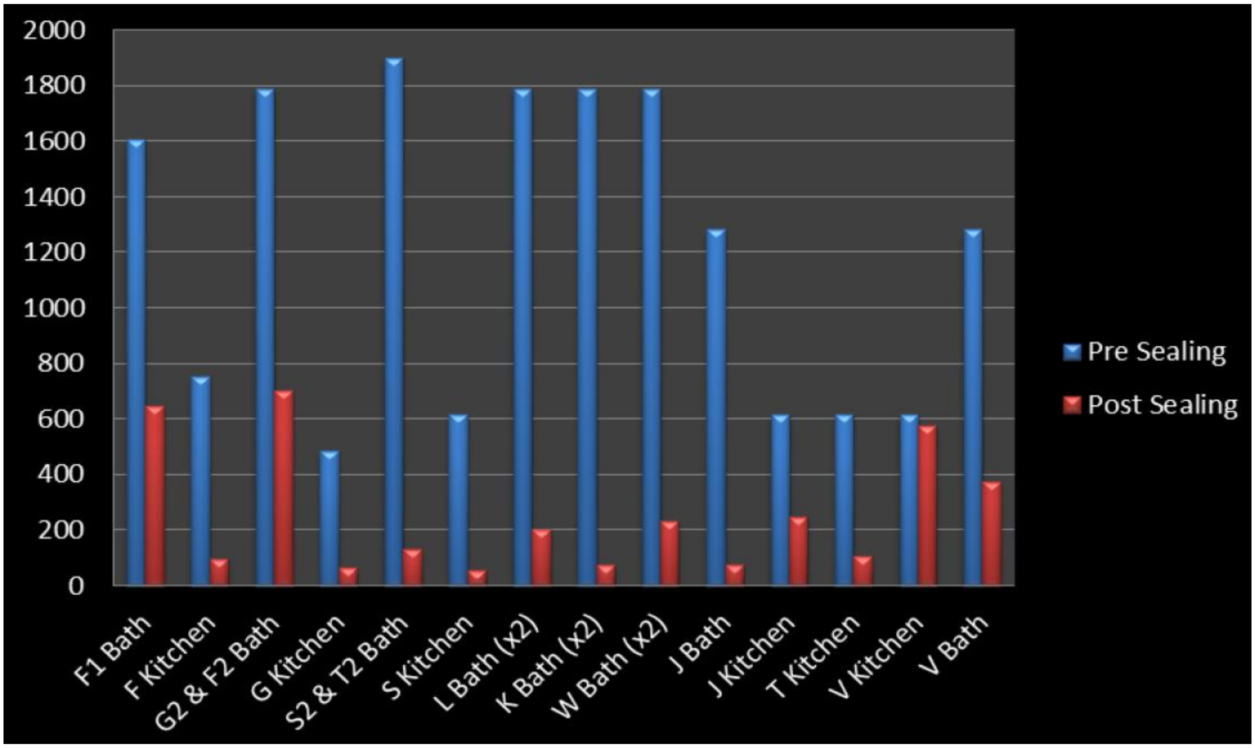


Figure 23: Central fan flow rates (cfm) pre- and post-sealing of central ventilation shafts in retrofitted multifamily building.

Source: AEA 2012

Because of the high energy savings predicted, the Statewide CASE Team used engineering calculations to estimate heating energy savings from this measure to compare with the energy modeling results. Equation 1 shows the engineering calculation for heating savings.

Equation 1: Savings Potential for Heating Savings from Ventilation Duct Sealing (Thermal)

$$Heating\ Savings\ (Therms) = \frac{1.08 * CFM * HDD * T}{EF * 99{,}976}$$

Where

Heating Savings = Annual space heating savings, in therms

1.08 = specific heat of air (in BTU/ft^3/hr) at standard barometric pressure

CFM = Exhaust rate in cubic feet per minute

HDD = Heating degree days

T = Hours per day fan operates

EF = Seasonal heating system efficiency

99,976 = conversion factor from BTUs to 1 therm

For the High-rise Mixed-Use Building (total ventilation leakage sealed is 3,043 cfm) in Sacramento (2,702 HDD), for continuous airflow (24 hours per day) at a heating system efficiency of 80 percent, the calculation is:

$$Heating\ Savings\ (Therms) = \frac{1.08 * 3{,}043 * 2{,}702 * 24}{0.80 * 99{,}976} = 2{,}664\ Therms$$

In comparison, the EnergyPlus simulations conducted in this analysis for Sacramento estimated 2,442 therms savings at the building level. These estimates are similar (within 10 percent), which supports the modeling result for natural gas savings.

4.3.3.2 Results for the Midrise Mixed Use and Low-rise Common Corridor Buildings

For the midrise and low-rise common corridor analysis, the Statewide CASE Team did not conduct energy simulations, in part because (unlike the high-rise prototype) these prototypes do not assume central ventilation. Instead, this analysis assumed that energy savings would be the same as what was found *per dwelling unit* in the high-rise simulation. Per dwelling unit impacts should be roughly similar, as long as the static pressure is the same. This is because, for these ventilation ducts providing continuous airflows, the airflow will increase with the number of dwelling units (on average 40 cfm per dwelling unit). The Statewide CASE Team interviewed two subject matter experts on this method, and both agreed that energy savings should scale with the number of dwelling units. They also reported that the static pressure assumed for the high-rise prototype (0.5” w.c. [125 Pa]) is likely low for high-rise but typical for midrise and low-rise. In addition, four participants at the March 25, 2020 stakeholder meeting responded to a poll question on typical static pressures in central ventilation ducts; all reported it is at least 0.5” w.c. (125 Pa) in high-rise buildings, and three of four reported it is at least 0.5” w.c. (125 Pa) for midrise and low-rise common corridor multifamily buildings[19].

Energy Savings for the midrise and low-rise common corridor buildings are shown in the Table 31 and Table 32 below.

[19] Although approximately one hundred participants called into the stakeholder meeting, most did not respond to these poll questions, likely because they did not feel qualified to answer them.

Table 31: First-Year Energy Impacts Per Dwelling Unit – Low-Rise Loaded Corridor

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	43	(0.02)	34	2,624
2	22	0.05	23	4,605
3	(4)	0.01	17	1,175
4	12	0.04	17	1,629
5	(5)	(0.01)	19	1,209
6	(23)	0.04	8	476
7	(45)	0.02	3	(104)
8	(4)	0.08	6	666
9	26	0.08	9	1,297
10	35	0.09	10	1,468
11	83	0.10	21	2,784
12	55	0.10	21	2,503
13	82	0.08	19	2,622
14	74	0.11	20	2,594
15	176	0.15	5	2,503
16	19	0.03	37	2,944

Table 32: First-Year Energy Impacts Per Dwelling Unit – Mid-Rise Mixed Use

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
1	43	(0.02)	34	7,421
2	22	0.05	23	13,021
3	(4)	0.01	17	3,322
4	12	0.04	17	4,607
5	(5)	(0.01)	19	3,419
6	(23)	0.04	8	1,346
7	(45)	0.02	3	(294)
8	(4)	0.08	6	1,883
9	26	0.08	9	3,668
10	35	0.09	10	4,151
11	83	0.10	21	7,873
12	55	0.10	21	7,077
13	82	0.08	19	7,414

Climate Zone	Electricity Savings (kWh)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms)	TDV Energy Savings (TDV kBtu)
14	74	0.11	20	7,333
15	176	0.15	5	7,077
16	19	0.03	37	8,324

5. Cost and Cost Effectiveness

5.1 Submeasure A: ERV/HRV

5.1.1 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 1044.1.2. 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 30 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 30 years.

The Statewide Case Team assumed different methods for low-rise and high-rise multifamily buildings. For both low-rise and the mid-rise prototypes, the Statewide CASE Team assumed a unitary ERV—i.e., one ERV in each dwelling unit. For the high-rise prototypes, the Statewide CASE Team assumed a central ERV—i.e., one rooftop ERV serving all dwelling units in the vertical column. The subsections below provide a rationale for each assumption and details on each approach.

5.1.1.1 Unitary ERV for Low-rise Multifamily Prototypes

Based on interviews with six HERS Raters and mechanical engineers, unitary ERVs are the most common solution for low-rise projects both garden and common corridor styles. This is because central systems, such as ERV serving multiple dwelling units, will require penetration of party walls. Figure 24 shows the lay-out assumed for the base case, which uses an in-line fan that operates continuously for supply air and a continuous bathroom exhaust fan to achieve balanced ventilation. Figure 25 shows the lay-out for the proposed case, which uses an ERV serving the dwelling unit and a pick-up in each bathroom in lieu of a bathroom fan. Both the in-line fan and ERV have MERV 13 filtration. The Statewide CASE Team assumed the least expensive ERV with MERV 13 filtration for this analysis, although there were three other products that had a similar price. The ventilation distribution systems in both the base case and proposed case were designed based on Energy Commission's guidance for the prototypes. The assumed heating and cooling system is a split air conditioner and gas furnace. In both cases, the ventilation ductwork layout is the same and it is connected to the heating and cooling distribution to reduce cost. The supply ducts extend from the registers at the exterior wall to the bedroom and living area where they provide ventilation and conditioned air. The exhaust ducts extend from the registers in the bathrooms to the exterior wall where it is separated from the supply register by three vertical feet. The

Statewide CASE Team assumed 1.4 bathrooms per dwelling unit using a weighted average from years 2016 to 2018 of number of bathrooms in the Western Region from the United States Census (U.S. Department of Commerce 2018).

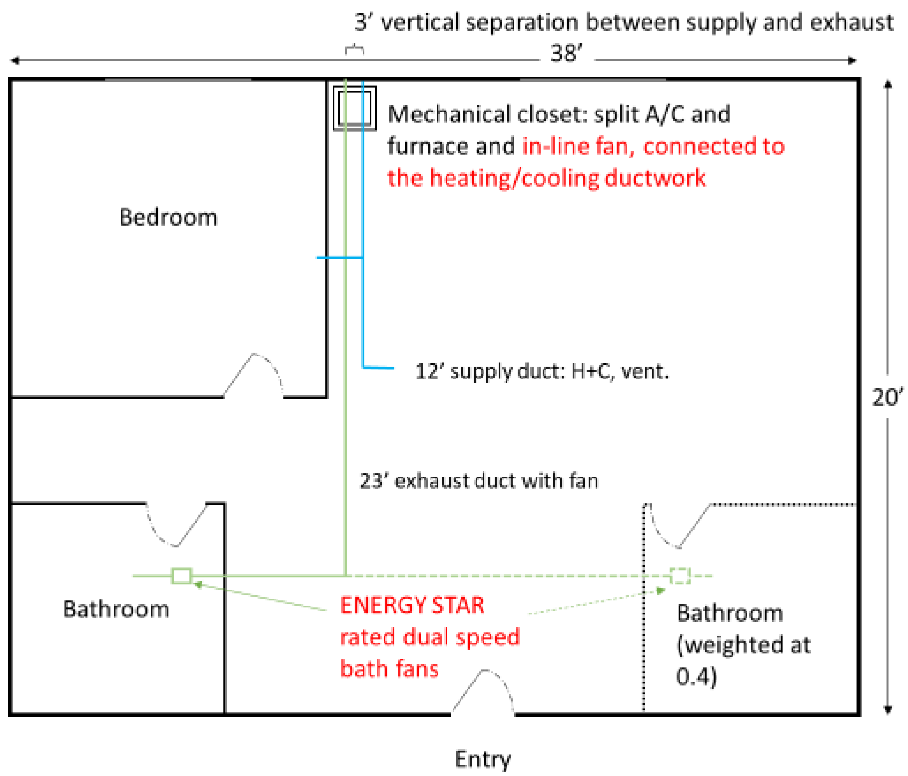


Figure 24: Base case: discrete supply in-line fan.

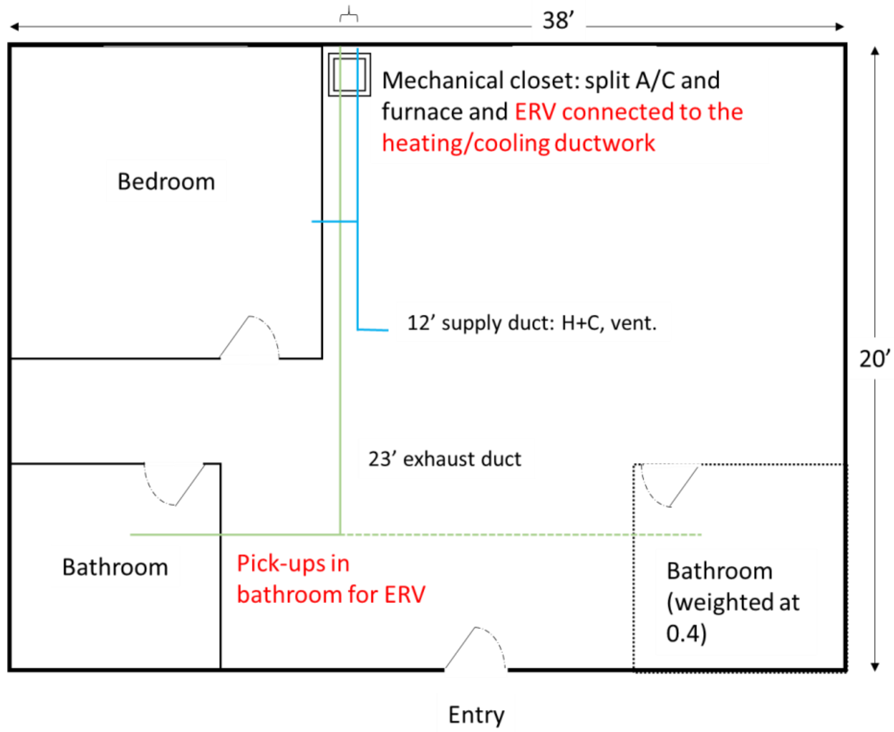


Figure 25: ERV proposed case.

The Statewide CASE Team used RSMeans to develop cost estimates for the equipment in each case that differed.

5.1.1.2 Central ERV Strategy for High-rise Prototype

For the high-rise prototype, the Statewide CASE Team assumed a central ERV strategy—i.e., one ERV serving a vertical column of units below it. This strategy reduces the number of exterior penetrations, leads to easier maintenance, and provides economies of scale for features such as bypass, which provides significant energy savings during the cooling season. It also aligns with the high-rise mixed-use prototype, which uses a dedicated outdoor air system (DOAS) ventilation system.

A consulting company that designs multifamily projects with central ERVs and DOAS developed the Basis of Design (BOD) for both the base and proposed case, which the Statewide CASE Team provided to a mechanical contractor for developing pricing.

Figure 26 show the schematics from the developed BOD. In the base case, the rooftop equipment is DOAS while in the proposed case, the rooftop equipment is a central ERV unit. Both cases use central supply ventilation air, but only the proposed (ERV) case has central bathroom exhaust air. In the base case, all dwelling units have an ENERGY STAR rated bathroom fan that is ducted through the wall to the exterior. Because the high-rise prototype assumes that the bottom floor is commercial space, the ERV does not serve this floor.

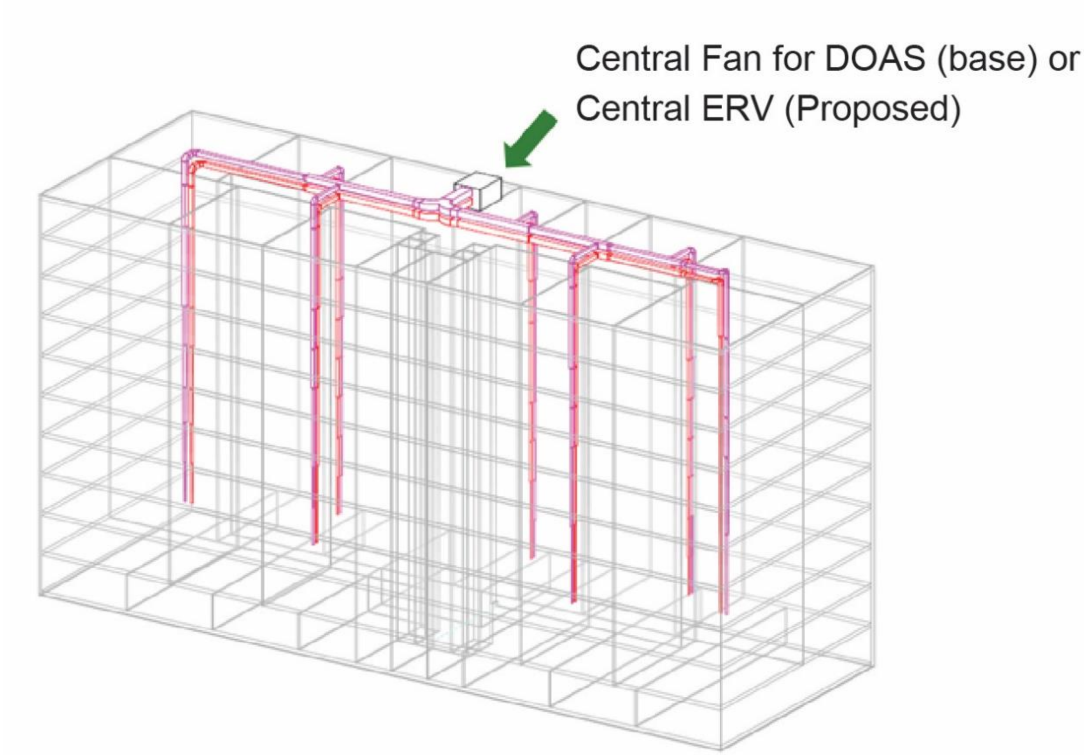
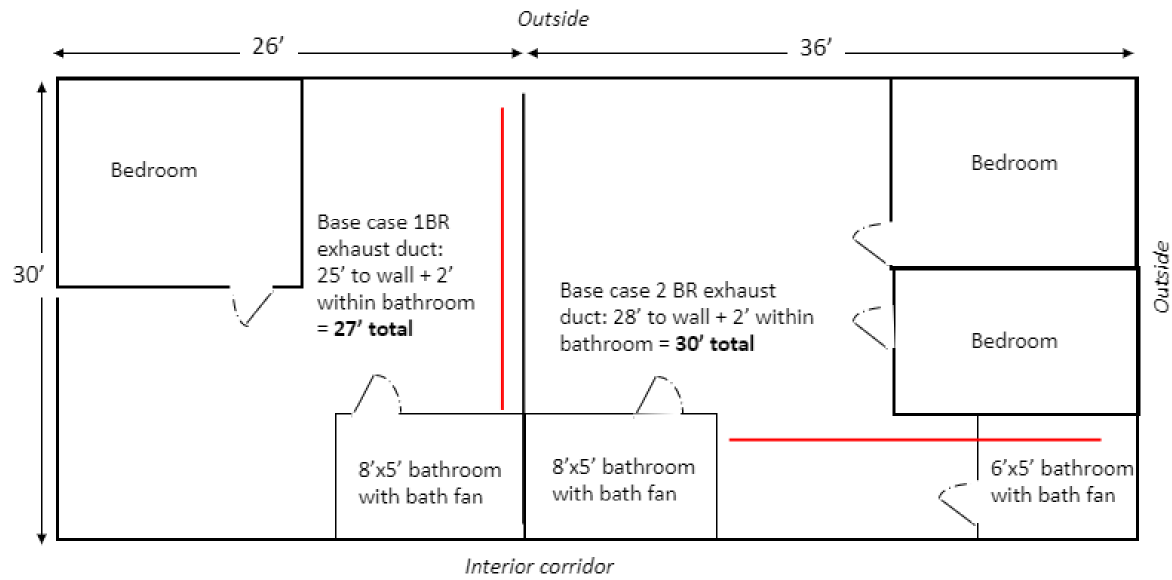


Figure 26: Central ERV strategy for high-rise mixed-use prototype.

As shown in the figure above, each rooftop supply fan or ERV would connect (via rooftop ductwork) to vertical shafts. Six vertical shafts serve two dwelling unit from each floor, and one vertical shaft serves one dwelling unit per floor. Each shaft has a short horizontal run-out to the dwelling units on each floor and fire smoke dampers (FSDs) at the entry of this duct to the dwelling unit.

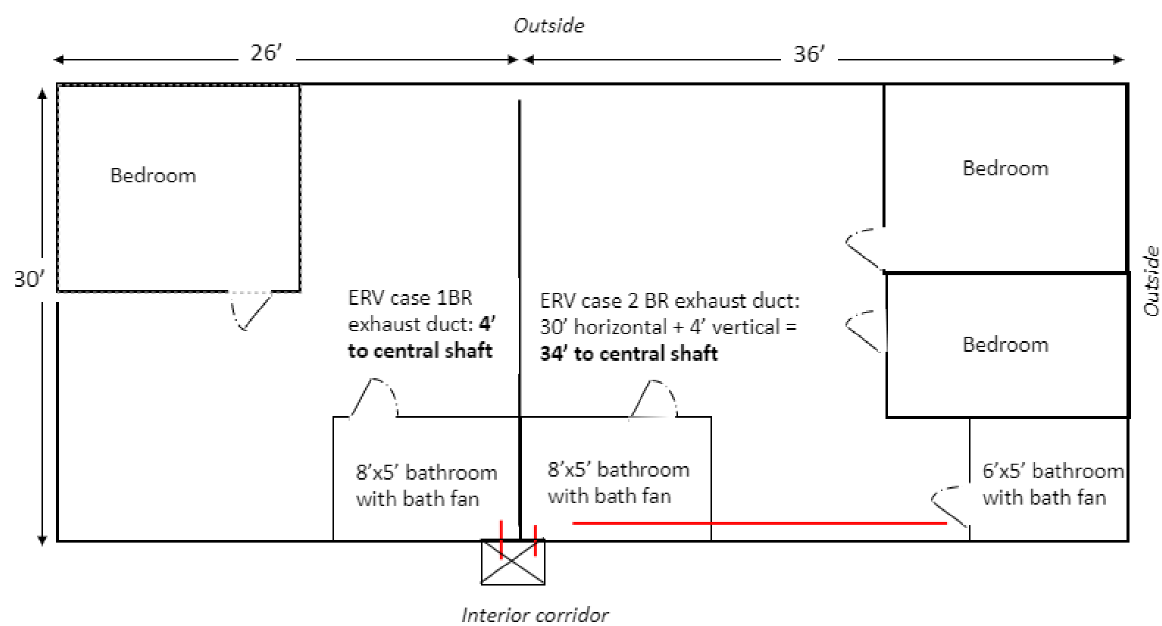
The Statewide CASE Team sent the BOD to a California-based contractor to develop cost estimates for the base and proposed cases.

One assumption that impacted price was the length of ductwork needed for each dwelling unit. The Statewide CASE Team developed sample floor plans for two dwelling units to estimate in-unit ductwork for connecting each bathroom to the exterior for the base case—shown in Figure 27, and each bathroom to the central shaft in the proposed case—shown in Figure 28. While in-unit ductwork is greater for the base case, the total amount of ductwork is still higher for the proposed (ERV) case, because of the central shaft.



Bathroom 1: 8 ft x 5 ft (has bath)
Bathroom 2: 6 ft x 5 ft (stand up shower)

Figure 27: Floor plan of base case for in-unit exhaust ducting.



Bathroom 1: 8 ft x 5 ft (has bath)
Bathroom 2: 6 ft x 5 ft (stand up shower)

Figure 28: Floor plan of proposed (central ERV) case for in-unit exhaust ducting.

5.1.1.3 Impact of ERV/HRV on Dwelling Unit Square Footage

The Statewide CASE Team considered the impact of ERV/HRV on dwelling unit square footage compared to the base case. Four subject matter experts (mechanical engineers or raters) reported that a dwelling unit ERV/HRV is typically installed in one of two ways, depending on the dwelling unit's heating/cooling system.

1. For an ERV/HRV installed in dwelling units with ducted heating/cooling systems, such as those assumed for our assumed system in this report, the ERV/HRV is installed in the mechanical closet. The ERV/HRV is installed vertically, so that its length runs parallel to the heating/ cooling system's air handling unit (AHU) and there is a short duct to connect supply air from the ERV/HRV into the heating/ cooling system ductwork. Thus, the ERV/HRV has its own fan, but uses the existing ductwork. This is the same strategy the Statewide CASE Team identified in a CMNFH project with an in-line fan (the base case assumed here). Both the ERV and in-line fan are approximately the same height (10.25" for the inline fan and 12" for the ERV assumed for this analysis) so the mechanical closet would need to be expanded by approximately the same amount to accommodate each. Thus, there should be no significant impact on floor space.
2. For an ERV/HRV installed in dwelling units with non-ducted heating/cooling systems (mini-splits, electric resistance heaters), the ERV/HRV is installed at the ceiling in a soffit and has supply ductwork running to each bedroom or living space. This is the same strategy that subject matter experts report is used for in-line fans (the base case), except it would be a supply fan instead of an ERV/HRV in the soffit. The ERV/HRV would take up more ceiling space than the in-line fan, but this does not impact floor space. The CMNFH project that the Statewide CASE Team identified with an ERV/HRV used this strategy.

For a central ERV/HRV, both the base case (DOAS ventilation) and proposed ERV/HRV have a chase for central supply air. The chase would only need to be expanded slightly to accommodate the central exhaust shaft for the central ERV/HRV case.

Overall, the Statewide CASE Team found there was no significant impact on dwelling unit square footage from installation of an ERV/HRV compared to the base case.

5.1.2 Energy Cost Savings Results

Below are energy savings estimates at the dwelling unit level in 2023 present value (PV) savings for different prototypes. Some climate zones have negative electricity savings, because the base case includes more nighttime "free cooling" (i.e., more outside air is provided to the dwelling unit when the outdoor air is below the cooling set point, thereby reducing cooling loads). A bypass function (which this analysis assumed for the high-rise prototype) makes use of this free cooling so generates more energy savings.

The following tables show results for each multifamily prototype.

Table 33: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – ERV/HRV in Low-Rise Garden-style New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
1	$620	$2,162	$2,783
2	$362	$1,271	$1,634
3	$146	$762	$908
4	$191	$740	$931
5	$92	$690	$782
6	($126)	$205	$79
7	($281)	$119	($161)
8	($79)	$92	$12
9	$117	$268	$385
10	$252	$468	$721
11	$776	$1,141	$1,917
12	$501	$1,073	$1,574
13	$733	$921	$1,654
14	$751	$1,102	$1,853
15	$1,097	$22	$1,119
16	$596	$2,080	$2,675

Table 34: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – ERV/HRV in Low-Rise Loaded Corridor New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
1	$456	$1,778	$2,234
2	($46)	$1,163	$1,118
3	($175)	$658	$482
4	($141)	$823	$682
5	($239)	$689	$450
6	($590)	$179	($410)
7	($697)	$6	($690)
8	($527)	$65	($462)

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
9	($429)	$182	($247)
10	($142)	$263	$121
11	$495	$1,077	$1,572
12	$84	$1,045	$1,129
13	$463	$964	$1,428
14	$466	$1,092	$1,557
15	$858	$0	$858
16	$469	$2,096	$2,564

Table 35: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – ERV/HRV in Mid-Rise Mixed-Use New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
1	$43	$1,889	$1,932
2	($52)	$1,097	$1,045
3	($177)	$893	$715
4	($99)	$675	$575
5	($402)	$764	$362
6	($387)	$285	($101)
7	($600)	$196	($404)
8	($347)	$228	($119)
9	($171)	$349	$179
10	($950	$476	$380
11	$424	$1,137	$1,561
12	$125	$1,007	$1,132
13	$333	$887	$1,220
14	$337	$1,035	$1,372
15	$674	$179	$854
16	$39	$1,888	$1,926

Table 36: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – ERV/HRV in High-Rise Mixed-use New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
1	$17	$1,665	$1,683
2	$234	$1,243	$1,477
3	$59	$613	$672
4	$255	$623	$878
5	$5	$763	$768
6	$88	$205	$293
7	$23	$102	$125
8	$244	$218	$462
9	$352	$323	$675
10	$339	$577	$916
11	$578	$1,172	$1,750
12	$428	$1,041	$1,469
13	$695	$940	$1,635
14	$493	$1,306	$1,799
15	$1,283	$177	$1,460
16	$24	$2,497	$2,521

Table 36 shows results for the high-rise dwelling units as assumed here—i.e., with bypass (i.e., the ability of the HRV or ERV to take advantage of free cooling so that incoming air bypasses the heat exchanger when outdoor air temperatures are below the cooing set point during the cooling season). For comparison, the results in Table 37 do not include bypass. When bypass is included, energy savings more than double in climate zones with high cooling loads. The Statewide CASE Team does not propose requiring bypass for unitary systems, because the only unitary ERV product identified that included bypass was over $1,000 more than other ERV or HRV products, as shown in Table 12 in 3.1.2. Central ERVs or HRVs, since they are larger equipment and have some economies of scale, can more easily accommodate bypass. The Statewide CASE Team recommends that the Residential and Nonresidential Compliance Manuals include language describing bypass and its benefits and recommending its use.

Table 37: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – ERV/HRV in High-rise Mixed-use New Construction without Bypass Function Enabled

Climate Zone	15/30-Year TDV Electricity Cost Savings (2023 PV$)	15/30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 15/30-Year TDV Energy Cost Savings (2023 PV$)
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	($1,370)	$1,284	($87)
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	($942)	$986	$44
11	N/A	N/A	N/A
12	($851)	$1,670	$820
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

Because the high-rise mixed use prototype includes central ventilation systems, this analysis assumes a central ERV and consequently energy savings from bypass for the high-rise mixed-use prototype for the cost-effectiveness calculations.

5.1.3 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.

This section provides incremental first-cost estimates. In general, the Statewide CASE Team estimated an average cost (either a Statewide average value, or an estimate for the Sacramento area) based on RSMeans, online prices, or manufacturer or contractor quotes, and then developed climate-zone specific estimates by applying materials, labor, and equipment multipliers based on cost differences by climate zone from RSMeans. The table below shows the multipliers by climate zone compared to national averages. Values in each column are normalized with respect to the appropriate climate zone before being used.

Table 38: Cost Multipliers by Climate Zone

Climate Zone	Material	Equipment	Labor
1	96.4	97.1	130.6
2	96.4	97.6	182.2
3	100.2	100.2	169.6
4	99.9	98.7	170.5
5	96.5	97.3	131
6	96.1	96.9	131
7	100	102.2	129.4
8	99.9	99.2	130.9
9	96.5	95.4	130.9
10	99.9	98.1	130.9
11	100.3	97.1	130.1
12	100.1	99	131.4
13	100.1	97.3	130.1
14	96.5	97.3	128.8
15	96.4	109.2	130.9
16	96.8	97.1	130.1

5.1.3.1 Unitary ERV for Low-rise Multifamily Prototypes

For the unitary ERV submeasure, the Statewide CASE Team estimated the cost to comply with a base case and a proposed case. The base case assumed an inline fan with MERV 13 filtration providing supply air and an average of 1.4 ENERGY STAR rated bathroom fans providing exhaust air. The proposed case assumed an ERV with a pick-up in the bathrooms that replaced the exhaust fan. The proposed case design was based on interviews with six HERS Raters and mechanical engineers. The duct layout is the same for the base case and the proposed case.

Most cost assumptions for the base case are based on price estimates from RSMeans and internet research. However, because the labor cost for inline supply fan installation is not listed in RSMeans, the Statewide CASE Team requested installation labor time estimates from multifamily designers, then used RSMeans to translate labor time to labor costs.

The cost of the base case in-line supply fan ($200) is typical for projects in California multifamily incentive programs. It is slightly higher than the material cost for exhaust fans in RSMeans. The cost of the supply fan air filter (MERV13) is from RSMeans. The cost of the bathroom ENERGY STAR exhaust fans ($149 each) is from internet research and is similar to exhaust fan material costs in RSMeans ($127). The Statewide CASE Team requested installation labor time estimates for the in-line supply fan from three mechanical engineers. The labor hours identified (1.5 hours) were multiplied by national labor rates for exhaust fan installation from RSMeans, then the California average multiplier was applied ($59.89/hour national x 1.45 for California average = $86.84/hour). The exhaust fan installation labor cost is from RSMeans; it was multiplied by the California average to find the labor rate.

For the proposed case, the Statewide CASE Team used internet research and calls with manufacturers to find the ERV material cost estimate. The labor hours (1.5 hours) are based on the multifamily designers' estimates for supply fan installation and translated to labor costs using RSMeans and the California average multiplier. The cost of ERV filters is based on internet research (pack of eight costs, $319). This is similar to cost estimates of high efficiency filters in RSMeans ($41) and other manufacturers' materials costs for MERV13 filters ($56 for an Aldes product).

The cost of the ductwork is equal in the base case and the proposed case.

The base case and proposed case costs using statewide average costs are provided in Table 39 and Table 40.

Table 39: Cost of Base Case: Discrete Supply In-line Fan

Product Description	Quantity	Material Cost	Labor Cost	Labor Hours	Cost per Residential Unit
Supply Fan	1	$200	$130	1.5	$330
Supply Air Filter (MERV13)	1	$41	$0	0	$41
Exhaust Fan	1.4	$209	$111	2.03	$319
Total Cost					$690

Table 40: Cost of Proposed Case: ERV

Product Description	Quantity	Material Cost	Labor Cost	Labor Hours	Cost per Residential Unit
ERV	1	$900	$130	1.5	$1,030
ERV Filter (MERV 13	1	$40	$0	0	$40
Total Cost					$1,070

As shown, the base case is $690 and proposed cost is $1,070, for an incremental first cost of **$380 per dwelling unit**.

The Statewide CASE Team then applied the climate zone-specific multipliers for materials and labor, as shown below.

Table 41: Unitary ERV Incremental Cost by Climate Zone per Dwelling Unit

Climate Zone	Incremental Equipment	Incremental Materials	Incremental Labor	Incremental Measure Cost
1	$476	$ -	$(100)	$376
2	$479	$ -	$(139)	$339
3	$491	$ -	$(129)	$362
4	$484	$ -	$(130)	$354
5	$477	$ -	$(100)	$377
6	$475	$ -	$(100)	$375
7	$501	$ -	$(99)	$402
8	$486	$ -	$(100)	$386
9	$468	$ -	$(100)	$368
10	$481	$ -	$(100)	$381
11	$476	$ -	$(99)	$377
12	$490	$ -	$(100)	$390
13	$477	$ -	$(99)	$378
14	$477	$ -	$(98)	$379
15	$535	$ -	$(100)	$436
16	$476	$ -	$(99)	$377

5.1.3.2 Central ERV for High-rise Prototype

To develop incremental cost estimates of the central ERV measure, a mechanical contractor priced out the base case and proposed systems in the Basis of Design described in Section 5.1.1.2. Table 37 shows costs of the base case of supply fans and the proposed case of central ERVs. This example is shown for Sacramento (Climate Zone 12), and the Statewide CASE Team then applied climate-zone specific multipliers to estimate costs for each climate zone. The Statewide CASE Team made the following assumptions:

- Both cases include one rooftop ventilation systems: one supply fan in the base case and one ERV in the proposed case. The analysis assumes four hours per system for installation. Consistent with the high-rise prototype, the base includes tempering so that supply air is delivered between 55°F and 75°F.
- Bathroom exhaust fans are only included in the base case since there is a pickup leading to a central shaft for the ERV strategy. The Statewide CASE Team assumed 1.4 bathrooms per unit using a weighted average from years 2016 to

2018 of number of bathrooms in the Western Region from the United States Census (U.S. Department of Commerce 2018).

- The ERV includes a bypass function and MERV 13 filtration.
- Bathroom exhaust fans in the base case are ducted to the exterior.
- This analysis includes three types of ductwork.
    - Exhaust ducts: For the base case, this entails 7,722 pounds (lbs) of in-unit ducts, which carries bathroom exhaust to the wall. The proposed case includes a combination of central supply shafts and a small amount of ductwork to carry exhaust air from the bathroom to the central shaft, for a total of 6,285 lbs. Since the bathrooms are located close to the corridor, much longer duct runs are needed in the base case to carry the bathroom exhaust to the exterior wall than in the proposed case to carry bathroom exhaust to the central shaft.
    - Central supply ducts: The supply shafts (in both the base and proposed cases) require 2,800 lbs of ductwork for the building.
    - Roof supply ductwork to carry air from the central supply fan (base case) or central ERV (proposed case). This requires 2,000 lbs for roof supply ductwork. The proposed case requires another 2,000 lbs for exhaust ductwork, or 4,000 lbs total. The Statewide CASE Team assumed supply ductwork to have external insulation (included in the insulation cost) and the exhaust ductwork to be uninsulated.
- The proposed case requires twice as many fire smoke dampers because there are twice as many connections between a unit and a central shaft.
- For grilles, registers, dampers (GRDs) and exhaust louvers: The base case includes exhaust louvers on the exterior, while the proposed case includes grilles for the exhaust pick-up, which are less expensive than louvers. Both cases include supply registers.
- For balancing and commissioning, the contractor assumed the same labor for each system. This was based on four hours for commissioning the supply fan and four hours for the ERV, and a half hour to commission or balance each system in the dwelling unit (supply air and each bathroom fan in the base case; supply air and each pick-up in the proposed case).
- The electrical budget is $10,000 for each supply fan or central ERV, since there is one large system to wire in each case.
- There is no difference in design fee between the proposed and base cases.

Table 42: Cost of Base (Supply Fans) and Proposed Case (Central ERV)

Cost Category	Labor Rate	Base Scope (Supply Fans)				Proposed Case: Central ERVs			
		Quantity	Material Cost	Labor Hours	Total Cost	Quantity	Material Cost	Labor Hours	Total Cost
Filtered Supply Fans	$106	1	$50,000	8	$50,848				
Bathroom Fans	$106	164	$24,570	328	$59,296				
ERVs	$106					1	$40,000	8	$40,848
Supply Ductwork	$106	2,800 lbs	$2,100	504	$55,524	2,800 lbs	$2,100	504	$55,524
Roof Supply Ductwork	$106	2,000 lbs	$2,000	160	$18,960	4,000 lbs	$6,150	320	$37,920
Exhaust Ductwork	$106	7,722 lbs	$4,050	387	$87,869	6,285 lbs	$6,428	845	$95,951
Detailing & Material Handling	$106			134	$14,204			146	$15,476
Fire Smoke Dampers	$106	117	$58,500	234	$83,304	234	$117,000	468	$166,608
GRDs/ Exhaust Louvers	$106	117	$29,250	117	$41,652	164	$8,190	82	$16,871
Startup, Balancing, & Commissioning	$104			144	$15,018			144	$15,018
Insulation Budget		4,100 ft^2			$39,500	5,700 ft^2			$71,500
Electrical Budget					$10,000				$10,000
		Mark Up		**Rate**		**Mark Up**		**Rate**	
		Taxes for material cost only (Sacramento)		7.75%	$16,569	Taxes for material cost only (Sacramento)		7.75%	$19,314
		Design & Engineering		5%	$23,809	Design & Engineering		5%	$26,286
		Permit, testing, & inspection		2.5%	$11,904	Permit, testing, & inspection		2.5%	$13,143
		General Costs & Overhead		15%	$79,269	General Costs & Overhead		15%	$87,669
		Contractor profit		5%	$30,386	Contractor profit		5%	$33,606
		Total			$638,112	Total			$705,735
		Incremental Cost for Building (117 dwelling units)							$67,623
		Incremental Cost per Dwelling unit							$578

Table 43 shows incremental costs by climate zone for the central ERV measure. Multipliers for equipment, materials and labor were used to translate costs for Climate Zone 12 in Table 42 to the 16 climate zones. Costs for fans, ERVs, fire smoke dampers, grilles and louvers were multiplied by material multipliers. Costs for ductwork and insulation were multiplied by equipment multipliers.

Table 43: Central ERV Incremental Cost by Climate Zone per Dwelling Unit

Climate Zone	Incremental Equipment	Incremental Materials	Incremental Labor	Incremental Markups	Incremental Measure Cost
1	$24	$268	$118	$150	$560
2	$34	$268	$119	$154	$575
3	$32	$278	$122	$158	$590
4	$32	$278	$120	$157	$587
5	$24	$268	$119	$150	$561
6	$24	$267	$118	$149	$559
7	$24	$278	$125	$155	$582
8	$24	$278	$121	$154	$577
9	$24	$268	$116	$149	$558
10	$24	$278	$120	$154	$576
11	$24	$279	$118	$154	$575
12	$25	$278	$121	$155	$578
13	$24	$278	$119	$154	$575
14	$24	$268	$119	$150	$561
15	$24	$268	$133	$154	$580
16	$24	$269	$118	$150	$562

5.1.4 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 30-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:

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

The effective useful life of packaged HVAC equipment is 15 years. As such, ERVs and HRVs, as well as supply and exhaust fans in the base case, will need to be replaced every 15 years. Both the base and proposed cases will require replacement MERV 13 filters. Filter replacements should be at a similar rate, therefore no incremental difference in cost is expected for filters.

Present Value of Maintenance Cost = Incremental Cost x $(1+0.03)^{15}$

5.1.4.1 Unitary ERV

The Statewide CASE Team calculated the incremental maintenance and replacement costs of unitary ERVs in the example dwelling unit under the base case and proposed case. This analysis assumed that all mechanical equipment would be replaced at year 15—i.e., the supply and exhaust fans (in the base case) and the ERV (in the proposed case). The Statewide CASE Team did not include filter replacements in this calculation, because our research found the filter costs for the proposed and base case were the same (approximately $40 per filter for each case), so the incremental cost is zero.

For the unitary ERV, the incremental cost is $380, so present value of maintenance cost = $380 x $(1+0.03)^{15}$ = $244

The total lifetime cost is $380 + $244 = $624.

The Statewide CASE Team found the statewide average replacement costs for the base and proposed cases, as shown below.

Table 44: Statewide Average Replacement Cost of Base (Supply Fan) and Proposed Case (Unitary ERV)

		Statewide Average Cost			Statewide Average Replacement Cost in 2023 PV$		
		Material	**Labor**	**Total**	**Material**	**Labor**	**Total**
Baseline	Supply Appliance: Stand-alone In-line Fan*	$198	$125	$675	$127	$80	$433
	Exhaust Appliance: ENERGY STAR Multi-Speed Bath Fan	$206	$106		$132	$68	
	Filter: MERV13	$41	$0		$26	$0	
Proposed	Appliance: ERV*	$889	$125	$1,053	$571	$80	$676
	Filter: MERV13	$39	$0		$25	$0	
Incremental Cost							$243

*For both the in-line fan and the ERV, the Statewide CASE Team identified products that have a MERV 13 filtration option.

Table 45: Incremental Replacement Cost of Base (Supply Fan) and Proposed Case (Unitary ERV) for all Climate Zones

Climate Zone	IMC Replacement, First Year	IMC Replacement at Year 15 (2023 $)	Lifetime IMC (2023 $)
1	$376	$242	$618
2	$339	$218	$557
3	$362	$232	$594
4	$354	$227	$581
5	$377	$242	$619
6	$375	$241	$616
7	$402	$258	$661
8	$386	$248	$635
9	$368	$236	$604
10	$381	$245	$626
11	$377	$242	$619
12	$390	$250	$640
13	$378	$242	$620
14	$379	$243	$622
15	$436	$280	$715
16	$377	$242	$619

5.1.4.2 Central ERV

For the high-rise prototype, which assumes a central ERV, this analysis assumed the ERV, supply and exhaust fans (in the base case), fire smoke dampers, and rooftop insulation would be replaced in 15 years. While code requires periodic visual inspections of fire smoke dampers (FSDs), the Statewide CASE Team assumed this cost would be roughly equal between the base and proposed case, because the most significant challenge is gaining access to the dwelling unit, and verifying two FSDs per dwelling unit instead of one would not be a significant increase in time.

The following table shows the incremental replacement cost estimate for the central ERV submeasure for Climate Zone 12.

Table 46: Replacement Cost of Base (Supply Fan) and Proposed Case (Central ERV)

Cost Category	Labor Rate	Base Scope (Supply Fans)				Proposed Case: Central ERVs			
		Quantity	Material Cost	Labor Hours	Total Cost	Quantity	Material Cost	Labor Hours	Total Cost
Filtered Supply Fans	$106	1	$50,000	8	$50,848				
Bathroom Exh. Fans	$106	164	$24,570	328	$59,296				
ERVs	$106					1	$40,000	8	$40,848
Detailing	$106			134	$14,204			146	$15,476
Fire Smoke Dampers	$106	117	$58,500	234	$83,304	234	$117,000	468	$166,608
Startup, Balancing, & Commissioning	$104			144	$15,018			144	$15,018
Insulation Budget		1,600 ft^2			$32,000	3,200 ft$_2$			$64,000
Electrical Budget					$10,000				$10,000
		Mark Up		Rate		Mark Up		Rate	
		Tax for material (Sacramento)		7.75%	$12,793	Taxes for material cost only (Sacramento)		7.75%	$17,128
		Design & Engineering		5%	$13,233	Design & Engineering		5%	$15,597
		Permit, testing, & inspection		2.5%	$6,617	Permit, testing, & inspection		2.5%	$7,799
		General Costs & Overhead		15%	$44,597	General Costs & Overhead		15%	$52,871
		Contractor profit		5%	$17,095	Contractor profit		5%	$20,418
		Total			$359,005				$425,612
		Incremental Cost for Building (117 dwelling units) at Year 15							$ 66,607
		Incremental Cost per Dwelling unit at Year 15							$569
		Incremental Cost per Dwelling unit (2023 $)							$365

The following table shows the incremental (abbreviated as “Incr.”) replacement (abbreviated as “Repl.”) cost estimate for the central ERV submeasure for all climate zones, by applying materials, labor, and equipment multipliers specific to each climate zone. The final column, Lifetime IMC, combines the first-year IMC (from Table 43) with the IMC replacement Cost in 2023 ($).

Table 47: Incremental Measure Cost (IMC) for Replacement by Climate Zone – Central ERV

Climate Zone	Incr. Equipment	Incr. Materials	Incr. Labor	Incr. Markups	IMC Repl.	IMC Repl. (2023 $)	Lifetime IMC (2023 $)
1	$203	$263	$(73)	$161	$555	$356	$917
2	$284	$263	$(73)	$193	$667	$428	$1,003
3	$264	$274	$(75)	$188	$651	$418	$1,008
4	$265	$273	$(74)	$189	$654	$419	$1,006
5	$204	$264	$(73)	$161	$556	$357	$918
6	$204	$263	$(72)	$161	$555	$356	$915
7	$201	$273	$(76)	$163	$561	$360	$943
8	$204	$273	$(74)	$165	$567	$364	$941
9	$204	$264	$(71)	$162	$558	$358	$916
10	$204	$273	$(73)	$165	$568	$365	$940
11	$203	$274	$(73)	$165	$569	$365	$941
12	$205	$274	$(74)	$165	$569	$365	$943
13	$203	$274	$(73)	$165	$568	$365	$940
14	$200	$264	$(73)	$160	$552	$354	$915
15	$204	$263	$(82)	$159	$544	$349	$929
16	$203	$264	$(73)	$161	$556	$357	$919

Using Climate Zone 12 as an example, the total lifetime IMC for the central ERV is $943.

5.1.5 Cost Effectiveness

The proposed measure is a prescriptive requirement. Because the primary benefit of this submeasure is energy savings, a cost analysis is required to demonstrate that the measure is cost effective over the 30-year period of analysis. This section describes the approach and results used for calculating cost effectiveness for the ERV/HRV. All results reflect analysis for new construction, because the ERV/HRV measure is only proposed for replaced components of an altered ventilation system in a low-rise alteration, and are not proposed for alterations for high-rise or for the central ventilation duct sealing measure. Results for additions should be similar as new construction.

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 30-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 B/C ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 30 years by the total incremental costs, which includes maintenance costs for 30 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

Table 48 presents results of the per-unit cost-effectiveness analyses for low-rise garden-style new construction dwelling units. The Statewide CASE Team assumed both low-rise prototypes and the mid-rise prototype would use unitary ERV, and the high-rise would use a central ERV. This assumption aligned with the prototypes, which used individual dwelling-unit ventilation for the low-rise and mid-rise prototypes, but central ventilation for the high-rise prototypes. However, project teams could choose to install either a unitary or central system (ERV or HRV) to meet the requirement. This analysis found that the unitary ERV was cheaper, but that the central ERV provided more energy savings. This is because the bypass function could be incorporated for a small incremental cost for the central ERV, and this function provided significantly more energy savings by leveraging the free cooling of nighttime outdoor air.

For simplicity and to promote multifamily unification, the Statewide CASE Team required the measure only if the it was found to be cost effective for all prototypes in a climate zone. As shown in the tables below, the benefit-to-cost ratio is greater than 1.0 for all prototypes for all climate zones where the requirement is proposed: 1, 2, and 11 through 16.

Table 48: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – Low-rise Garden Style

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	$2,783	$618	4.5
2	$1,634	$557	2.9
3	$908	$594	1.5
4	$931	$581	1.6
5	$782	$619	1.3
6	$79	$616	0.1
7	$(161)	$661	(0.2)
8	$12	$635	0.0
9	$385	$604	0.6
10	$721	$626	1.2
11	$1,917	$619	3.1
12	$1,574	$640	2.5
13	$1,654	$620	2.7
14	$1,853	$622	3.0
15	$1,119	$715	1.6
16	$2,675	$619	4.3

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – 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 49: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – Low-rise Loaded Corridor

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	$2,234	$618	3.6
2	$1,118	$557	2.0
3	$482	$594	0.8
4	$682	$581	1.2
5	$450	$619	0.7
6	$(410)	$616	(0.7)
7	$(690)	$661	(1.0)
8	$(462)	$635	(0.7)
9	$(247)	$604	(0.4)
10	$121	$626	0.2
11	$1,572	$619	2.5
12	$1,129	$640	1.8
13	$1,428	$620	2.3
14	$1,557	$622	2.5
15	$858	$715	1.2
16	$2,564	$619	4.1

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – 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 50: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – Mid-Rise Mixed Use

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	$1,932	$618	3.1
2	$1,045	$557	1.9
3	$715	$594	1.2
4	$575	$581	1.0
5	$362	$619	0.6
6	$(101)	$616	(0.2)
7	$(404)	$661	(0.6)
8	$(119)	$635	(0.2)
9	$179	$604	0.3
10	$380	$626	0.6
11	$1,561	$619	2.5
12	$1,132	$640	1.8
13	$1,220	$620	2.0
14	$1,372	$622	2.2
15	$854	$715	1.2
16	$1,926	$619	3.1

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – 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 51: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – High-Rise Mixed Use

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	$1,683	$917	1.8
2	$1,477	$1,003	1.5
3	$672	$1,008	0.7
4	$878	$1,006	0.9
5	$768	$918	0.8
6	$293	$915	0.3
7	$125	$943	0.1
8	$462	$941	0.5
9	$675	$916	0.7
10	$916	$940	1.0
11	$1,750	$941	1.9
12	$1,469	$943	1.6
13	$1,635	$940	1.7
14	$1,799	$915	2.0
15	$1,460	$929	1.6
16	$2,521	$919	2.7

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – 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.

This is a prescriptive requirement that will affect all multifamily dwelling units following the balanced ventilation path in Section 150.0(o)1E (for low-rise multifamily dwelling units) and Section 120.1(b)2Aivb (for high-rise multifamily dwelling units) that are new construction or additions; it will only affect replaced ventilation equipment in alterations in low-rise units. The B/C ratios are valid for additions, because the cost-effectiveness analysis for this measure is the same for new construction and additions.

The following figure summarizes the costs compared to benefits (monetized energy savings). For cost-effective savings, the yellow dot (low and mid-rise incremental cost) must be lower than the light green, dark green, and light blue bars (low-rise garden, low-rise loaded corridor, and midrise); and the purple dot (high-rise incremental cost) must be lower than the dark blue bar (high-rise incremental cost).

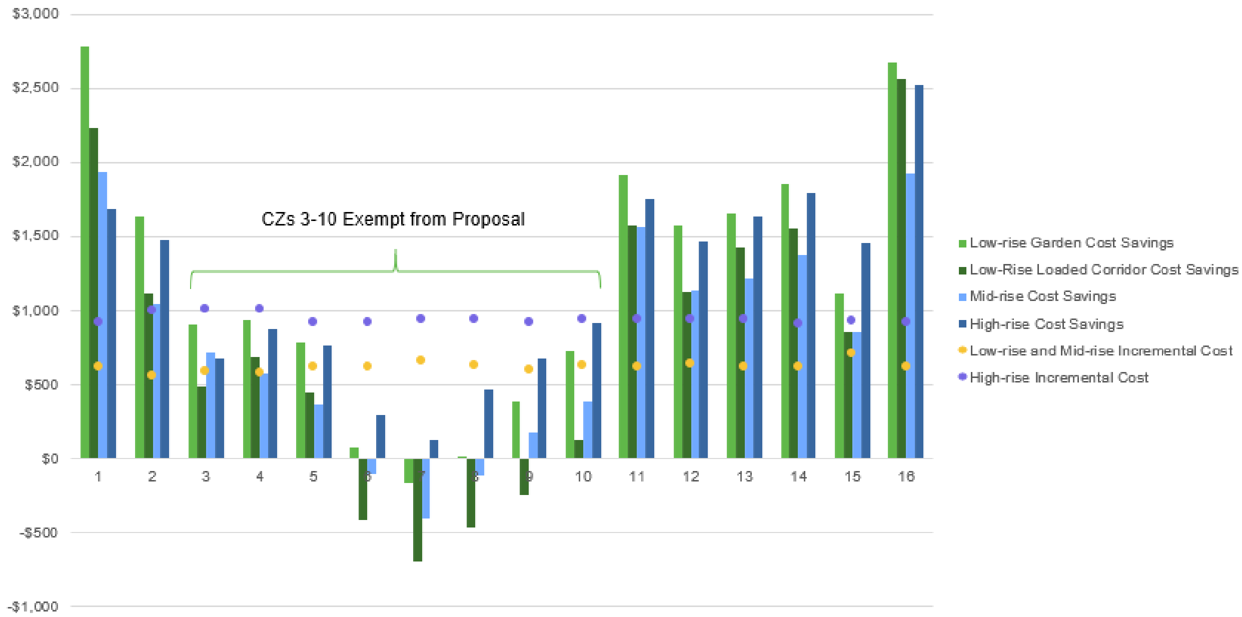


Figure 29: ERV/HRV cost – benefit analysis summary

5.2 Submeasure B: Kitchen Exhaust Minimum Capture

5.2.1 Cost Impact Investigation Methodology

Section 5 of CASE Reports typically present a detailed cost-effectiveness analysis. Because this proposed requirement is to ensure good IAQ rather than provide energy savings, cost-effectiveness is not calculated. Instead, this section provides results of a price comparison of range hoods that would and would not comply with the proposed requirement—under the pathway for a minimum range hood airflow of 250 cfm and 290 cfm. There were not enough products without a minimum range hood airflow of 200 cfm to analyze cost differences for the 175 cfm and 200 cfm minimum airflow requirements. Most existing products would also comply with the 175 and 200 cfm minimum airflow requirements.

The Statewide CASE Team used the HVI database to take a random sample of products compliant under the minimum range hood airflow pathway (“compliant” products: i.e., vented range hood over electric ranges in unit less than 750 ft^2 with a minimum airflow of 250 cfm at 0.1 inches w.c. static pressure or greater) and compare them with those that comply with the current but not proposed requirement (“noncompliant” products: vented range hood with airflow between 100 and 250 cfm at 0.1 inches w.c. in unit less than 750 ft^2). The prices of products were found online (i.e., Home Depot, Amazon, Best Buy, Appliances Connection). To sample products that would most likely be used in a multifamily building, the Statewide CASE Team only considered microwave and undercabinet range hoods (commonly used in multifamily dwelling units due to space constraints), and filtered out products with an airflow rating of greater than 400 cfm. Some products had model numbers with similar numbers and characters (usually constituting the same product but with different colors) and were grouped as one product. Since prices differed by color, the price of the black product was used if available. When black was not available, the next commonly available color was stainless steel.

Because capture efficiency is not available for range hood products, the Statewide CASE Team could not make a similar pricing comparison for products that do and do not comply with the first proposed compliance path for kitchen exhaust (range hood meeting the minimum capture efficiency requirement). Because the proposed requirement would not make substantive changes to the third (downdraft exhaust with airflow of at least 300 cfm) or fourth (continuous exhaust at five kitchen air changes per hour at 50 Pa) compliance paths, this analysis does not provide a pricing comparison for those paths.

5.2.2 Cost Impact Results

The below tables show the average prices found for a sample of products that would be compliant and noncompliant with the proposed requirement. For each case, the Statewide CASE Team used the Welch's t-test to determine the significance of price differences for compliant and noncompliant products. On average for the 250 and 290 cfm proposed requirements, compliant products were more expensive than non-compliant products. For the requirement of a minimum airflow of 250 cfm (for units less than 750 ft_2 with electric range of less than 1,000 ft^2 with natural gas range), the average compliant product was more expensive by $147 and $200 for microwave and undercabinet range hoods, respectively, and was found to be statistically significant at the 5 percent significance level (since p-values were less than 0.05 for both microwave and undercabinet range hoods). For the requirement of a minimum of 290 cfm (for units less than 750 ft^2 with natural gas range), compliant products had higher prices with significance at the 10 percent significance level since p-values were less than 0.1. Some of the product estimates had low precision for undercabinet range hoods (with relative precision greater than 20 percent) due to low number of products or inability to find cost information online.

Table 52: Sampled Costs of Microwave Range Hood Products – 250 cfm Requirement

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (two-tailed)
Microwave Range Hood Noncompliant: >100, <250 cfm	$358	$147	19%	12	25	0.02
Microwave Range Hood Compliant: ≥250 cfm	$500	$184	16%	19	82	

Table 53: Sampled Costs of Undercabinet Range Hood Products – 250 cfm Requirement

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (two-tailed)
Undercabinet Range Hood Noncompliant; >100, <250 cfm	$304	$52	32%	3	7	0.01
Undercabinet Range Hood Compliant; ≥250	$541	$283	20%	17	39	

Table 54: Sampled Costs of Microwave Range Hood Products – 290 cfm Requirement

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (two-tailed)
Microwave Range Hood Noncompliant; >100, <290 cfm	$370	$159	15%	25	87	0.01
Microwave Range Hood Compliant; ≥290	$596	$206	20%	9	20	

Table 55: Sampled Costs of Undercabinet Range Hood Products – 290 cfm Requirement

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (two-tailed)
Undercabinet Range Hood Noncompliant; >100, <290 cfm	$420	$223	22%	10	15	0.05
Undercabinet Range Hood Compliant; ≥290	$628	$225	19%	11	30	

5.3 Submeasure C: Central Ventilation Duct Sealing

5.3.1 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 30 years. The TDV cost impacts are presented in nominal dollars and in 2023 present value dollars and represent the energy cost savings realized over 30 years.

The Statewide CASE Team modeled energy savings from the central ventilation duct sealing measure using EnergyPlus, which enabled changes to rooftop fan pressure and ventilation shaft leakage value. The default assumption in CBECC-Com is a fan pressure of approximately 1,000 Pa (4 inches w.c.). Because leakage is proportional to pressure, this resulted in very high energy savings, because it produced an assumption that almost twice the air would need to be provided at the rooftop fan to provide the ventilation air needed to all dwelling units. Two subject matter experts estimated static pressure in these types of ducts in high-rise multifamily buildings at 125 to 250 Pa (0.5 to 1 inches w.c.), which was corroborated by the four participants that responded to a poll as part of the March 25, 2020 stakeholder meeting. In addition, a review of rooftop fans used in central ventilation ducts in CMFNH projects found their average pressure was 280 Pa. To be conservative in savings estimates, this analysis assumed 125 Pa (0.5 inches w.c.), which produced lower energy savings than the CBECC-Comm assumptions.

Savings for this measure come from reduced fan energy and reductions in heating and cooling needs. The Statewide CASE Team applied TDV factors to determine energy savings. Section 4.3.1 provides an overview of key modeling assumptions. Energy cost savings were determined for new construction, although additions (which would also be affected by this measure) should have similar savings.

5.3.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings that are realized over the 30-year period of analysis are presented in 2023 dollars in the figures below. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

The following table provides TDV savings in 2023 present value ($) from central ventilation duct sealing for the high-rise mixed-use prototype. As shown, savings range from slightly negative in Climate Zone 7 to $2,223 in Climate Zone 2.

Table 56: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – High-Rise Mixed Use: 2023 PV TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – New Construction – High-Rise Mixed Use

Climate Zone	30-Year TDV Electricity Cost Savings (2023 PV$)	30-Year TDV Natural Gas Cost Savings (2023 PV$)	Total 30-Year TDV Energy Cost Savings (2023 PV$)
1	$98	$1,169	$1,267
2	$3,405	-$1,181	$2,223
3	($34)	$601	$567
4	$175	$612	$787
5	($85)	$668	$584
6	($60)	$290	$230
7	($174)	$124	($50)
8	$84	$238	$322
9	$308	$318	$626
10	$328	$381	$709
11	$596	$749	$1,344
12	$445	$763	$1,208
13	$581	$685	$1,266
14	$504	$748	$1,252
15	$1,038	$170	$1,208
16	$118	$1,303	$1,421

5.3.3 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.

To develop incremental cost estimates, the Statewide CASE Team estimated an average cost (either a Statewide average value, or an estimate for the Sacramento area) based on RSMeans, online prices, or manufacturer or contractor quotes. The Statewide CASE Team then developed climate-zone specific estimates by applying materials, labor, and equipment multipliers based on cost differences by climate zone from RSMeans. The table below shows the multipliers by climate zone compared to national averages. Values in each column are normalized with respect to the appropriate climate zone before being used.

Table 57: Labor Cost Multipliers by Climate Zone

Climate Zone	Material	Equipment	Labor
1	96.4	97.1	130.6
2	96.4	97.6	182.2
3	100.2	100.2	169.6
4	99.9	98.7	170.5
5	96.5	97.3	131
6	96.1	96.9	131
7	100	102.2	129.4
8	99.9	99.2	130.9
9	96.5	95.4	130.9
10	99.9	98.1	130.9
11	100.3	97.1	130.1
12	100.1	99	131.4
13	100.1	97.3	130.1
14	96.5	97.3	128.8
15	96.4	109.2	130.9
16	96.8	97.1	130.1

For this measure, the Statewide CASE Team assumed central ventilation for supply air and individual dwelling unit exhaust for the high-rise prototype, because three subject matter experts reported that is what they commonly see for balanced ventilation in multifamily buildings. This also aligns with data from Gabel Energy, which found that of

38 mid- and high-rise new construction projects in California, 18 projects used central supply shafts with individual exhaust, one used central supply and central exhaust shafts, and the remainder used unitized ventilation (i.e., each dwelling unit had its own through-wall ventilation—either exhaust-only or balanced ventilation).

For the high-rise prototype, the analysis assumed:

- Seven shafts (i.e., vertical ducts serving multiple dwelling units) for ventilation supply air, 90 feet long, (roof to first floor ceiling)
- Six of the shafts have two branches per shaft for each of nine floors– one for each unit; serving 12 apartments per floor.
- One shaft has one branch serving one apartment per floor
- Shaft size: 8 inch by 18 inch (8x2+18x2)12 = 4.33 ft. perimeter
- Branch length: two feet with two elbows each. 2 x (3.14 x .5) = 3.14 ft_2 of surface area.
- Branch size six-inch diameter round.

Measure cost includes the cost of sealing and testing the shaft assemblies.

Based on RSMeans and assumptions outlined in Section 5.1.3, the Statewide CASE Team developed the following labor and material first cost for sealing ducts.

5.3.3.1 Sealing Cost Assumptions

Duct sealing mastic is a water-based material with the consistency of drywall joint compound; it is applied with a brush or an airless sprayer at a thickness of one-sixteenth of an inch. It cures over one to three days. The cured product is flexible yet aggressively adheres to the metal substrate. The material cost calculation below is based on the manufacturer's coverage data and a 10 percent waste allowance.

Material costs are based on coverage data given by the manufacturers and pricing found on building supply and manufacturer's websites (e.g. Grainger Industrial Supply, RCD Corp, Home Depot, EFI.org, Amazon.com) for water-based mastic in gallons as applied to the seams on the shafts and on the branches to the registers in the units.

Spray application of mastic is faster than brush and therefore less costly for the labor of applying the coating. The spray equipment is a standard airless sprayer that can be carried by one worker. The spray equipment operates off a 20 Amp, 110 Volt circuit.

The cost calculations assumed two components that would require sealing: the vertical shaft, assumed to be rectangular and constructed of L-shaped sections, and horizontal branches composed of circular ducts.

For the vertical shaft: the length of seams to be sealed is determined by the length of the vertical shaft, the perimeter of the cross section of the shaft, and the number of vertical shaft segments. The shafts are 90 feet long made up of 8 x 18 inch, 5 foot sections made with two “L” shaped sections as shown in Figure 19. The number of joints between segments are determined by dividing the length of the shaft by the length of the segments. An additional joint is included to account for the end of the shaft.

The branch elbows have four seams and two ends each which need to be sealed. Because they are short branches the Statewide CASE Team assumed that the whole branch would be sealed. Based on the assumptions above and the materials costs from web based suppliers mentioned above, the Statewide CASE Team developed the central shaft sealing materials assumptions shown in Table 58.

Table 58: Material Cost Assumptions for Central Shaft Sealing

Sealing Component	**Assumption**
Material	RCD 6 water-based mastic
Coverage: linear feet (LF) per gallon. Based on manufacturer’s data: Wet film coverage at 50 mils thick x 3” wide	125 LF/gallon
Coverage: square feet (ft_2) per gallon – 125 linear feet x 3/12 ft wide	31 ft_2/gallon
Coverage per shaft: vertical seams plus connection seams Length of seam from Table 59/ 125 LF/gallon = 262/125=	2.1 gallon/shaft
Cost per shaft: branches Area of branch from Table 59 / 31 ft_2/gallon = 3.14/31 =	0.10 gal/branch
Building total, vertical seams plus connection seams 7 shafts X 2.1 gallons/shaft	14.7 gallons
Building total, branches 1 shaft x 1 branch per floor x 9 floors x 0.10 gallons per branch 6 shafts x 2 branches per floor x 9 floors x 0.10 gallons per branch	0.90 gallons 1.9 gallons
Total Gallons = 14.7 + 0.9 + 1.9=	18 gallons
Waste allowance	15%
Waste and rounding(gallon) = 18*(1+15%) =	20.7 Gallons
Gallon cost (web pricing)	$35.95/gallon
Total for all 7 shafts in building	$744
Cost per dwelling unit: $744 / 117 units	**$6.36**

For labor estimates, RS Means provides cost estimates for duct construction, which includes duct sealing, but does not provide cost estimates for duct sealing on its own.

Because the duct sealing cost is not a stand-alone operation in RS Means, the Statewide CASE Team estimated cost as follows: Duct sealing involves applying sealant to seams and joints in the ductwork. Sealant is sprayed on or applied with a brush, similar to painting. Therefore, labor cost pricing for painting for both brush-applied and sprayed-on methods is a reasonable proxy for applying duct sealant. The cost was therefore based on the time per linear foot (LF) or time per ft_2 required for the application of coatings times the labor rate for Sacramento, CA sheet metal worker.

- Labor rates are based on RS Means average rate for a sheet metal worker including overhead and profit working in Sacramento, CA: $117.74/hour.
- Labor rate of linear application of sealant = 0.013 hour/linear foot per RS Means reference number 099113800120.
- Labor time for area application of sealant = 0.012 hour/square foot per RS Means reference number 099113601800

Following are the data and assumptions used to calculate duct sealing costs.

Table 59: Labor Cost Assumptions for Central Shaft Sealing

Length of seam to seal per shaft: (linear feet) Long seams = length of shaft x 2 seams = 90 x 2 =	180 LF
Perimeter of 8in. x 18in. shaft = (8*2+18x2)/12 = 4.33 ft	4.33 LF
Number of joint seams = (Length of shaft / length of each segment) = 90 / 5 =	18
Total length of joint seams = (No. of joints + end cap) x perimeter = (18+1) x 4.33	82.3 LF
Totals length of seam to seal: Long seams + joint seams = 180 + 82.3	262.3 LF
Surface area of each branch 2ft length x 0.5ft diameter x 3.1415	3.14 ft^2
Surface area of branches per shaft with 1 branch/floor 3.14 x 1 per floor x 9 floors	28.3 ft^2
Surface area of branches on shafts with 2 branches/floor 3.14 x 2 per floor x 9 floors	56.6 ft^2
labor time, 1 branch/floor shafts 262 LF / shaft x 0.013 hr. per linear foot coated = 3.4 hours 28.3 ft^2 of branch per 1-branch shaft x .012 hr./ ft^2 = 0.4 hrs. Hours per 2 branch per floor shaft = 3.4 + 0.4=	3.7 hrs.
labor time, brush application: 2 branch/floor shafts 262 LF / shaft x 0.013 hr. per linear foot coated = 3.4 hours 56.5 ft^2 of branch per 2-branch shaft x .012 hr./ ft^2. = 0.7 hrs. Hours per 2 branch per floor shaft = 3.4 + 0.7=	10.3 hrs.
Labor cost brush application: 1 branch/floor shafts hrs. per shaft x 111.45	$412.24
Labor cost brush application: 2 branch/floor shafts 4.1 hrs. per shaft x 111.45	$455.57
Total Labor Brush Application: all 7 shafts 1 x $477.41 + 6 x $482.73	$3,145.65
Cost per shaft: Total Cost / 7 shafts	$419.38
Cost per dwelling unit:	$26.89

The total cost per dwelling units for the central shaft sealing is the combination of material costs and labor costs: $6.36+$26.89 = $33.25.

5.3.3.3 Testing Cost and Sampling Assumptions

In addition, the sealing costs calculated above, a HERS Rater or ATT would need to conduct a duct pressurization test for a sample of the central ventilation ducts, per the proposed requirement. This section provides the cost estimate for that test.

To set up the leakage test, the tester would seal each opening (e.g., register) with a temporary air barrier, such as self-sticking plastic sheeting made for this purpose or plastic sheeting applied with masking tape. The tester would then remove the exhaust fan and seal the test fan to the opening with tape and an air barrier such as cardboard.

The cost calculations assume one hour for mounting each duct tester fan, and one-quarter hour for temporarily sealing each opening—i.e., each supply grille in the multifamily unit.

The Statewide CASE Team proposes that sampling be allowed for the testing portion of this measure. The Title 24 Nonresidential Appendices outlines a sampling protocol that states 1 out of 7 unique systems shall be tested. The Statewide CASE Team proposes to require a higher sampling rate of one (1) in three (3) for this measure, to provide additional rigor for this new measure and because some buildings will have a small number of duct systems that trigger this requirement (e.g., five or ten), which would result in only one or two systems tested. The strategy assumed for the high-rise prototype uses seven central ventilation duct systems, so three systems would need to be sampled for testing in our example. This is somewhat of “worst case” assumption, since one fewer systems (six total) would lead to only two systems sampled for testing. As shown below, testing is not costly, and the measure is still cost effective under the proposed sampling requirement of one in three.

The following table shows cost assumptions for leakage testing all shafts in the high-rise prototype building, with labor and materials shown for Sacramento. The analysis assumed a senior field engineer ($74.40 per hour in Sacramento) for mounting the duct tester fans and junior field engineer ($38.48 per hour) for sealing the openings.

Material costs include seal adhering polyethylene duct mask that comes in 8 inch x 200 ft. rolls with perforations every four inches that cost about 0.05$ per 4” x 8” sheet (TruTech Tools n.d.).

This analysis includes costs for project planning and mobilization, which include coordinating with construction site personnel, travel, staging equipment and clean up. Although the leakage test can be conducted at pre-drywall (so that leaks can be sealed more easily), this cost analysis assumes that the ATT will inspect the seam sealant for adequate thickness during construction (i.e., before the test). While this visual inspection during construction is not required, it is helpful to verify the quality of work before duct sealing is completed, to help assure that the duct systems pass the pressure test.

Table 60: Cost for Leakage Testing Central Ventilation Ducts without Sampling

Cost Summary	Count	Labor (hours) each fan	Total hours	Labor rate per hour	Labor ($) each duct	Total labor
Mounting duct tester fans 2 person crew.	7	1.0	7.0	$181.48	$181.48	$1,270.38
Temporarily sealing openings 2 person crew.	117	0.3	29.3	$181.48	$45.37	$5,308.37
Run test. 2 person crew.	7	2.0	14.0	$181.48	$362.97	$2,540.76
Building Total			50.3			$9,119.50
Project Planning & Coordination			8.0	$119.35	$954.83	$954.83
Travel: 2 hour round trip, 2 person crew.			8.4	$181.48	$1,519.92	$1,519.92
Visual Inspection 3 ½-day trips includes travel			12.0	$119.35	$1,432.24	$1,432.24
Reporting			6.0	$119.35	$716.12	$716.12
Grand Total without sampling			84.6			$13,742.60
Cost per dwelling unit: without sampling	Grand total / 117					$117.46

Table 61: Cost for Leakage Testing Central Ventilation Ducts with Sampling

Costs with Sampling	Count	Labor (hours) each	Total hours	Labor rate per hour	Labor ($) each	Total labor
Mounting duct tester fans 2 person crew.	3	1.0	2.0	$181.48	$181.48	$544.44
Temporarily sealing openings 2 person crew.*	50	0.3	15	$181.48	$45.37	$2,268.50
Run test. 2 person crew.	3	2.0	6.0	$181.48	$362.97	$1,088.88
Building Total			23			$3,901.82
Project Planning & Coordination			6.0	$119.35	$716.12	$716.12
Travel: 2 hour round trip, 2 person crew.			2.1	$181.48	$385.65	$385.65
Visual Inspection 1 ½-day trips includes travel			4.0	$119.35	$477.41	$477.41
Reporting			4.0	$119.35	$477.41	$477.41
Grand Total with sampling			39.1			$5,958.41
Cost per dwelling unit with sampling	Total cost with sampling / 117 units					$50.93

Labor rates are from the RS Means General Requirements -013113.2 Field Personnel table with a Sacramento, California city index (Q1 2020) of 131.4 applied. For the testing labor the Statewide CASE Team assumed a crew of one senior field engineer and one junior field engineer would be adequate for the task.

Table 62: Labor Rate Assumptions for Central Ventilation Duct Testing

Rates	RS Means Index	Weekly Salary	Hourly	City Index	Adjusted Hourly
jr eng	013113200100	$1,887.00	$47.18	132%	$62.13
sr eng	013113200140	$3,625.00	$90.63	132%	$119.35
Crew Hourly					$181.48

5.3.3.4 Total Costs for Sealing and Testing

Combining the total central shaft sealing costs of $33 per unit with the testing costs of $51 per unit, sampled, **the total measure cost is $84 per dwelling unit**.

In a 2014 study, The Western Cooling Efficiency Center (WCEC) estimated costs for this central shaft sealing measure as $35 per dwelling unit for sealing and $50 per dwelling unit for testing, based on a 80-unit prototype, with eight shafts (Western Cooling Efficiency Center 2014).

Table 63 compares sealing and testing costs as estimated by this Final CASE Report with the costs estimated by the previous studies. Values from the previous studies were converted to 2019 dollars for a direct comparison with the estimates made in this Final CASE Report.

Table 63: Comparison of Sealing Costs

Source	Cost for Sealing	Cost for Testing	Total Cost	Cost for Sealing per dwelling unit (2019$)	Cost for Testing per dwelling unit (with sampling) (2019$)	Total Cost per dwelling unit (2019$)
Statewide CASE Team analysis conducted here	$33 per unit	$117 per unit without sampling, $51 with sampling	$151 per unit without sampling, $84 with sampling	$33	$51	$84
2005 Title 24 CASE Report	$200-300 for system serving 2,000 ft^2	$150	$350-450 per 2,000 ft^2	$121-181	$91	$212-272
WCEC (2014)	$35 per unit	$50 per unit	$85 per unit	$38	$54	$92

5.3.4 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 30-year period of analysis. However, the Statewide CASE Team does not anticipate maintenance requirements for this measure within 30 years. Properly applied duct mastic will last the lifetime of the duct assembly. The mastic is applied on the outside of the duct, so it is not in contact with moist air from an exhaust stream.

5.3.5 Cost Effectiveness

The proposed measure is a mandatory requirement for all multifamily buildings with central ventilation ducts. Because the primary benefit of this submeasure is energy savings, a cost analysis is required to demonstrate that the measure is cost effective over the 30-year period of analysis. This section describes the approach and results used for calculating cost effectiveness for the ERV/HRV and central ventilation duct sealing measures. All results reflect analysis for new construction, because the measures only affect replaced components of an altered ventilation system, and results for additions should be similar as new construction.

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 30-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 B/C ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 30 years by the total incremental costs, which includes maintenance costs for 30 years. The B/C ratio was calculated using 2023 PV costs and cost savings.

Table 64: 30-Year Cost-Effectiveness Summary Per Dwelling Unit – High-Rise Mixed Use

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	$1,267	$78	16.2
2	$2,223	$84	26.6
3	$567	$84	6.7
4	$787	$83	9.4
5	$584	$78	7.4
6	$230	$78	2.9
7	$(50)	$82	(0.6)
8	$322	$80	4.0
9	$626	$77	8.1
10	$709	$79	9.0
11	$1,344	$78	17.2
12	$1,208	$80	15.2
13	$1,266	$78	16.2
14	$1,252	$78	16.0
15	$1,208	$87	14.0
16	$1,421	$78	18.2

a. **Benefits: TDV Energy Cost Savings + Other PV Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – 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.

6. First-Year Statewide Impacts

6.1 Submeasure A: ERV/HRV

6.1.1 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 4.1.3, by assumptions about the percentage of newly constructed buildings that will 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 will 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 30-year energy cost savings represent the energy cost savings over the entire 30-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

The Statewide CASE Team determined through a poll during the first stakeholder meeting and through interviews with raters that most projects plan to use balanced ventilation to meet the 2019 Title 24, Part 6 requirement for either compartmentalization or balanced ventilation in all new construction multifamily dwelling units. This analysis assumes that 20 percent of buildings will use compartmentalization and 80 percent will use balanced ventilation. Projects using compartmentalization will not be affected by the proposed requirement. In addition, due to the cost-effectiveness results, the Statewide CASE Team is not proposing this measure in Climate Zones 3-10, so these climate zones will not be affected by this proposed requirement.

Table 65 below presents the first-year statewide energy and energy cost savings from newly constructed buildings by climate zone.

Table 65: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (multifamily: dwelling units in Millions)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (million therms)	30-Year Present Valued Energy Cost Savings (PV$ million in 2023)
1	212	0.006	0.04	0.01	$0.44
2	1,258	(0.05)	0.11	0.03	$1.40
3	-	-	-	-	$0.00
4	-	-	-	-	$0.00
5	-	-	-	-	$0.00
6	-	-	-	-	$0.00
7	-	-	-	-	$0.00
8	-	-	-	-	$0.00
9	-	-	-	-	$0.00
10	-	-	-	-	$0.00
11	898	0.04	0.14	0.02	$1.43
12	5,068	(0.09)	0.53	0.10	$5.91
13	1,479	0.04	0.21	0.03	$1.96
14	672	0.03	0.10	0.01	$0.99
15	438	0.05	0.05	0.001	$0.39
16	271	0.0043	0.05	0.01	$0.60
TOTAL	10,296	0.04	1.23	0.20	$13.11

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

Table 66 presents first-year statewide savings from newly constructed buildings by climate zone.

Table 66: 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 (million therms)	30-Year Present Valued Energy Cost Savings (PV$ million in 2023)
New Construction	0.04	1.23	0.20	$13.11
TOTAL	0.04	1.23	0.20	$13.11

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

6.1.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the 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 67 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 1,117 metric tons of carbon dioxide equivalents (Metric Tons CO2e) will be avoided.

Table 67: First-Year Statewide GHG Emissions Impacts: ERV/HRV

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons CO2e)	Natural Gas Savings[a] (million therms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
ERV/HRV	0.04	9	0.20	1,108	1,117
TOTAL	0.04	9	0.20	1,108	1,117

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

b. Assumes the following emission factors 240.4 MTCO2e/GWh and 5,454.4 MTCO2e/million therms.

6.1.3 Statewide Water Use Impacts

The proposed code change will not result in water savings.

6.1.4 Statewide Material Impacts

The proposal to require ERV or HRV in non-mild climate zones will have an impact on material use. It will require switching existing types of equipment for new ones. This impact is limited to the installed appliance, since it should not require significant changes in duct design.

ERV and HRV do not typically contain heavy metals or other toxic materials, and the materials increased will be primarily steel and plastic. The unitary ERV studied are primarily steel with a polypropylene core.

To estimate the First-Year Statewide Impacts on Material Use, the Statewide CASE Team used manufacturer's data for the equipment studied for the base case and proposed case for the cost-effectiveness analysis.

The base case design for unitary systems includes one exhaust fan and one supply fan. According to product specification sheets, the exhaust and supply fans studied for the cost analysis, which represent typical installed equipment, weigh 11 and 11.5 lbs, respectively. Consequently, the base case materials total 22.5 lbs.

For the proposed case, the Statewide CASE Team averaged the weight of the ERV assumed for the cost-effectiveness analysis and another unitary ERV with MERV 13 filtration. Based on product spec sheets, the average weight of two ERVs that could be used for a unitary ERV approach is 56 lbs. The ERV has a polypropylene core and polystyrene insulation weigh 10 lbs; the remainder of the weight (23.1 lbs) is steel. Consequently, the incremental weight of the appliances is 33.5 lbs.

Table 68 summarizes the weight of the components of the base and proposed case using manufacturer's data for the equipment studied for the base case and proposed case. All weights are shown as unit weights, since shipping weights may vary and the difference between unit and shipping weights are minimal.

Table 68: Base Case and Proposed Case Materials for Unitary ERV/HRV

Appliance	Weight (lbs)
ENERGY STAR Multi-speed Exhaust fan	11
In-line Supply fan	11.5
Total for Base Case	22.5
ERV (Average of two unitary ERVs with MERV 13 filtration)	56
Incremental Weight of Appliances	33.5

Table 69 summarizes the expected materials impact from the proposed measure for the central ERV/HRV case. For the exhaust fans in the base case, this analysis assumed the same Broan exhaust fan as in the materials estimate for the unitary case, multiplied by the 1.4 bathrooms in each of the 117 dwelling units in the prototype. For the supply fan (base case) and central ERV (proposed case), this analysis assumed the products shown below.

Table 69: Base Case and Proposed Case Materials for Central ERV/HRV

Appliance	Base case (lbs)	Proposed case (lbs)	Incremental Weight (lbs)
Exhaust fan: ENERGY STAR Multi-speed Bath Fan	1,886	N/A	(1,886)
Supply fan (2500-8500 cfm)	494	N/A	(494)
ERV (5500 cfm) with bypass		1,322	1,322
Supply Ductwork	2,800	2,800	-
Roof Supply Ductwork	2,000	4,000	2,000
Exhaust Ductwork	7,722	6,285	(1,437)
Fire Smoke Dampers	1,170	2,340	1,170
GRDs/Exhaust Louvers	234	328	94
Roof Supply Insulation	320	640	320

Table 70: First-Year Statewide Impacts on Material Use

Material	Impact on Material Use (pounds/year)						
	Unitary ERV (Assumed for Low-rise and Mid-rise) Per-Unit Impacts (I, D, or NC)[a]	Central ERV (Assumed for High-Rise): Per-Unit Impacts (I, D, or NC)[a]	Bldgs impacted by proposal	% using unitary	% using central ERV	Unitary ERV: First-Year[b] Statewide Impacts	Central ERV: First-Year[b] Statewide Impacts
Steel	23.5 (I)	19 (I)	13,440	95%	5%	300,048 (I)	12,768 (I)
Plastic	10 (I)	4 (I)				127,680 (I)	2,688 (I)
Aluminum	0 (NC)	3 (I)				0 (NC)	2,016 (I)

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.

The number of buildings impacted by this proposal is from Appendix A: Statewide Savings Methodology. All low rise and midrise are assumed to use unitary, and all the high rise use central ERV. Table 29 shows the percent of buildings that are low, mid, and high rise.

6.1.5 Other Non-Energy Impacts

In addition to the energy savings, the ERV/HRV measure would provide increased thermal comfort, because it would pre-heat or pre-cool incoming ventilation air.

6.2 Submeasure B: Kitchen Exhaust Minimum Capture

6.2.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team did not calculate energy savings from this measure, because they estimate there would be no significant difference in energy use from the proposed requirement.

6.2.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team did not calculate GHG emissions reductions from this measure, because the Statewide CASE Team estimates there would be no significant difference in energy use from the proposed requirement.

6.2.3 Statewide Water Use Impacts

The proposed code change would not result in water savings.

6.2.4 Statewide Material Impacts

The proposed measure would not impact materials, because kitchen ventilation is already required under 2019 Title 24, Part 6. The requirement would limit the types of kitchen range hoods that could be installed.

6.2.5 Other Non-Energy Impacts

This submeasure would provide significant IAQ benefits. As detailed throughout this report, the kitchen exhaust minimum capture measure would improve IAQ by reducing pollution released by cooking—both the act of cooking and natural gas ranges—which can cause respiratory illnesses, cardiovascular disease, and other health problems.

6.3 Submeasure C: Central Ventilation Duct Sealing

6.3.1 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 4.3.3, 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 30-year energy cost savings represent the energy cost savings over the entire 30-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

The Statewide CASE Team determined applicability of this measure based on consultant data comprised of 39 multifamily projects. The Statewide CASE Team reviewed the data to see how many projects have central ventilation and classified them into the prototypes of interest based on the number of stories. Low-Rise projects are those with one two three stories. Mid-Rise Mixed-Use projects are those that have between four and six stories and High-Rise Mixed Use have seven stories and up.

Based on data from Gabel Energy, the Statewide CASE Team found that 9 in 14 (approximately 64 percent) of mid-rise projects with balanced ventilation and 9 of 11 (approximately 82 percent) of high-rise projects with balanced ventilation use central ventilation strategies. For the purpose of this measure, the Statewide CASE Team assumed that 10 percent of the Low-Rise Garden Style and Low-Rise Loaded Corridor prototypes have central ventilation.

Table 71: Statewide Energy and Energy Cost Impacts – New Construction

Climate Zone	Statewide New Construction Impacted by Proposed Change in 2023 (multifamily: dwelling units)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (million therms)	30-Year Present Valued Energy Cost Savings (PV$ million in 2023)
1	78	0.003	(0.001)	0.003	$0.08
2	461	0.010	0.024	0.011	$0.86
3	2,237	(0.008)	0.013	0.037	$1.06
4	1,165	0.014	0.049	0.019	$0.77
5	207	(0.001)	(0.002)	0.004	$0.10
6	988	(0.022)	0.042	0.008	$0.19
7	1,062	(0.047)	0.017	0.004	-$0.04
8	1,389	(0.006)	0.108	0.009	$0.37
9	3,262	0.083	0.248	0.028	$1.71
10	1,152	0.040	0.106	0.012	$0.68
11	329	0.027	0.032	0.007	$0.37
12	1,857	0.101	0.178	0.038	$1.88
13	542	0.044	0.044	0.010	$0.58
14	246	0.018	0.026	0.005	$0.26
15	160	0.028	0.023	0.001	$0.16
16	99	0.002	0.003	0.004	$0.12
TOTAL	15,236	0.29	0.91	0.20	$9.16

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

Table 72: 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 (million therms)	30-Year Present Valued Energy Cost Savings (PV$ million in 2023)
New Construction	0.29	0.91	0.20	$9.16
TOTAL	0.29	0.91	0.20	$9.16

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

6.3.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions assuming the emissions factors specified in the 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 68 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 1,146 metric tons of carbon dioxide equivalents (Metric Tons CO2e) would be avoided.

Table 73: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tons O2e)	Natural Gas Savings[a] (million therms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tons CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tons CO2e)
Central Ventilation	0.29	69	0.2	1,077	1,146
TOTAL	0.29	69	0.2	1,077	1,146

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

b. Assumes the following emission factors: 240.4 MTCO2e/GWh and 5,454.4 MTCO2e/million therms.

6.3.3 Statewide Water Use Impacts

The proposed code changes would not result in water savings.

6.3.4 Statewide Material Impacts

The Statewide CASE Team estimated material impacts for the central ventilation duct sealing measure based on the cost calculation discussed in Section 5.3.3. The Statewide CASE Team is assuming no material impacts in the baseline case. Additionally, more tape would be used to seal registers during the leakage test, but this analysis does not account for material impacts from tape.

Mastic does not contain any significantly hazardous chemicals and does not pose a significant risk to those handling it or the environment. It is primarily made of ground limestone and hydrated aluminum silicate.

The Statewide CASE Team estimated that the materials impact from central ventilation duct sealing is approximately 29 gallons for the High-Rise Mixed Use prototype as shown in Table 58.

Since this prototype contains 117 dwelling units, about one quarter of a gallon is required for shaft sealing per dwelling unit. Based on a density of 12.1 pounds per gallon, shaft sealing uses about three gallons of mastic per unit (RCD 2008). To extrapolate to statewide impacts, the Statewide CASE Team multiplied the number of units impacted by this measure by the pounds of mastic used per dwelling unit.

Table 74: First-Year Statewide Impacts on Material Use

Material	Impact on Material Use (pounds/year)	
	Central Ventilation Shaft Sealing Per-Unit Impacts (I, D, or NC)[a]	**Central Ventilation Shaft Sealing : First-Year[b] Statewide Impacts**
Mastic	3 (I)	45,695 (I)

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.

Overall, this measure has a relatively low materials impact.

6.3.5 Other Non-Energy Impacts

In addition to the energy savings, the proposed requirement would provide IAQ benefits. The central ventilation duct sealing measure would improve IAQ by working with the central ventilation shaft balancing requirement in 2019 Title 24, Part 6 to help ensure that each dwelling unit receives the minimum ventilation rate—both at the time of testing and in the future. In addition, the measure would help ensure that central ventilation ducts carrying exhaust air would maintain negative pressure, thereby preventing exhaust air transfer to dwelling units.

7. Proposed Revisions to Code Language

7.1 Guide to Markup Language

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2019 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

The Energy Commission is planning consolidation of low-rise and high-rise multifamily requirements under a new multifamily section(s) in 2022 Title 24, Part 6. Restructuring the standards for multifamily building may also result in revisions to Reference Appendices, ACM Reference Manuals, compliance manuals, and compliance documents. Location and section numbering of the 2022 Standards and supporting documents for multifamily buildings depend on the Energy Commission's approach to and acceptance of a unified multifamily section(s). For clarity, the changes proposed in this Final CASE Report are demonstrated in terms of the 2019 structure and language.

7.2 Standards

The requirements proposed do not differ between low-rise and high-rise, but the Statewide CASE Team has demonstrated the change through mark-up to the requirements for both low-rise residential and high-rise residential. In some instances, the Statewide CASE Team references a nonresidential appendix within the residential standard, or requires ATT testing for residential measures. While this is not currently done in the residential standard, this approach aligns with the unified multifamily code.

Note that these changes do not apply to low-rise single family or nonresidential buildings.

7.2.1 Submeasure A: ERV/HRV

The proposed language would affect Section 120.1(b)2Aivb, 140.X, 141.0(a) and 141.0(b) for high-rise multifamily dwelling units and Section 150.0(o)1E, and 150.1 for low-rise multifamily dwelling units.

Draft language for high-rise multifamily buildings:

Section 120.1(b)2Aivb

The mechanical ventilation system shall comply with one of the following subsections 1 or 2 below. When subsection 2 is utilized for compliance, all dwelling units in the multifamily building shall use the same ventilation system type.

1. Balanced Ventilation. A balanced ventilation system shall provide the required dwelling-unit ventilation airflow. Systems with heat or energy recovery serving a single dwelling unit shall have a fan efficacy of ≤1.0 W/cfm.

2. Compartmentalization. Continuously operating supply ventilation systems, or continuously operating exhaust ventilation systems shall be allowed to be used to provide the required dwelling unit ventilation airflow if the dwelling-unit envelope leakage is less than or equal to 0.3 cubic feet per minute at 50 Pa (0.2 inches water) per ft^2 of dwelling unit envelope surface area as confirmed by field verification and diagnostic testing in accordance with the procedures specified in Reference Nonresidential Appendix NA7.18.2.

…

Section 140.X

When balanced ventilation is used to meet Section 120.1(b)Aivb in Climate Zones 1, 2, and 11-16, the ventilation system shall be a heat recovery ventilator (HRV) or energy recovery ventilator (ERV) system type that meets the requirements in either 140.X(a) or 140.X(b):

a. An ERV or HRV serving one individual dwelling unit shall be field verified in accordance with RA3.7.4 to confirm the model has a minimum sensible recovery efficiency of 67 percent, rated at 32 degrees F (0 degrees C), and a minimum fan efficacy of 0.6 W per cfm, or

b. An ERV or HRV serving multiple dwelling unit shall be field verified in accordance with NA2.4 to confirm the model has a minimum sensible recovery efficiency or effectiveness of 67 percent, rated at 32 degrees F (0 degrees C), fan efficacy meeting the requirements in Section 140.4, and recovery bypass or free cooling control capabilities to directly economize with ventilation air based on outdoor air limits that meet the requirements in Table 140.4(e). The bypass control capability shall be tested in accordance with NA7.5.4.

Additions would need to follow proposed language for new construction. The Statewide CASE Team proposes to add "or ventilation" system in the new multifamily chapter to the list of newly installed equipment that must meet requirements.

Section 141.0

Additions, alterations, and repairs to existing nonresidential, high-rise residential, and hotel/motel buildings, existing outdoor lighting for these occupancies, and internally and externally illuminated signs, shall meet the requirements specified in Sections 100.0 through 110.10, and 120.0 through 130.5 that are applicable to the building project, and either the performance compliance approach (energy budgets) in Section 141.0(a)2 (for additions) or 141.0(b)3 (for alterations), or the prescriptive compliance approach in

Section 141.0(a)1 (for additions) or 141.0(b)2 (for alterations), for the climate zone in which the building is located.

…

141.0(a) Additions

(a) Additions. Additions shall meet either Item 1 or 2 below.

1. **Prescriptive approach.** The envelope and lighting of the addition; any newly installed space-conditioning or ventilation system, electrical power distribution system, or water-heating system; any addition to an outdoor lighting system; and any new sign installed in conjunction with an indoor or outdoor addition shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5, and 140.2 through 140.9.

2. **Performance approach.**

A. The envelope and indoor lighting in the conditioned space of the addition, and any newly installed

space-conditioning or ventilation system, electrical power distribution system, or water-heating system, shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5; and

…

Section 141.0(b) Alterations

Alterations in high-rise dwelling units would not be required to meet this requirement.

Language for low-rise multifamily buildings:

Section 150.0(o)1E

E. Multifamily attached dwelling units shall have mechanical ventilation airflow provided at rates in accordance with Equation 150.0-B [ASHRAE 62.2:4.1.1] and comply with one of the following Subsections i or ii below. When Subsection ii below is utilized for compliance, all dwelling units in the multifamily building shall use the same ventilation system type.

i. Balanced Ventilation. A balanced ventilation system shall provide the required dwelling-unit ventilation airflow. Systems with heat or energy recovery serving a single dwelling unit shall have a fan efficacy of ≤1.0 W/cfm. Or

ii. Compartmentalization. Continuously operating supply ventilation systems, or continuously operating exhaust ventilation systems shall be allowed to be used to provide the required dwelling unit ventilation airflow if the dwelling-unit envelope leakage is less than or equal to 0.3 cubic feet per minute at 50 Pa (0.2 inches water) per ft^2 of dwelling unit envelope surface area as confirmed by field verification and diagnostic testing in accordance with the procedures specified in Reference Residential Appendix RA3.8.

Section 150.1IX (new section)

X. Ventilation.

i. When balanced ventilation is used to meet Section 150.0(o)1E in Climate Zones 1, 2, and 11-16, the ventilation system shall be a heat recovery ventilator (HRV) or energy recovery ventilator (ERV) system type that meets one of the following

  a. An ERV or HRV serving one individual dwelling unit shall be field verified in accordance with RA3.7.4 to confirm the model has a minimum sensible recovery efficiency of 67 percent, rated at 32 degrees F (0 degrees C), and a minimum fan efficacy of 0.6 W per cfm, or

  b. An ERV or HRV serving multiple dwelling unit shall be field verified in accordance with NA2.4 to confirm a minimum sensible recovery efficiency or effectiveness of 67 percent, rated at 32 degrees F (0 degrees C), fan efficacy meeting the requirements in Section 140.4, and recovery bypass or free cooling control capabilities to directly economize with ventilation air based on outdoor air limits that meet the requirements in Table 140.4(e). The bypass control capability shall be tested in accordance with NA7.5.4.

TABLE 150.1-B COMPONENT PACKAGE – Multifamily Standard Building Design (continued)

				Climate Zone								
				1	**2**	**3 through 10**	**11**	**12**	**13**	**14**	**15**	**16**
HVAC SYSTEM	Balanced Ventilation*	Unitary (serving one dwelling unit)	Sensible Recovery Efficiency	0.67	0.67	NR	0.67	0.67	0.67	0.67	0.67	0.67
			Fan Efficacy (W/cfm)	0.6	0.6	1.0	0.6	0.6	0.6	0.6	0.6	0.6
		Central (serving multiple dwelling units)	Sensible Recovery Efficiency or Effective-ness	067	0.67	NR	0.67	0.67	0.67	0.67	0.67	0.67
			Bypass Function	Req	Req	NR	Req.	Req.	Req.	Req.	Req.	Req.

*Requirements only apply when using Balanced Ventilation to meet 150.0(o)1E.7

…

Section 150.2 Low-Rise Residential Buildings – Additions and Alterations to Existing Low-Rise Residential Buildings

Additions would need to follow proposed language for new construction. No changes are needed to the language in Section 150.2, since 150.0(o) is already listed as a requirement for additions.

Alterations would follow the proposed requirement for any replaced components of a ventilation system.

7.2.2 Submeasure B: Kitchen Exhaust Minimum Capture

For this submeasure:

- Black is the current language in 2019 Title 24, Part 6.
- Purple is from ASHRAE Standard 62.2-2016, so required in 2019 Title 24, Part 6 by reference
- Red is new proposed language

10-103 Permit, Certificate, Informational, and Enforcement Requirements for Designers, Installers, Builders, Manufacturers, and Suppliers

Section 10-103(b)4. Ventilation information. For ~~low-rise~~ residential buildings, the enforcement agency shall require the builder to leave in the building, for the building owner at occupancy:

i. A~~a~~ description of the quantities of outdoor air that the whole dwelling unit ventilation system(s) are designed to provide to the building's conditioned space, and instructions for proper operation and maintenance of the ventilation system, and

ii. Instructions for proper operation and maintenance of local exhaust systems, including instructions for when any user-controlled systems (such as kitchen range hoods and bathroom exhaust fans) should be used.

For systems in buildings or tenant spaces that are not individually owned and operated, instructions shall state that the building's owner or their representative shall provide a copy of such information to all tenants at the start of their occupancy. For systems in buildings or tenant spaces that, ~~or~~ are centrally operated, such information shall be provided to the person(s) responsible for operating and maintaining the feature, material, component or mechanical ventilation device installed in the building. For some multifamily buildings, this may require two sets of information: one for tenants and one for the person(s) responsible for operating and maintaining the building. This information shall be in paper or electronic format.

For nonresidential buildings, ~~high-rise residential buildings and~~ hotels, and motels, the enforcement agency shall require the builder to provide the building owner at occupancy a description of the quantities of outdoor and recirculated air that the ventilation systems are designed to provide to each area. For buildings or tenant spaces that are not individually owned and operated, or are centrally operated, such information shall be provided to the person(s) responsible for operating and maintaining the feature, material, component or mechanical device installed in the building. This information shall be in paper or electronic format.

100.1 Definitions and Rules of Construction

ASTM Standard E3087-18 is the American Society of Testing and Materials document titled "Standard Test Method for Measuring Capture Efficiency of Domestic Range Hoods", 2018

kitchen, enclosed: a kitchen whose permanent openings to interior adjacent spaces do not exceed a total of 60 ft2 (6 m2).…

vented: exhausting to the outdoors

Draft language for high-rise dwelling units

Section 120.1(b) High-rise Residential Buildings

…

1. **Attached dwelling units.** All dwelling units shall meet the requirements of ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Residential Buildings, subject to the amendments specified in Subsection A below. All dwelling units shall comply with the Acceptance requirements specified in Subsection B below.

…

Section 120.1(b)2Avi. A local mechanical exhaust system shall be installed in each kitchen meeting the requirements of Section a and b below.

a. Kitchen exhaust systems ~~range hoods~~ shall be rated for sound in accordance with Section 7.2 of ASHRAE 62.2.

EXCEPTION to Section 120.1(b)2Avii: Kitchen range hoods may be rated for sound at a static pressure determined at working speed as specified in HVI Publication 916 Section 7.2.

b. Exhaust systems in non-enclosed kitchens must meet 1, 2, or 3 below, and exhaust systems in enclosed kitchens must meet 1, 2, 3, or 4 below:

1. A vented range hood with at least one speed setting with a minimum capture efficiency shown in Table 120.1-A, measured in accordance with ASTM Standard E3087-18 at nominal installed airflow described in HVI Publication 920; or

2. A vented range hood with at least one speed setting with a minimum airflow shown in Table 120.1-A at 25 Pa (0.1 inches w.c.) or higher; or

3. A vented downdraft kitchen exhaust fan with at least one speed setting with a minimum airflow of 300 cfm at 25 Pa (0.1 inches w.c.) or higher; or

4. Continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour.

Table 120.1-A Minimum Capture Efficiency (CE) or Airflow (cfm) for demand-controlled range hoods

Dwelling unit floor area (ft2)	Hood over electric range	Hood over natural gas range
≤ 750	65% CE or 250 cfm	75% CE or 290 cfm
750 – 999	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500	50% CE or 175 cfm	55% CE or 200 cfm
>1,500		50% CE or 175 cfm

…

Section 120.1(b)2C. Combustion Requirements and Ventilation information compliance

i. All ventilation systems shall meet the requirements of California Mechanical Code Chapter 7, Combustion Air.

ii. To meet the kitchen range hood requirements in this section and requirements of ASHRAE Standard 62.2 Section 6.4 for Combustion and Solid-Fuel Appliances, neither atmospherically vented combustion appliances nor solid-fuel-burning appliances may be installed in dwelling units smaller than 1,000 ft2. For dwelling units larger than 1,000 ft2 with atmospherically vented combustion appliances or solid-fuel-burning appliances, the total net exhaust flow of the two largest exhaust fans shall not exceed 15 cfm per 100 ft2 of occupiable space.

iii. Builders for all high-rise residential units must meet the ventilation information requirements in Title 24, Part 1 Section 10-103.

…

Additions would need to follow proposed language for new construction. The Statewide CASE Team proposes to add "or ventilation" system in the new multifamily chapter to the list of newly installed equipment that must meet requirements.

Section 141.0

Additions, alterations, and repairs to existing nonresidential, high-rise residential, and hotel/motel buildings, existing outdoor lighting for these occupancies, and internally and externally illuminated signs, shall meet the requirements specified in Sections 100.0 through 110.10, and 120.0 through 130.5 that are applicable to the building project, and either the performance compliance approach (energy budgets) in Section 141.0(a)2 (for additions) or 141.0(b)3 (for alterations), or the prescriptive compliance approach in Section 141.0(a)1 (for additions) or 141.0(b)2 (for alterations), for the climate zone in which the building is located.

…

141.0(a) Additions

(a) Additions. Additions shall meet either Item 1 or 2 below.

1. **Prescriptive approach.** The envelope and lighting of the addition; any newly installed space-conditioning or ventilation system, electrical power distribution system, or water-heating system; any addition to an outdoor lighting system; and any new sign installed in conjunction with an indoor or outdoor addition shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5, and 140.2 through 140.9.

2. **Performance approach.**

A. The envelope and indoor lighting in the conditioned space of the addition, and any newly installed space-conditioning or ventilation system, electrical power distribution system, or water-heating system, shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5; and

…

Section 141.0(b) Alterations

1. **Mandatory Requirements.** Altered components in a nonresidential, high-rise residential, or hotel/motel building shall meet the minimum requirements in this section.

….

D. Kitchen Ventilation in High-rise Residential Units. The altered component and any newly installed kitchen ventilation equipment in the alteration shall meet the applicable requirements of Section 120.1(b)2.

Language for low-rise multifamily dwelling units

Section 150.0(o). Requirements for Ventilation and Indoor Air Quality. All dwelling units shall meet the requirements of ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Residential Buildings subject to the amendments specified in Section 150.0(o)1 below.

…

Section 150.0(o)1G. A local mechanical exhaust system shall be installed in each kitchen meeting the requirements of Section i or ii below.

i. Single family exhaust systems shall meet the requirements of ASHRAE 62.2. Kitchen range hoods shall be rated for sound in accordance with Section 7.2 of ASHRAE 62.2.

EXCEPTION to Section 150.0(o)1Gi: Kitchen range hoods may be rated for sound at a static pressure determined at working speed as specified in HVI Publication 916 Section 7.2

ii. Multifamily exhaust systems shall meet the requirements of a and b below:

a. Kitchen exhaust systems ~~range hoods~~ shall be rated for sound in accordance with Section 7.2 of ASHRAE 62.2.

EXCEPTION to Section 120.1(b)2Avii: Kitchen range hoods may be rated for sound at a static pressure determined at working speed as specified in HVI Publication 916 Section 7.2.

b. Exhaust systems in non-enclosed kitchens must meet 1, 2, or 3 below, and exhaust systems in enclosed kitchens must meet 1, 2, 3, or 4 below:

1. A vented range hood with at least one speed setting with a minimum capture efficiency shown in Table 150.0(o)-A, measured in accordance with ASTM Standard E3087-18 at nominal installed airflow described in HVI Publication 920; or

2. A vented range hood with at least one speed setting with a minimum airflow shown in Table 150.0(o)-A at 25 Pa (0.1 inches w.c.) or higher; or

3. A vented downdraft kitchen exhaust fan with at least one speed setting with a minimum airflow of 300 cfm at 25 Pa (0.1 inches w.c.) or higher; or

4. Continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour.

Table 150.0(o)-A Minimum Capture Efficiency (CE) or Airflow (cfm) for demand-controlled range hoods

Dwelling unit floor area (ft2)	Hood over electric range	Hood over natural gas range
≤ 750	65% CE or 250 cfm	75% CE or 290 cfm
750 – 999	55% CE or 200 cfm	65% CE or 250 cfm
1,000 – 1,500	50% CE or 175 cfm	55% CE or 200 cfm
>1,500		50% CE or 175 cfm

…

Section 150.0(o)3. California Requirements and Ventilation information compliance

i. All ventilation systems shall meet the requirements of California Mechanical Code Chapter 7, Combustion Air.

ii. To meet the kitchen range hood requirements in this section and requirements of ASHRAE Standard 62.2 Section 6.4 for Combustion and Solid-Fuel Appliances, neither atmospherically vented combustion appliances nor solid-fuel-burning appliances may be installed in dwelling units smaller than 1,000 ft2. For dwelling units larger than 1,000 ft2 with atmospherically vented combustion appliances or solid-fuel-burning appliances, the total net exhaust flow of the two largest exhaust fans shall not exceed 15 cfm per 100 ft2 of occupiable space.

iii. Builders for all dwelling units must meet the ventilation information requirements in Title 24, Part 1 Section 10-103.

…

Section 150.2 Low-Rise Residential Buildings – Additions and Alterations to Existing Low-Rise Residential Buildings

Additions would need to follow proposed language for new construction. No changes are needed to the language in Section 150.2, since 150.0(o) is already listed as a requirement.

Alterations are already required to meet 150.0(o) requirements for any altered components.

7.2.3 Submeasure C: Central Ventilation Duct Sealing

High-rise multifamily building requirements. Note that shifting requirements from Section 140.4(l) to Section 120.4(g) was done in coordination with the Statewide Nonresidential HVAC CASE Team, which is recommending changes to duct leakage requirements for other types of nonresidential buildings in Section 120.4(g)1 and 120.4(g)3. The recommended changes to Section 120.4(g)1 and 120.4(g)3 are not presented below due to timing issues, but will be available in the Nonres HVAC CASE report.

Section ~~140.4(l)~~ 120.4(g). Requirements For Air Distribution System Ducts And Plenums. ~~Air Distribution System Duct Leakage Sealing~~. Duct systems shall be sealed in accordance with a~~1~~, ~~or~~ b~~2~~, or c below:

a~~1~~. Systems serving high-rise residential buildings, hotel/motel buildings and nonresidential buildings other than healthcare facilities, the duct system shall be sealed to a leakage rate not to exceed 6 percent of the nominal air handler airflow rate as confirmed through field verification and diagnostic testing, in accordance with the applicable procedures in Reference Nonresidential Appendices NA1 and NA2 if the criteria in Subsections A, B and C below are met:

A. The duct system provides conditioned air to an occupiable space for a constant volume, single zone, space-conditioning system; and

B. The space conditioning system serves less than 5,000 square feet of conditioned floor area; and

C. The combined surface area of the ducts located in the following spaces is more than 25 percent of the total surface area of the entire duct system:

i. Outdoors; or

ii. In a space directly under a roof that

a. Has a U-factor greater than the U-factor of the ceiling, or if the roof does not meet the requirements of Section 140.3(a)1B, or

b. Has fixed vents or openings to the outside or unconditioned spaces; or

iii. In an unconditioned crawlspace; or

iv. In other unconditioned spaces.

b~~2~~. Ventilation ducts in multifamily buildings shall meet duct sealing requirements in the California Mechanical Code Section 603.10 and confirmed through field verification and diagnostic testing conducted by a Certified Acceptance Test Technician per NA 2.1.4.2 that leakage is no greater than six percent of the rooftop or central fan design airflow rate if all criteria in Subsections A and B are met. The leakage test shall be conducted using NA 2.1.4.2 at a test pressure of 25 Pa (0.1 inches) for ducts serving six or fewer dwelling units and 50 Pa (0.2 inches) for ducts serving more than six dwelling units, and shall measure the leakage of all ductwork between the central fan and the connection point to the in-unit grille or fan.

A. The ventilation ducts serve multiple dwelling units.

B. The ventilation ducts provide continuous airflows or airflows to provide balanced ventilation to meet 120.1(b)2Aivb.

c. Duct systems serving healthcare facilities shall be sealed in accordance with the California Mechanical Code.

…

Section 120.5 Required Nonresidential Mechanical System Acceptance

Section 120.5(a)3. Duct systems shall be tested in accordance with NA7.5.3 where either:

A. They are new duct systems; or that meet the criteria of Sections 140.4(l)1, 140.4(l)2, and 140.4(l)3; or

B. They are part of an altered system. a system that meets the criteria of Section 141.0(b)2D.

Additions would need to follow the proposed requirement.

Section 141.0

Additions, alterations, and repairs to existing nonresidential, high-rise residential, and hotel/motel buildings, existing outdoor lighting for these occupancies, and internally and externally illuminated signs, shall meet the requirements specified in Sections 100.0 through 110.10, and 120.0 through 130.5 that are applicable to the building project, and either the performance compliance approach (energy budgets) in Section 141.0(a)2 (for additions) or 141.0(b)3 (for alterations), or the prescriptive compliance approach in Section 141.0(a)1 (for additions) or 141.0(b)2 (for alterations), for the climate zone in which the building is located.

…

141.0(a) Additions

(a) Additions. Additions shall meet either Item 1 or 2 below.

1. **Prescriptive approach.** The envelope and lighting of the addition; any newly installed space-conditioning or ventilation system, electrical power distribution system, or water-heating system; any addition to an outdoor lighting system; and any new sign installed in conjunction with an indoor or outdoor addition shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5, and 140.2 through 140.9.

2. **Performance approach.**

A. The envelope and indoor lighting in the conditioned space of the addition, and any newly installed space-conditioning or ventilation system, electrical power distribution system, or water-heating system, shall meet the applicable requirements of Sections 110.0 through 120.7, 120.9 through 130.5; and

141.0(b) Alterations

Alterations would not need to follow the proposed requirements.

Low-rise multifamily requirements

Section 150.0(m)11

11. **Duct System Sealing and Leakage Testing**.

A. When space conditioning systems utilize forced air duct systems to supply conditioned air to an occupiable space, the ducts shall be sealed, as confirmed through field verification and diagnostic testing, in accordance with all applicable procedures specified in Reference Residential Appendix RA3.1, and the leakage compliance criteria specified in Reference Residential Appendix TABLE RA3.1-2, and conforming to one of the following Subsections A, B, or C as applicable:

~~A~~i. For single family dwellings and townhouses with the air-handling unit installed and the ducts connected directly to the air handler, the total leakage of the duct system shall not exceed 5 percent of the nominal system air handler airflow as determined utilizing the procedures in Reference Residential Appendix Section RA3.1.4.3.1.

~~B~~ii. For single family dwellings and townhouses at the rough-in stage of construction prior to installation of the dwelling's interior finishing:

~~i~~a. **Air-handling unit installed.** If the air-handling unit is installed and the ducts are connected directly to the air handler, the total leakage of the duct system shall not exceed 5 percent of the nominal system air handler airflow as determined utilizing the procedures in Reference Residential Appendix Sections RA3.1.4.3.2, RA3.1.4.3.2.1 and RA3.1.4.3.3.

~~ii~~b. **Air-handling unit not yet installed.** If the air-handling unit is not yet installed, the total leakage of the duct system shall not exceed 4 percent of the nominal system air handler airflow as determined utilizing the procedures in Reference Residential Appendix Sections RA3.1.4.3.2, RA3.1.4.3.2.2 and RA3.1.4.3.3.

~~C~~iii. For multifamily dwellings with the air-handling unit installed and the ducts connected directly to the air handler, regardless of duct system location:

~~i~~a. The total leakage of the duct system shall not exceed 12 percent of the nominal system air handler airflow as determined utilizing the procedures in Reference Residential Appendix Section RA3.1.4.3.1; or

~~ii~~b. The duct system leakage to outside shall not exceed 6 percent of the nominal system air handler airflow as determined utilizing the procedures in Reference Residential Appendix Section RA3.1.4.3.4.

B. Ventilation ducts in multifamily buildings shall be sealed and confirmed through field verification and diagnostic testing conducted by a Certified Acceptance Test Technician per NA2.1 that leakage is no greater than six percent of the rooftop or central fan design airflow rate if all criteria in Subsections I and ii are met. The leakage test shall be conducted using NA2.1 at a test pressure of 25 Pa (0.1 inch) for ducts serving six or fewer dwelling units and 50 Pa (0.2 inches) for ducts serving more than six dwelling units, and shall measure the leakage of all ductwork between the central fan and the connection point to the in-unit exhaust grille or fan.

i. The ventilation ducts serve multiple dwelling units.

ii. The ventilation ducts provide continuous airflows or airflows to provide balanced ventilation to meet 120.1(b)2Aivb.

Section 150.2 Low-Rise Residential Buildings – Additions and Alterations to Existing Low-Rise Residential Buildings

Additions would need to follow proposed language for new construction. No changes are needed to the language in Section 150.2, since Sections 150.0(a) through (q) are already required.

Alterations would meet the proposed requirement for any altered or replaced components.

7.3 Reference Appendices

7.3.1 Submeasure A: ERV/HRV

NONRESIDENTIAL APPENDIX

NA2 – Nonresidential Field Verification and Diagnostic Test Procedures:

NA2.4 Rated Heat Recovery and Energy Recovery Ventilation Verification Procedures [new section]

When required for compliance with 140.X, for unitary ERVs/HRVs (one ERV or HRV serves each dwelling unit), a HERS Rater or ATT will:

1. Verify in the field that an ERV or HRV is installed, and verify using product specifications that it will provide airflows to meet or exceed the dwelling unit's balanced ventilation system airflows, and
2. Visually verify the installed equipment's nominal sensible recovery efficiency and fan efficacy for the installed model via product databases (HVI, AHRI, or Energy Commission – approved alternatives) or from product specifications from the manufacturer.

When required for compliance with 140.X, for central ERVs/HRVs (one ERV or HRV serves multiple dwelling units), an ATT will:

1. Verify in the field that an ERV or HRV is installed, and verify using product specifications that it will provide airflows to meet or exceed the dwelling unit's balanced ventilation system airflows, and

2. Visually verify the installed equipment's nominal sensible recovery efficiency and fan efficacy for the installed model via product databases (HVI, AHRI) or from product specifications from the manufacturer, and
3. Verify that the ERV/HRV systems include a bypass or free cooling function, using product specifications. Field verify that the bypass function exists and meets the requirements of Table 140.4(e).
4. Conduct functional testing of the bypass function according to NA7.5.4

NA7.5.4 Air Economizer Controls and Exhaust Air Heat Recovery

The following language was proposed by the Statewide Nonresidential HVAC Controls CASE Team and is copied into this Final CASE Report for completeness.

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.

RESIDENTIAL APPENDIX

RA3.7.4 Procedures: The proposed change will add a subsubsection, 3.7.4.4

RA3.7.4.4: Rated Heat Recovery and Energy Recovery Ventilation Verification Procedures. A HERS Rater or ATT will determine if an energy recovery ventilator (ERV) or heat recovery ventilator (HRV) is needed based on requirements of Section 150.1, and if so, verify requirements as follows:

For unitary ERVs/HRVs (one ERV or HRV serves each dwelling unit), the HERS Rater or ATT will:

1. Verify in the field that an ERV or HRV is installed, and verify using product specifications that it will provide airflows to meet or exceed the dwelling unit's balanced ventilation system airflows, and
2. Verify that the fan efficacy and sensible recovery effectiveness or efficiency requirements in Section 150.1X are met using product databases (HVI or Energy Commission – approved alternatives) or from product specifications.

For central ERVs/HRVs (one ERV or HRV serves multiple dwelling units), an ATT will:

1. Verify in the field that an ERV or HRV is installed, and verify using product specifications that it will provide airflows to meet or exceed the dwelling unit's balanced ventilation system airflows, and
2. Verify that the fan efficacy and sensible recovery effectiveness or efficiency requirements in Section 150.1X are met using product databases (HVI or Energy Commission – approved alternatives) or from product specifications, and
3. Verify that ERV/HRV systems that provide ventilation to more than one dwelling unit include a bypass or free cooling function, using product specifications.
4. Conduct functional testing of the bypass function according to NA7.5.4

7.3.2 Submeasure B: Kitchen Exhaust Minimum Capture

NA2.2.4.1.3 ~~Kitchen Range Hood~~ Kitchen Exhaust Equipment Verification

The verification shall utilize certified rating data from the Home Ventilating Institute (HVI) Certified Home Ventilating Products Directory at https://hvi.org/proddirectory/index.cfm, AHAM directory, or another directory of certified product performance ratings approved by the Energy Commission for determining compliance (abbreviated here as "HVI Directory"). The verification procedure shall consist of visual inspection of the installed kitchen ~~range hood~~ exhaust equipment to verify and record the following information:

(a) The manufacturer name and model number.

(b) The model is listed in the HVI Directory.

(c)The rated airflow value or rated capture efficiency listed in the HVI directory.

(d) The sound rating value listed in the HVI directory.

(e) If the value for the rated airflow or capture efficiency given in the directory is greater than or equal to the airflow requirements specified in the standards, and if the value for the sone rating given in the directory is less than or equal to the sone rating requirements specified in standards, then the kitchen ~~range hood~~ exhaust equipment complies, otherwise the kitchen ~~range hood~~ exhaust equipment does not comply.

RA3.7.4.3 ~~Kitchen Range Hood~~ Kitchen Exhaust Equipment Verification

The verification shall utilize certified rating data from the Home Ventilating Institute (HVI) Certified Home Ventilating Products Directory at https://hvi.org/proddirectory/index.cfm, Association of Home Appliance Manufacturers (AHAM) directory, or another directory of certified product performance ratings approved by the Energy Commission for determining compliance (abbreviated here as "HVI Directory"). The verification procedure shall consist of visual inspection of the installed kitchen ~~range hood~~ exhaust equipment to verify and record the following information:

(a) The manufacturer name and model number.

(b) The model is listed in the HVI Directory.

(c)The rated airflow value or rated capture efficiency listed in the HVI directory.

(d) The sound rating value listed in the HVI directory.

(e) If the value for the rated airflow or capture efficiency given in the directory is greater than or equal to the airflow requirements specified in the standards, and if the value for the sone rating given in the directory is less than or equal to the sone rating requirements specified in standards, then the kitchen ~~range hood~~ exhaust equipment complies, otherwise the kitchen ~~range hood~~ exhaust equipment does not comply.

7.3.3 Submeasure C: Central Ventilation Duct Sealing

Sampling Procedures

NA1.6.3 HERS Procedures – Group Sample Field Verification and Diagnostic Testing

After the initial field verification and diagnostic testing is completed, the builder or the ATT shall identify a group of up to seven individual systems or dwelling units in the building from which a sample will be selected and identify the names and license numbers of the subcontractors responsible for the installations requiring field verification and diagnostic testing. The date the first system or dwelling unit in the group is identified shall establish the start date for the new opened sample group. The HERS provider shall recorded and track the start date for each sample group. For the leakage requirements in Section 120.4(g)2, an ATT shall identify a group of up to three central ventilation duct systems in the building from which a sample will be selected.

…

NA1.9.1 Duct Leakage Field Verification by the Acceptance Test Technician

Under this alternative procedure, when the Certificate of Compliance indicates that field verification and diagnostic testing of duct leakage is required as a condition for compliance with Title 24, Part 6, a certified ATT may perform the duct leakage verification to satisfy the condition of compliance, at the discretion of the enforcement agency. Systems verified under this procedure are not eligible for sampling.

The exception is verification of requirements in Section 120.4(g), which must be conducted by an ATT, and verification of requirements in Section 120.4(g)3 is eligible for sampling.

NA2 – Nonresidential Field Verification and Diagnostic Test Procedures:

NA 2.1.1.1 - Purpose and Scope

The proposed code change would add 120.4(g) to the scope of this section and update 140.4(l) references.

NA2.1.4.2 – Diagnostic Duct Leakage

The proposed code change would add the requirements of Section 140.4(1)3 to the compliance criteria in Table NA2.1-1-1

NA2.1.4.2.2: Diagnostic Ventilation Duct Leakage from Fan Pressurization of Ducts, and subsequent subsections would be renumbered. The language in the new subsection would be similar to that in the existing Subsection NA2.1.4.2.1: Diagnostic Duct Leakage from Fan Pressurization of Ducts, which applies to testing of ducts providing conditioned air at 25 Pa (0.1 inches w.c.). However, the new subsection would specify that the test be conducted at 50 Pa (0.2 inches w.c.), and language would be revised so that it applies to ventilation duct systems as opposed to space conditioning duct systems.

The revised language would also state that sampling can be used for duct testing following NA1.6 procedures. If sampling is used for this measure, a sampling group would be defined as all ventilation ducts that carry the same type of airflow—i.e., either supply ventilation or exhaust ventilation—and that have the same make and model for their central ventilation fan.

RA2.6.2 HERS and ATT Procedures – Initial Model Field Verification and Diagnostic Testing

The HERS Rater shall diagnostically test and field verify the first dwelling unit of each model within a subdivision or multifamily housing development when the builder elects to demonstrate HERS verification compliance utilizing group sampling. To be considered the same model, dwelling units shall have the same basic floor plan layout, energy design, and compliance features as shown on the Certificate of Compliance. Variations in the basic floor plan layout, energy design, compliance features, zone floor area, or zone volume, that do not change the HERS features to be tested, the heating or cooling capacity of the HVAC unit(s), or the number of HVAC units specified for the dwelling units, shall not cause dwelling units to be considered a different model.

For multifamily buildings, variations in exterior surface areas caused by location of dwelling units within the building shall not cause dwelling units to be considered a different model.

For multifamily buildings meeting Section 150.0(m)11B, each central ventilation duct system that meets the criteria of 150.0(m)11B shall be treated as a “dwelling unit” for the sampling procedures specified in this section; an Acceptance Test Technician (ATT) shall identify a group of up to three central ventilation duct systems in the building from which a sample will be selected and conduct the leakage test for those systems.

RA3.1.4.3.1 Diagnostic Duct Leakage from Fan Pressurization of Ducts

The objective of this procedure is for an installer to determine or a rater to verify the total leakage of a new duct system or one that is replaced as part of an alteration. The total duct leakage shall be determined by pressurizing the entire duct system to a positive pressure of 25 Pa (0.1 inches water) with respect to outside, except for Section 150.0(m)11B. For Section 150.0(m)11B, the system shall be positively pressurized for supply ducts and negatively pressurized for exhaust ducts, and the test shall be conducted at 25 Pa (0.1 inches water) for ducts serving six or fewer dwelling units and at 50 Pa (0.2 inches water) for systems serving more than six dwelling units.

7.4 ACM Reference Manual

7.4.1 Submeasure A: ERV/HRV

The following provides marked up language for the Residential ACM Reference Manual.

Section 2.4.9 Indoor Air Quality Ventilation

Standard Design

> The mechanical ventilation system in the standard design is the same type as the proposed design. The airflow rate is equal to the proposed design for exhaust, supply, and balanced fans with no heat or energy recovery. For balanced fans with heat or energy recovery, the airflow rate is equal to the proposed design up to a maximum of 1.5 times the minimum CFM required by ASHRAE 62.2. For multifamily buildings with balanced fans with or without heat recovery in Climate Zones 1, 2, and 11-16 the ~~The~~ sensible heat recovery effectiveness is 67 percent and the fan power ratio is 0.6 W/CFM. For multifamily buildings with balanced fans with or without heat recovery in all other climate zones the sensible heat recovery effectiveness is zero and the fan power ratio is 0.6 W/CFM. For single family buildings the sensible heat recovery effectiveness is always zero. For standalone IAQ fan systems, the fan power ratio is equal to the proposed design value or 1.2 W/CFM, whichever is smaller. For central air handler fans, the fan power ratio is 0.45 (gas furnaces) or 0.58 W/CFM (heat pumps) of central system airflow in ventilation mode.

NONRESIDENTIAL ACM REFERENCE MANUAL

The following language should be incorporated into the Nonresidential ACM Reference Manual. The Statewide CASE Team recommends that the Energy Commission consider providing multiple boxes with the various requirements for the heat exchanger, including sensible recovery effectiveness, fan efficacy, and a bypass function.

Section 5.6.6.4 Outdoor Air Ventilation

Subsection 5.6.6.4.1 Heat/Energy Recovery

Heat/Energy Recovery	
Applicability	Zones serving multifamily apartments
Definition	Details of heat or energy recovery systems
Units	Various
Input Restrictions	As designed
Standard Design	If the Proposed Design is a unitary balanced or heat recovery ventilation system, in Climate Zones 1, 2, and 11-16 the Standard Design is a heat recovery ventilation system with a rated heat recovery effectiveness of 67%. In all other climates zones, the Standard Design is a balanced ventilation system without heat recovery. For all climate zones, the Standard Design has a fan power index of 0.6 W/cfm If the Proposed Design is a central ventilation system serving more than one apartment, in Climate Zones 1, 2, and 11-16, the Standard Design has a heat recovery system with a sensible heat exchange effectiveness of 67% in both heating and cooling and includes bypass of the heat exchanger when outdoor temperatures are cool. In all other climate zones, the Standard Design is a balanced ventilation system that does not have a heat recovery system. In all climate zones, the Standard Design meets the fan efficacy requirements in Section 140.4.
Standard Design: Existing Buildings	n/a

7.4.2 Submeasure B: Kitchen Exhaust Minimum Capture

There are no proposed changes to the ACM Reference Manual for this measure.

7.4.3 Submeasure C: Central Ventilation Duct Sealing

There are no proposed changes to the ACM Reference Manual for this measure.

7.5 Compliance Manuals

The proposed code changes would modify the following section of the Residential and Nonresidential Compliance Manuals:

RESIDENTIAL COMPLIANCE MANUAL

Section 4.6 – Indoor Air Quality and Mechanical Ventilation: The manual would include language that summarizes the requirement. The manual would provide an overview of strategies to meet the requirement, including unitary HRV or ERV, central HRV or ERV (such as a rooftop strategy or cluster strategy - such as one on every floor). The sizing and installation of bypass ducting would be illustrated and discussed.

The manual should also include language recommending that, for all multifamily projects that install HRV or ERV (including in climate zones not regulated by this requirement), the HRV or ERV include a bypass function, or that the dwelling units have mechanical cooling, to prevent overheating. The purpose of this language is to promote energy-efficient thermal comfort for occupants.

ERV/HRV can use multiple strategies for distributing outside air and (if interfacing with an air handling unit) integrating the supply duct into an AHU. However, the outside air distribution issues for ERV/HRVs would be similar to issues faced under the current requirements for other types of balanced ventilation systems. 2019 Title 24, Part 6 prohibits the "continuous operation of central forced air system air handlers used in central fan integrated ventilation systems." There are no requirements in ASHRAE Standard 62.2 for distributing outside air within the dwelling unit—i.e., providing all outdoor air through one supply register is compliant, although it is best practice to distribute it throughout the dwelling unit, particularly when the outside air is outside of thermostat set points. The manual should describe at least two options for how outside air can be distributed within the dwelling unit:

1. One example in which the ERV/HRV has its own duct work, and supply air is distributed to each bedroom and the living area, and
2. One example in which the ERV/HRV interfaces with the HVAC system, by ducting the supply air into the return plenum of the forced air system.

Section 4.6.1 – Compliance and Enforcement: The manual would stipulate that the HERS Rater must document the SRE or effectiveness and verify it is ≥67 and that fan efficacy is a value of 0.6 W/cfm or lower.

Section 4.6.3.3 – Multifamily Dwelling Unit Compartmentalization: The manual would describe the new requirement for an ERV or HRV in certain climate zones for projects following the balanced ventilation path.

NONRESIDENTIAL COMPLIANCE MANUAL

Sections 4.3.2 – High-Rise Residential Dwelling Unit Mechanical Ventilation: The manual would include language that summarizes the requirement. The manual would provide an overview of strategies to meet the requirement, including unitary HRVs or ERVs, and central HRVs or ERVs serving multiple dwelling units.

The manual would also include language recommending that, for all multifamily projects that install HRV or ERV (including in climate zones not regulated by this requirement), the HRV or ERV include a bypass function, or that the dwelling units have mechanical cooling, to prevent overheating. The purpose of this language is to promote thermal comfort for occupants. The manual would frame this guidance, so it is clear what is required, versus what is recommended. The current compliance manual uses this approach for other measures, such as Section 4.5.2.4 for Supply-Air Temperature Reset Control, which specifies certain set points for this measure and provides recommendations for how this can be achieved.

Section 4.3.2.5.3 – Multifamily Dwelling Unit Compartmentalization (which describes the balanced ventilation alternative to compartmentalization): The manual would describe that an ERV or HRV is required in certain climate zones for projects following the balanced ventilation path.

7.6 Compliance Documents

Several compliance documents would need to be revised. The intention of these revisions is to ensure that all new requirements are documented and verified in a way that is consistent with existing ventilation requirements. Some new documents may need to be created, but existing documents could also be expanded to capture the new information.

To determine which compliance documents would be affected, the Statewide CASE Team reviewed all 2019 compliance documents and flagged those with direct relevance to the newly proposed requirements. The tables below call out which documents would need what changes to cover the new requirements. The Statewide CASE Team has not specified exact language for the document updates, but rather highlighted the sections where final language, requirements, and procedures would need to be included.

In general, the proposed requirements would trigger small changes to HERS Rater verifications—such as verifying a few additional features in an HVI database compared to current requirements, and significant additions for ATT forms due to additional testing requirements for central ERV/HRV bypass functional testing and central ventilation duct leakage.

Table 75: Proposed Changes to Compliance Forms – CF1R

Form Group	Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
CF1R	2019-CF1R-NCB-01-E and 2019-CF1R-PRF-01E	Energy consultant	- Form would need to be adapted to include references to unitary (each serves one dwelling unit) and "central ERV/HRV" (each serves multiple dwelling units), and to document sensible recovery effectiveness and fan efficacy	Update HERS Feature Summary	N/A

Table 76: Proposed Changes to Compliance Forms – CF2R

Form Group	Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
CF2R	2019-CF2R-MCH-27b-Multifamily.pdf	Installing Contractor or HERS Rater	-Many locations: references to "mechanical supply system, exhaust system, or combination thereof" should be updated to include unitary and central ERV/HRV -**G. Other Requirements** would need to reflect ERV/HRV requirements -**H. Air Moving Equipment** would need to reflect ERV/HRV requirements	-**F. Other Requirements** would need to kitchen exhaust requirements	-**H. Air Moving Equipment** would need to reflect central shaft sealing requirements
CF2R	2019-CF2R-MCH-27c-SingleFamilyAndMultifamilyScheudledandRealTimeControl.pdf	Installing Contractor or HERS Rater	-**B. Other Requirements** would need to reflect ERV/HRV requirements -**C. Air Moving Equipment** would need to reflect ERV/HRV requirements	-**B. Other Requirements** would need to reflect kitchen exhaust requirements	-**C. Air Moving Equipment** would need to reflect central shaft sealing requirements

Form Group	Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
CF2R	2019-CF2R-MCH-30-VentilationCooling.pdf	Installing Contractor or HERS Rater	-A. Central Fan Ventilation Cooling System Equipment Information and B. Additional Requirements would need to be reconfigured to document unitary and central ERV/HRV w/ bypass	N/A	N/A
CF2R	2019-CF2R-MCH-32-LocalMechanicalExhaust.pdf	Installing Contractor or HERS Rater	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** would need to be reconfigured to document unitary and central ERV/HRV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** would need to add any new kitchen exhaust requirements and identify which path (capture efficiency, minimum airflow, or continuous exhaust) will be used for compliance -**C. Kitchen Exhaust System** would need to include fields for any new requirements	N/A

Table 77: Proposed Changes to Compliance Forms – CF3R

Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
2019-CF3R-MCH-27b-Multifamily.pdf	ATT/ HERS Rater	-Many locations: references to "mechanical supply system, exhaust system, or combination thereof" should be updated to include unitary ERV/HRV and central ERV/HRV -**G. Other Requirements** would need to reflect ERV/HRV requirements -**H. Air Moving Equipment** would need to reflect ERV/HRV requirements—verify nominal SRE and fan efficacy (nominal fan Watt draw / nominal airflow) meets or is better than CF1R claim	-**F. Other Requirements** would need to reflect kitchen exhaust requirements	-**H. Air Moving Equipment** would need to reflect central shaft sealing requirements
2019-CF3R-MCH-27c-SingleFamilyAndMultifamilySc heudledandRealTimeControl.pdf	ATT/ HERS Rater	-**B. Other Requirements** would need to reflect ERV/HRV requirements -**C. Air Moving Equipment** would need to reflect ERV/HRV requirements	-**B. Other Requirements** would need to reflect kitchen exhaust requirements	-**C. Air Moving Equipment** would need to reflect central shaft sealing requirements
2019-CF3R-MCH-32-LocalMechanicalExhaust.pdf	ATT/ HERS Rater	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** would need to be reconfigured to document unitary or central ERV/HRV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** would need to add any new kitchen exhaust requirements -**C. Kitchen Exhaust System** would need to include fields for any new requirements	N/A

Table 78: Proposed Changes to Compliance Forms – NRCC

Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
2019-NRCC-MCH-E.pdf	Energy Consultant	-Any new NRCI & NRCA forms would need to be added	-Any new NRCI & NRCA forms would need to be added	-Any new NRCI & NRCA forms would need to be added
2019-NRCC-PRF-01-E.pdf	Energy Consultant	-Information about ERV/HRV SRE, bypass would need to be displayed on form	New NRCA/NRCI/NRCV forms would need to be added to required forms section	-Forms would need to indicate whether central shafts requiring sealing verification are present. - New NRCA/NRCI/NRCV forms would need to be added to required forms section

Table 79: Proposed Changes to Compliance Forms – NRCA

Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
2019-NRCA-MCH-02-A Outdoor Air.pdf	ATT	-A. Construction Inspection would need AT procedure for ERV/HRV verification	N/A	N/A
2019-NRCA-MCH-04a-H-AirDistribution DuctLeakage.pdf	ATT	N/A	N/A	Applicable to multifamily occupancies only: -A. Construction Inspection would need to include requirements for central shafts that is distinct from heating/cooling systems. -B. Functional Testing would need procedure for testing central shafts that is distinct from existing procedure for recirculating systems.
2019-NRCA-MCH-04b-A-AirDistribution DuctLeakage.pdf	ATT	N/A	N/A	Applicable to multifamily occupancies only: -A. Construction Inspection would need to include requirements for central shafts that is distinct from heating/cooling systems. -B. Functional Testing would need procedure for testing central shafts that is distinct from existing procedure for recirculating systems.
2019-NRCA-MCH-20-H-MultifamilyVentilation.pdf	ATT	-A. Construction Inspection would need to include new ERV/HRV requirements.	-A. Construction Inspection would need to include new kitchen exhaust requirements.	-A. Construction Inspection would need to include requirements for central shafts that is distinct from heating/cooling systems. -B. Functional Testing would need procedure (and requirements) for testing central shafts that is distinct from existing procedure for recirculating systems.

Table 80: Proposed Changes to Compliance Forms – NRCV

Form Group	Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
NRCV	2019-NRCV-MCH-04a-DuctLeakageTest-NewConst.pdf	HERS Rater	N/A	N/A	N/A (since HERS Raters will not verify this measure)
NRCV	2019-NRCV-MCH-27b-HighriseResidential.pdf	HERS Rater	-Many locations: references to "mechanical supply system, exhaust system, or combination thereof" should be updated to include unitary ERV/HRV -**H. Other Requirements** would need to reflect ERV/HRV requirements -**I. Air Moving Equipment** would need to reflect ERV/HRV requirements	-H**. Other Requirements** will need to reflect kitchen exhaust requirements	N/A
NRCV	2019-NRCV-MCH-27c-HighriseResidentialHighriseResidScheduledRealTimeControl.pdf	HERS Rater	-**C. Other Requirements** would need to reflect ERV/HRV requirements -**D. Air Moving Equipment** would need to reflect ERV/HRV requirements	-**C. Other Requirements** would need to reflect kitchen exhaust requirements	N/A

Form Group	Compliance Form	Who completes?	ERV/HRV	Kitchen Exhaust	Central Shaft Sealing
NRCV	2019-NRCV-MCH-32-LocalMechanicalExhaust.pdf	HERS Rater	-B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance would need to be reconfigured to document unitary ERV/HRV	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** would need to add any new kitchen exhaust requirements -**C. Kitchen Exhaust System** would need to include fields for any new requirements	N/A

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Appendix A: Statewide Savings Methodology

The Statewide CASE Team estimated statewide impacts for the first year by multiplying per-unit savings estimates by statewide construction forecasts that the Energy Commission provided (California Energy Commission 2019). The Statewide CASE Team made assumptions about the percentage of buildings in each climate zone that will be impacted by the proposed code change. Table 81 presents the number of dwelling units, both newly constructed and existing, that the Statewide CASE Team assumed will be impacted by the proposed code change during the first year the 2022 code is in effect.

For the ERV/HRV measure, the Statewide CASE Team assumes that 20 percent of multifamily buildings will comply with indoor air quality requirements for either balanced ventilation or compartmentalization (2019 Title 24, Part 6 Section 120.1(b)2Aiv for high-rise and 150.(o)E for low-rise) through compartmentalization and the remaining 80 percent will comply through installation of an ERV or HRV. Thus, the ERV/HRV measure is applicable to 80 percent of new construction multifamily buildings. This measure is only applicable to altered or replaced ventilation equipment in an alteration in a low-rise multifamily building. Due to cost-effectiveness results, the Statewide CASE Team is proposing this measure in all climate zones except Climate Zone 3 through Climate Zone 10.

Table 81: ERV/HRV Estimated New Construction and Existing Building Stock for Multifamily Buildings by Climate Zone

Building Climate Zone	New Construction in 2023 (number buildings)			Existing Building Stock in 2023 (number of buildings)		
	Total Buildings Completed in 2023 [A]	Percent of New Buildings Impacted by Proposal [B]	Buildings Impacted by Proposal in 2023 C = A x B	Total Dwelling Units Completed in 2020 [D]	Percent of Existing Buildings Impacted by Proposal [E]	Buildings Impacted by Proposal in 2023 F = D x E
1	265	80%	212	17,126	0%	0
2	1,573	80%	1,258	101,721	0%	0
3	7,630	0%	0	530,089	0%	0
4	3,975	0%	0	278,535	0%	0
5	706	0%	0	44,816	0%	0
6	3,370	0%	0	315,784	0%	0
7	3,623	0%	0	291,804	0%	0
8	4,738	0%	0	489,337	0%	0
9	11,124	0%	0	1,086,699	0%	0
10	3,930	0%	3,144	316,384	0%	0
11	1,122	80%	898	81,820	0%	0
12	6,335	80%	5,068	455,265	0%	0
13	1,849	80%	1,479	154,048	0%	0
14	840	80%	672	79,142	0%	0
15	547	80%	438	40,033	0%	0
16	339	80%	271	27,505	0%	0
TOTAL	51,966	20%	10,296	4,310,108	0%	0

The kitchen exhaust minimum capture measure is applicable to all new construction multifamily buildings in all climate zones. Consequently, 100 percent of new construction multifamily buildings will be impacted by the measure.

Table 82: Kitchen Exhaust Minimum Estimated New Construction and Existing Building Stock for Multifamily Buildings by Climate Zone

Building Climate Zone	New Construction in 2023 (number buildings)			Existing Building Stock in 2023 (number of buildings)		
	Total Buildings Completed in 2023 [A]	Percent of New Buildings Impacted by Proposal [B]	Buildings Impacted by Proposal in 2023 C = A x B	Total Dwelling Units Completed in 2020 [D]	Percent of Existing Buildings Impacted by Proposal [E]	Buildings Impacted by Proposal in 2023 F = D x E
1	265	100%	265	17,126	0%	0
2	1,573	100%	1,573	101,721	0%	0
3	7,630	100%	7,630	530,089	0%	0
4	3,975	100%	3,975	278,535	0%	0
5	706	100%	706	44,816	0%	0
6	3,370	100%	3,370	315,784	0%	0
7	3,623	100%	3,623	291,804	0%	0
8	4,738	100%	4,738	489,337	0%	0
9	11,124	100%	11,124	1,086,699	0%	0
10	3,930	100%	3,930	316,384	0%	0
11	1,122	100%	1,122	81,820	0%	0
12	6,335	100%	6,335	455,265	0%	0
13	1,849	100%	1,849	154,048	0%	0
14	840	100%	840	79,142	0%	0
15	547	100%	547	40,033	0%	0
16	339	100%	339	27,505	0%	0
TOTAL	51,966	100%	51,966	4,310,108	0%	0

The central ventilation duct sealing requirement will only impact multifamily buildings with central ventilation ducts. The Statewide CASE Team reviewed data from 38 midrise and high-rise multifamily buildings from Gabel Energy to determine the percentage of multifamily buildings that have central ventilation ducts. This data analysis is described in 6.3.1. Based on this data, the Statewide CASE Team assumed that 39 percent of midrise and 60 percent of high-rise dwelling units have central ventilation ducts. The Statewide CASE Team used industry judgment to assume that 10 percent of both low-rise prototypes use central ventilation ducts. Therefore, low rise buildings contribute a small percentage of savings while mid and high rise buildings contribute a much larger percentage of savings. Table 83 summarizes these assumptions.

Table 83: Percent of Dwelling Units Meeting Central Ventilation Duct Requirements by Prototype

Prototype	Percentage
Low-Rise Garden Style	10%
Low-Rise Loaded Corridor	10%
Mid-Rise Mixed Use	39%
High-Rise Mixed Use	60%

The Statewide CASE Team calculated statewide savings from this measure as shown in Table 84.

Table 84: Central Ventilation Duct Sealing Estimated New Construction and Existing Building Stock for Multifamily Buildings by Climate Zone

Building Climate Zone	New Construction in 2023 (number buildings)			Existing Building Stock in 2023 (number of buildings)		
	Total Buildings Completed in 2023 [A]	Percent of New Buildings Impacted by Proposal [B]	Buildings Impacted by Proposal in 2023 C = A x B	Total Dwelling Units Completed in 2020 [D]	Percent of Existing Buildings Impacted by Proposal [E]	Buildings Impacted by Proposal in 2023 F = D x E
1	265	29%	77	17,126	0%	0
2	1,573	29%	455	101,721	0%	0
3	7,630	29%	2,207	530,089	0%	0
4	3,975	29%	1,150	278,535	0%	0
5	706	29%	204	44,816	0%	0
6	3,370	29%	975	315,784	0%	0
7	3,623	29%	1,048	291,804	0%	0
8	4,738	29%	1,370	489,337	0%	0
9	11,124	29%	3,217	1,086,699	0%	0
10	3,930	29%	1,137	316,384	0%	0
11	1,122	29%	324	81,820	0%	0
12	6,335	29%	1,832	455,265	0%	0
13	1,849	29%	535	154,048	0%	0
14	840	29%	243	79,142	0%	0
15	547	29%	158	40,033	0%	0
16	339	29%	98	27,505	0%	0
TOTAL	51,966	29%	15,028	4,310,108	0%	0

Appendix B: Embedded Electricity in Water Methodology

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

Appendix C: Environmental Impacts Methodology

Greenhouse Gas (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 (EPA 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 of 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) (EPA 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 million therms.

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/MTCO_2e.

Water Use and Water Quality Impacts Methodology

There are no impacts to water quality or water use.

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

8.1 Submeasure A: ERV/HRV

The compliance software already has the following features:

- Ability to model an ERV and an HRV.
- Ability to change the sensible recovery efficiency.
- Ability to differentiate between unitary and central ERV or HRV. And
- If the user chooses central equipment, the software provides different inputs for sensible and latent recovery, to provide additional energy savings if the user proposes equipment with higher recovery than the standard.

The following revisions would need to be added to the compliance software:

- Change the default SRE to 67 percent for multifamily projects that choose a balanced system in California Climate Zones 1-2 and 11-16.
- Include a bypass function as the default option for central HRV or ERV in projects that choose a balanced system in California Climate Zones 1-2 and 11-16.
- Add the ability for the user to add bypass to the proposed design for unitary HRV or ERV equipment in both CBECC-Comm and CBECC-Res.
- Adjust the heating and cooling capacity auto sizing to account for reduced capacity needs due to addition of an HRV or ERV in the Standard Design.

The user inputs would include the following:

- A “grayed out” SRE value in the Standard Design for multifamily projects that choose a balanced system in California Climate Zones 1-2 or 11-16.
- Checks, including an error if the proposed equipment has an SRE lower than 67 percent or if the proposed design has a central HRV or ERV without bypass. These checks should only be identified if the multifamily project chooses a balanced system in California Climate Zones 1-2 or 11-16.

In addition, this analysis assumed different infiltration assumptions than CBECC-Comm and the Nonresidential ACM for the midrise and high-rise prototype, using a literature review of air leakage data from multifamily buildings. CBECC-Comm and the Nonresidential ACM would need to be revised to assume new infiltration values. Section 4.1.2 shows that the infiltration assumptions have a major impact on energy savings from this measure, and Appendix G shows that the infiltration rates assumed in

CBECC-Comm are much lower than measured infiltration of newly constructed multifamily buildings. Projects will not estimate the same energy savings from this measure from CBECC-Comm software that this analysis found if the infiltration assumptions are not increased.

The Statewide CASE Team proposed a minimum sensible recovery efficiency (SRE) value for unitary ERVs/HRVs since this is currently used in CBECC-Res software and a minimum sensible recovery effectiveness value for central ERVs/HRVs since this is currently used in CBECC-Com software. The Energy Commission may shift to an Adjusted Sensible Recovery Efficiency (ASRE) accounts for HRV and ERV fan or blower energy as a separate input. The Statewide CASE Team recommends that Energy Commission compare the SRE and ASRE for a sample of ERV and HRV equipment with MERV 13 filtration to determine a minimum set point for the prescriptive requirement.

8.2 Submeasure B: Kitchen Exhaust Minimum Capture

The proposed requirement would not result in any changes.

8.3 Submeasure C: Central Ventilation Duct Sealing

The Statewide CASE Team recommends that the compliance software be updated so that the assumptions in CBECC-Comm aligns more with the values assumed for this analysis. This should be done by adjusting the following modeling inputs:

- DesignSpecification: OutdoorAir. The ventilation system flow rate should change so that the ventilation air provided at the central (typically rooftop) fan is enough so that (given the leakage allowed by this measure) the dwelling unit airflow rate requirement is met. The default value should assume 10 percent leakage at 125 Pa (0.5 inches w.c.). For example, a building for which dwelling units need 5,000 cfm of airflow should deliver 5,500 cfm of airflow at the rooftop.
- Fan: ConstantVolume. The static pressure assumed in the Nonresidential ACM for a DOAS system (950 Pa) was found to be higher than what this analysis found based on a review of central fans used in California Multifamily New Homes (CMFNH) projects (average of 280 cfm) reviewed by the Statewide CASE Team. The Statewide CASE Team recommends that the Energy Commission adjust the static pressure for this assumption to a default of 125 Pa for a building

with *either* central ventilation or central exhaust ducts[20]; and a default of 250 Pa for a building with *both*. This will prevent the software from overestimating savings from this measure.

The Energy Commission could also consider adding an input for “leakage assumption” so that the user can adjust the percent of leakage in the central ventilation ducts affected by this proposal. While the proposed measure is mandatory, and an error message should be generated if the user enters a leakage value higher than the allowable value, this will allow users to enter a lower leakage value than the requirement if the leakage test results indicate the ducts were tighter than allowed.

[20] As a reminder, this measure would only apply to central exhaust ducts that carry continuous airflows or airflows that are part of a balanced ventilation system, but not intermittent airflows such as kitchen or dryer exhaust.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.3.5, could impact various market actors. Table 85, Table 86, and Table 87 identify the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. The information contained in Appendix F 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.

Table 85: Roles of Market Actors in the Proposed Compliance Process – ERV/HRV

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Mechanical Designer	• Select compliance path for ventilation system • Perform minimum ventilation flowrate calculations • Select ERV/HRV equipment to meet filtration, flowrate, SRE, and (if central) bypass requirements. • Layout ductwork for ERV/HRV system • Review submittals during bid/VE and construction. • Coordinate with commissioning agent/ATT as necessary.	• Quickly and easily determine requirements based on scope. • Easily identify compliant ventilation products • Streamline coordination with other team members. • Clearly communicate system requirements to builder. • Easily identify noncompliant substitutions. • Minimize coordination during construction.	• Will need to more carefully review ventilation product documentation to ensure all requirements are met. • Will need to include new information in design documents so that energy consultant (if separate party) can model to comply via performance path.	• Modeling software will need to be updated to easily model different configurations, include central ventilation systems combined with individual heating/cooling systems.
Plans Examiner	• Identify relevant requirements. • Confirm data on documents is compliant. • Confirm plans/specifications match data on documents. • Provide correction comments if necessary. •	• 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 will resolve issue.	Will need to verify new equipment requirements are met.	Record equipment information 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
Installing Contractor	• Submit specified system or compliant alternate • Install system per design • Test system to ensure design flowrates are delivered • Document installation via CF2R/NRCI form	• Quickly and easily determine requirements so that any substitution requests can also comply • Understand and execute design and operation requirements, including programming of bypass temperature range. • Quickly and easily complete CF2R/NRCI documentation	• Will need to consider new compliance requirements (SRE, bypass) when suggesting substitutions. • Will need to appropriately program bypass function for systems that have it.	• Compliance outputs could include bypass outdoor air temperature range, as well as other requirements in case design engineer omits from plans

Table 86: Roles of Market Actors in the Proposed Compliance Process – Kitchen Exhaust

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Mechanical Designer	• Select kitchen ventilation equipment that meets either capture efficiency or flowrate requirements. • Layout ductwork to minimize pressure drop. • Confirm California Mechanical Code Chapter 7 will be met. • Review submittals during bid/VE and construction. • Coordinate with commissioning agent/ATT as necessary.	• Quickly and easily determine requirements based on scope. • Easily identify compliant ventilation products • Streamline coordination with other team members. • Clearly communicate system requirements to builder. • Easily identify noncompliant substitutions. • Minimize coordination during construction.	Will need to more carefully review ventilation product documentation to ensure all requirements are met.	Compliance documents should indicate which kitchen ventilation compliance path a project is taking.
Plans Examiner	• Identify relevant requirements. • Confirm data on documents is compliant. • Confirm plans/specifications match data on documents. • Provide correction comments if necessary. •	• 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 will resolve issue.	Will need to verify new equipment requirements are met.	Record equipment information 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
Installing Contractor	• Submit specified system or compliant alternate • Install system per design • Test system to ensure design flowrates are delivered • Document installation via CF2R/NRCI form. • Develop ventilation information in accordance with Section 10-103	• Quickly and easily determine requirements so that any substitution requests can also comply • Quickly and easily complete CF2R/NRCI documentation	Will need to consider new compliance requirements when suggesting substitutions.	Compliance documents could indicate which kitchen ventilation pathway a project is taking.
ATT	• Conduct functional testing of bypass function on central ERVs/HRVs	• Confirm the equipment operates per NA 7.5.4 Air Economizer Controls to reduce fan energy use during cooling periods	Will need to conduct functional testing after equipment is installed and commissioned	This Final CASE Report proposes the same functional testing as the Nonres HVAC CASE Report, reducing training needs

Table 87: Roles of Market Actors in the Proposed Compliance Process – Central Ventilation Duct Sealing

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Mechanical Designer	• Specify duct sealing materials and methods appropriate to achieve required tightness. • Review submittals during bid/VE and construction. • Coordinate with commissioning agent/ATT as necessary.	• Quickly and easily determine requirements based on scope. • Easily identify appropriate duct sealing materials & methods • Streamline coordination with other team members. • Clearly communicate sealing requirements to builder. • Easily identify inappropriate substitutions. • Minimize coordination during construction.	Will need to more carefully specify duct sealing materials and methods to ensure all requirements are met.	Compliance Manuals should be updated with recommended approaches to achieve tight central shaft ductwork and meet leakage targets.
Plans Examiner	• Identify relevant requirements. • Confirm plans/specifications match data on documents. • Provide correction comments if necessary. •	• 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 will resolve issue.	Minimal impact	N/A

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
Installing Contractor	• Submit specified duct sealing materials or compliant alternate • Seal ducts per specifications • Test ducts to ensure required tightness is achieved • Document installation via CF2R/NRCI form	• Quickly and easily determine requirements so that any substitution requests can also comply • Seal ducts sufficiently the first time and avoid testing and re-sealing. • Quickly and easily complete CF2R/NRCI documentation	• Will need to increase time spent on duct sealing to meet targets. • Will need to test ducts before closing walls to ensure targets can be met at final testing by HERS Rater/ATT.	• Compliance Manuals should be updated with recommended approaches to achieve tight central shaft ductwork, including any intermediate testing recommendations for installing contractors.
ATT	Tests central shaft leakage at final completion and document results on CF3R/NRCA	Quickly and easily determine requirements and which systems need to be tested	Will need to test leakage of central shafts in addition to in-unit duct systems	Compliance forms could indicate exactly how many different central shafts are subject to sealing requirements.

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 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 asked 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 two stakeholder meeting for MF IAQ via webinars, as documented on the event pages on Title24Stakeholders.com. The Energy Commission also hosted an IAQ Workshop to discuss research regarding pollution from cooking and cooking appliances in the context of the range hood proposal.

Table 88: Schedule for Stakeholder Meetings

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
First Round of Multifamily HVAC and Envelope Utility-Sponsored Stakeholder Meeting	August 22, 2019	https://title24stakeholders.com/event/multifamily-hvac-and-envelope-utility-sponsored-stakeholder-meeting/
Second Round of Multifamily HVAC and Envelope Utility-Sponsored Stakeholder Meeting	March 25, 2020	https://title24stakeholders.com/event/multifamily-hvac-and-envelope-utility-sponsored-stakeholder-meeting/
IAQ Workshop (Energy Commission hosted)	September 30, 2020	

The first round of utility-sponsored stakeholder meetings occurred from August 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 May 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.

The IAQ workshop provided additional research and stakeholder comments related to the range proposal.

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[21]

[21] Title 24 Stakeholders' LinkedIn page can be found here: https://www.linkedin.com/showcase/title-24-stakeholders/.

(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 into 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 and phone with numerous stakeholders when developing this report.

8.4 Submeasure A: ERV/HRV

The Statewide CASE Team gathered feedback from several stakeholders, including several mechanical engineers who specialize in multifamily construction and manufacturers of HVAC equipment.

Table 89: Stakeholders that Provided Feedback for ERV/HRV Submeasure

Company	Role	Primary Contact
Energy 350	Mechanical Engineer	Meg Waltner
Smith Group	Mechanical Engineer	Stet Sanborn
EBTRON	Manufacturer	Darryl DeAngelis
Greentek	Manufacturer	William LeBlanc
Alter Consulting Engineers	Mechanical Engineer	Stefan Gracik
Newport Ventures	Mechanical Engineer and code consultant	Mike Moore
Association of Home Appliance Manufacturers	Manufacturer	Randall Cooper
Emerald City Engineers	Mechanical Engineer	John Toman
Gabel Energy	HERS Rater and energy consultant	Gina Rodda
North America Passive House Network	HERS Rater and energy consultant	Barry Bronwyn

8.5 Submeasure B: Kitchen Exhaust Minimum Capture

In addition to the broader stakeholder meeting covering all three submeasures on August 22, 2019, the Statewide CASE Team held a conference call with stakeholders on this particular submeasure on October 2, 2019. The agenda is shown below:

- Objectives for proposed requirement.
- How the HVI schedule for publishing test results coincides with the rulemaking schedule and the need for a grace period.
- Range of airflows, static pressures, and noise levels for currently listed hoods (stand-alone versus microwave).
- Adequacy of listed static pressures for representing airflow of installed hoods and possible tests needed.
- Maximum exposure to be used for identifying a target capture efficiency.
- Definition of rating points (CFM, static pressure, noise).
- Review and discussion of alternative compliance approaches.
- Straw man code language for 2022 Title 24, Part 6 requirement.

The stakeholder meeting included primarily manufacturers, Home Ventilating Institute (HVI) and Association of Home Appliance Manufacturers (AHAM) representatives, and staff from Lawrence Berkeley National Laboratory (LBNL), Energy Commission, and California Air Resources Board to elicit feedback.

Table 90: Stakeholder Participants in Kitchen Exhaust System Proposal Discussion on October 2, 2019

Name	Affiliation	Attendee Type
Payam Bororgchami	Energy Commission	Energy Commission
Jeff Miller and support staff	Energy Commission	Energy Commission
Jon McHugh	McHugh Energy Consultants	Statewide CASE Team
Zoe Zhang	CA Air Resources Board	Government
Bobby Windmeyer	HVI	Industry Representative
John Rose	HVI	Industry Representative
Randy Cooper	AHAM	Industry Representative
John Park	AHAM	Industry Representative
Russell Pope	Panasonic	Industry Representative
Stephen Gatz	Whirlpool	Industry Representative
Daniel Forest	Venmar	Industry Representative
Mike Moore	Newport Ventures	Industry Representative
Jim Sweeney	Texas A&M	Researcher
Rengie Chan	LBNL	Researcher
Dave Springer	Frontier Energy	Statewide CASE Team
Marian Goebes	TRC	Statewide CASE Team

The Statewide CASE Team also held phone meetings with several stakeholders in response to their comments on the Draft CASE Report for this submeasure, including staff members from Rocky Mountain Institute, AHAM, Natural Resources Defense Council, and Guttmann & Blaevoet.

8.6 Submeasure C: Central Ventilation Duct Sealing

The Statewide CASE Team held several communications with members of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) and other trade associations, including one in-person meeting on October 16, 2019.

Table 91: Attendees of Central Ventilation Shaft Sealing Discussion on October 16, 2019

Name	Affiliation	Attendee Type
Mark Alatorre	PG&E	Statewide CASE Team
Marian Goebes	TRC	Statewide CASE Team
Heidi Werner	Energy Solutions	Statewide CASE Team
Benny Zank	Energy Solutions	Statewide CASE Team
John Barbour	SDG&E	Statewide CASE Team
Jeremy Reefe	SDG&E	Statewide CASE Team
James Kemper	LADWP	Statewide CASE Team
Bob Grindrod	TRC	Statewide CASE Team
Mark Modera	WCEC	Statewide CASE Team
Jeff Miller	Energy Commission	Energy Commission
Payam Bozorgchami	Energy Commission	Energy Commission
Chang Moua	Energy Commission	Energy Commission
Dave Dias	Sheet Metal Workers 104	Industry Representative
Duane Davies	Cal SMACNA	Industry Representative
Thomas Enslow	SMACNA – counsel	Industry Representative
Chris Walker	Cal SMACNA	Industry Representative
Chris Ruch	NEMI	Industry Representative
Eli Howard	SMACNA (national)	Industry Representative
Mark Terzigni	SMACNA (national)	Industry Representative

The Statewide CASE Team also received input from subject matter experts Iain Walker (LBNL), Andy Brooks (AEA), Mark Modera (WCEC at UC Davis), Duane Davies (National Air Balance Company), and Mark Terzigni (SMACNA).

In addition, the Statewide CASE Team collaborated with the Nonresidential Duct Sealing CASE Team during development of the proposal.

Appendix G: Infiltration Assumptions and Multifamily Building Leakage Data

The Statewide CASE Team is providing this appendix with:

1. Background on where the ASHRAE 90.1 and Nonresidential ACM Reference Manual infiltration assumptions come from
2. Infiltration data based on actual building measurements, which indicates that the Nonresidential ACM Reference Manual infiltration assumptions are much lower (i.e., tighter) than actual leakage
3. Plan for the Statewide CASE Team to use an adjustment factor for the Final CASE Report analysis, and suggested research to inform an ACM Reference Manual update
4. Appendix: An explanation (from John McHugh) of why the infiltration assumption has a significant impact on the proposed ERV/HRV measure.

Background on ASHRAE 90.1 and Title 24 / Nonresidential ACM Assumptions

Both ASHRAE 90.1 and the Nonresidential ACM Reference Manual assume 0.4cfm75/ft^2. But ASHRAE 90.1 assumes 0.4 cfm75 per square foot of envelope, whereas Nonresidential ACM Reference Manual assumes 0.4cfm75 per square foot of walls, so CBECC-Comm assumes less leakage.

Both ASHRAE 90.1 and Title 24, Part 6/ Nonresidential ACM Reference Manual assumptions are based on the same permeance factors. As shown in 2019 Title 24, Part 6 Section 140.3.9, the materials must have an air permeance no greater than 0.004 cfm75/ft^2 of material, the assembly must have an air leakage value no greater than 0.04 cfm/ ft^2 of assembly, and the entire building must have a leakage rate no greater than 0.4 cfm/ ft^2—not specified as to whether this is ft$_2$ of wall area or total envelope area. Since the material and assembly requirements apply to the roof and floor, the Statewide CASE Team's interpretation would be that (as is done in ASHRAE 90.1) the 0.4 cfm/ft^2 would be based on ft$_2$ of envelope area, not wall area only.

From 2019 Title 24, Part 6 Section 140.3.9:

9. **Air Barrier**. To meet the requirement of TABLE 140.3-B, all buildings shall have a continuous air barrier that is designed and constructed to control air leakage into, and out of, the building's conditioned space. The air barrier shall be sealed at all joints for its entire length and shall be composed of:

   A. Materials that have an air permeance not exceeding 0.004 cfm/ft^2, under a pressure differential of 0.3 in. of water (1.57 psf) (0.02 L/(sec-m^2) at 75 pa), when tested in accordance with ASTM E2178; or

B. Assemblies of materials and components that have an average air leakage not exceeding 0.04 cfm/ft^2, under a pressure differential of 0.3 in. of water (1.57 psf) (0.2 L/m^2 at 75 pa), when tested in accordance with ASTM E2357, ASTM E1677, ASTM E1680, or ASTM E283; or

C. The entire building has an air leakage rate not exceeding 0.40 cfm/ft^2 at a pressure differential of 0.3 in of water (1.57 psf) (2.0 L/ m^2 at 75 pa), when the entire building is tested, after completion of construction, in accordance with ASTM E779 or another test method approved by the Commission.

Building Leakage Data

The Statewide CASE Team agree with the Energy Commission that it is more critical to assume a leakage rate that aligns with actual leakage data, rather than with ASHRAE 90.1 assumptions.

- ASHRAE 90.1 references a PNNL method (Gowri, Winiarski and Jarnagin 2019), which cites a NIST (2005) paper for leakage data: “The Envelope Subcommittee recommended a baseline infiltration rate of 1.8 cfm/ft^2 (@ 0.3 in. w.c.) of exterior above grade envelope surface area, based on the average air tightness levels summarized in the National Institute of Standards and Technology (NIST) report” (Emmerich, McDowell and Anis 2005).
- The NIST (2005) paper included a literature review of infiltration values and found the average for Canadian apartment buildings was 0.61 cfm/ft^2) all at 75 Pa, normalized by above-grade envelope surface area.

While the Statewide CASE Team do not have infiltration data specific to California, here are two other more recent field studies that measured infiltration.

The first is a study done by Center for Energy and Environment (CEE) and Ecotope of 16 newly constructed multifamily buildings in the U.S. All buildings had common corridors, although they were low-rise. The Statewide CASE Team assumes the results would be similar to at least midrise multifamily in California, since all midrise multifamily buildings in the market research the Statewide CASE Team found to develop prototypes were stick framed for the dwelling units (either all the way through the building or above the podium, where the dwelling units are). Also, see results from an RDH study further in this section that found little correlation between leakage and number of stories.

From p. 4, the median whole building leakage value was 1.3 ACH50. Fifteen of the 16 buildings tested had a leakage value >=1 ACH50, whereas CBECC Comm’s assumption equates to 0.68 ACH50 for the midrise prototype. There is an arrow to show the 0.68 ACH50 that CBECC-Comm calculates for the midrise prototype (see the attached calculations for that conversion from the Infiltration factor).

Whole building exterior leakage ranges from 0.4 to 3.3 ACH50 with a median of 1.3 ACH50. The leakage for only the residential portion of the buildings ranges from 0.4 to 3.2 ACH50 with a median 1.4 ACH50. Common area leakage computed by subtracting residential portion from total. Common area leakage ranges from 0.4 to 6.2 ACH50 with a median of 1.9 ACH50 (chart below).

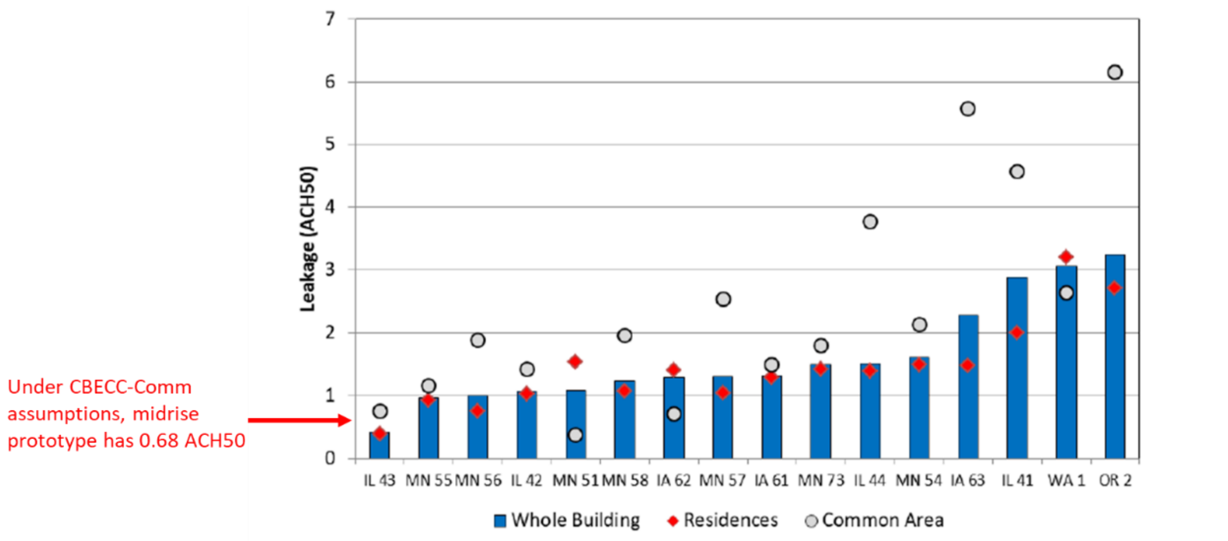

Figure 30: Multifamily leakage (measured at the whole building level) compared to CBECC-Comm infiltration assumption.

Source: (Center for Energy and Environment 2020)

The graph above shows *whole building* leakage results. The graph below (from p. 6) shows *dwelling unit* leakage results, for those same buildings. California's only leakage requirement for multifamily buildings—**the compartmentalization value of 0.3 cfm50/ft^2 dwelling unit enclosure area corresponds to 6 to 7 ACH50 of dwelling unit leakage*, which is leakier than the median found in their study: 4.57 ACH50 of dwelling unit leakage**. The Statewide CASE Team added the red dot for the leakage value that Title 24's 0.3 cfm50/ft^2 corresponds to. Note that, because many California buildings may do balanced ventilation instead, those buildings are likely even leakier than 0.3 cfm50/ft^2.

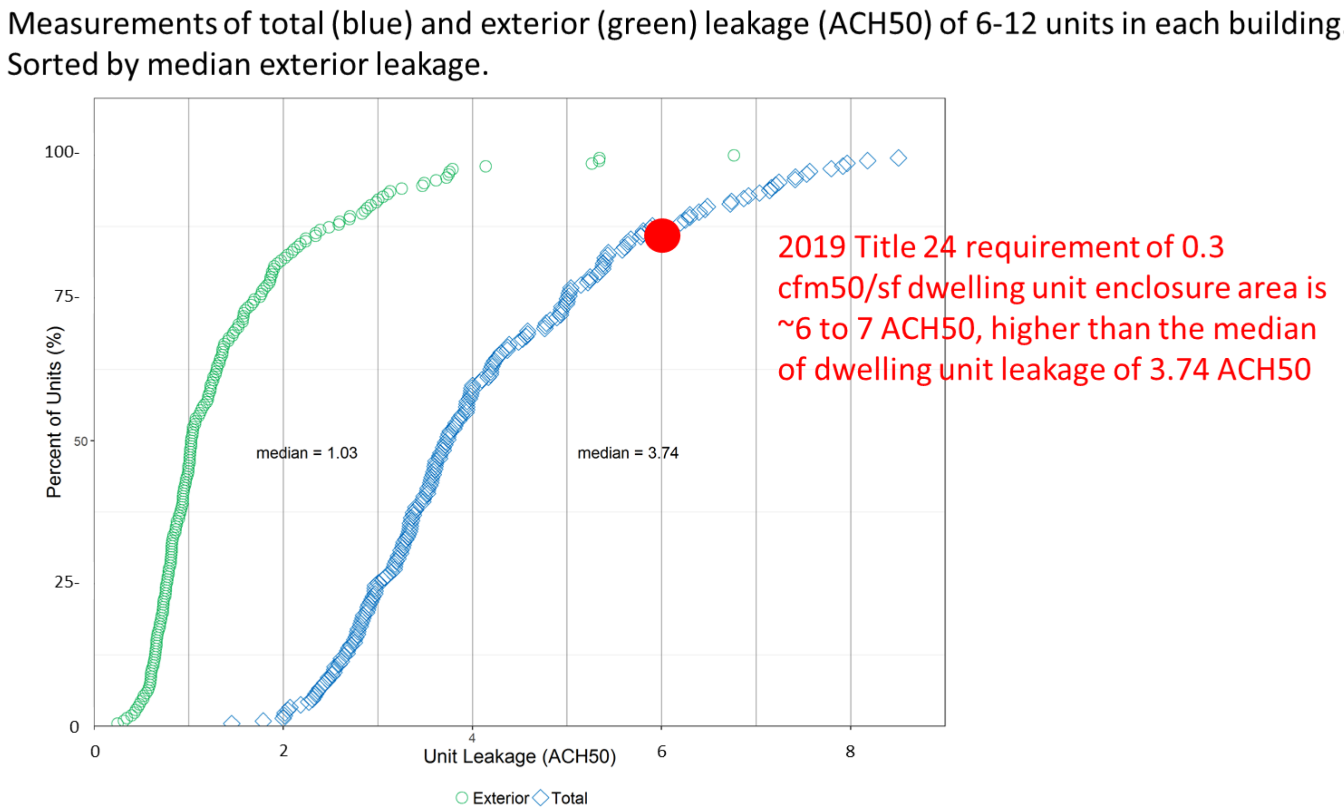

Figure 31: Leakage results in multifamily dwelling units: total envelope leakage and exterior leakage only.

Source: (Center for Energy and Environment 2020)

The other field study, conducted by RDH, (RDH, Air Leakage Control in Multi-Unit Residential Buildings 2017) measured leakage in multiunit residential buildings (what they term “MURBs”)—primarily in Canada. They found that older air barriers are leakier. The median for all MURBs was 0.72, but for newer air barriers, the median appears to be between 0.4 or 0.5 cfm75/ft^2 building envelope area. The Statewide CASE Team converted the cfm75/ft^2 of wall area assumed from the Nonresidential ACM to cfm75/ft^2 of total envelope area to align with how the data is presented. **The leakage value assumed by the Nonresidential ACM for the midrise prototype (red arrow) is 0.17 cfm/ft^2 envelope area, which is the tightest building in the RDH data set**. The leakage value assumed by the Nonresidential ACM for the high-rise prototype (purple arrow) is 0.27 cfm75/ft^2 envelope area, which is also very low compared to the data.

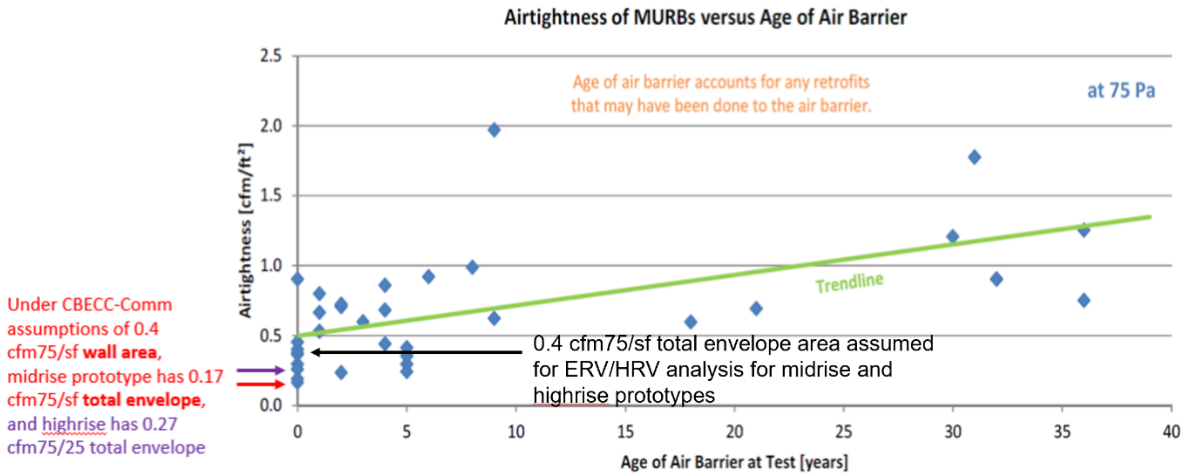

Figure 32: Airtightness of multifamily buildings versus age of air barrier.

Source: (RDH, Air Leakage Control in Multi-Unit Residential Buildings 2017)

RDH also found little change in tightness with number of stories for multifamily buildings, although there's a slight downward trend (slightly tighter for taller buildings).

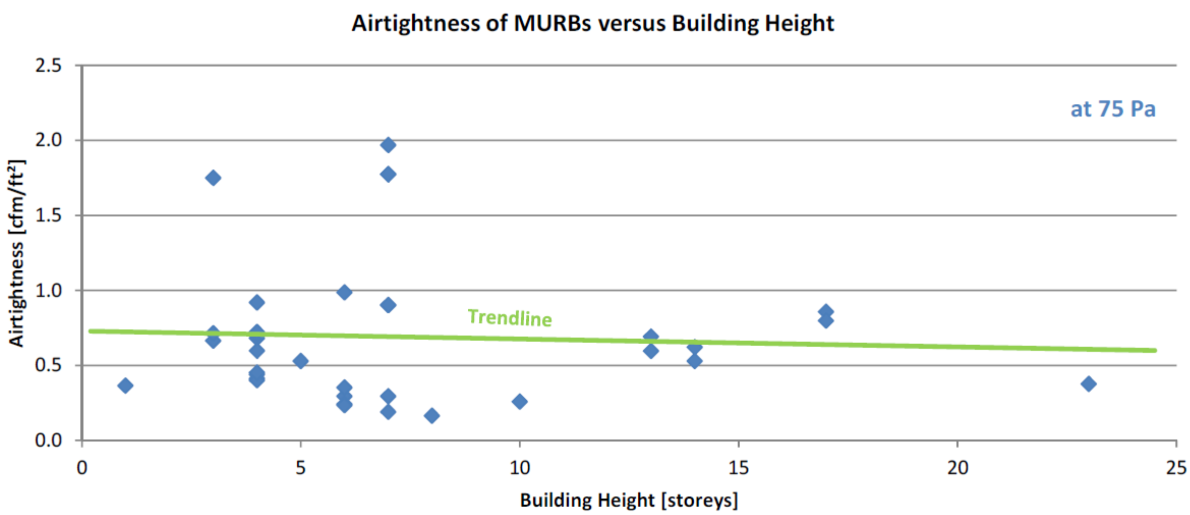

Figure 33: Airtightness of multifamily buildings versus building height.

Source: (RDH, Air Leakage Control in Multi-Unit Residential Buildings 2017)

All leakage data in these graphs indicate that the infiltration assumption in the Nonresidential ACM Reference Manual is much too low. The graphs indicate that the assumption of 0.4 cfm/ft^2 envelope area may be a conservative value but provide step in the right direction. In addition, in the latest version of Appendix G of ASHRAE 90.1, the new default leakage rate is 0.6 cfm/ft^2 at 75 Pa of the building envelope (so has increased / loosened).

ii. Approach for CASE analysis for ERV/HRV and high performance walls and future considerations

- The Statewide CASE Team plans to adjust the infiltration assumptions for the midrise and high-rise prototypes in the MF IAQ CASE Report analysis as follows: Multiply the current Nonresidential ACM Reference Manual Idesign assumption of 0.0448 cfm/ft² by the ratio of building envelope area to exterior wall area.
    - These ratios are 2.4 for midrise, and 1.5 for high-rise, for design values of 0.106 cfm/ft² for the midrise prototype and 0.0665 cfm/ft² for high-rise prototype.
    - This calculates what the leakage would be assuming that the 0.4 cfm75/ft^2 of envelope area came just through the walls. Consequently, it takes the value assumed in the older version of 90.1 and the leakage results backed by field data, but applies it to the existing calculation method of the NR ACM. The results better reflect actual building leakage, although they may still be conservative (tighter) than actual construction.
- Although the Statewide CASE Team acknowledged the idea of adjusting the A and B coefficients (a suggestion by the Energy Commission), we do not have enough information to do so accurately at this time.

This infiltration rate should be revisited more thoroughly for the ACM Reference Manual update. The Code Readiness Team has investigated this issue and perhaps could look into:

- Identifying a field-based value for the infiltration rate that is more appropriate for CA buildings, possibly using field leakage testing,
- Investigating whether the infiltration rate should be based on total building envelope area (as ASHRAE 90.1 assumes) or total building wall envelope only (as CBECC-Com assumes)
- And adjusting the A and B coefficients in the Idesign calculation

Why does infiltration affect ERV/HRV?

From McHugh Energy Associates:

Increases in infiltration rate <u>increase the effective UA</u> (conductance area product) of the building envelope.

Uaeff = sum(Uawall + Uawindows + Uaattic + …) + Volume x **ACH** x RHO x Cp

Internal gains when converted from a Btu/hr basis to a degree F basis (such when used for a DHH analysis) are simply

Internal gain (Btu/hr) / Uaeff = Internal gain (deg F).

Increasing UA eff decreases the internal gain temperature in terms of degrees and increases balance point temperature for a DHH (degree heating hours) analysis, which in turn **increases the number of hours the space is in heating mode**.

Balance point = Internal air setpoint (F) – Internal gain (F).

Additionally, since the UA has increased the heating loads have increased.

Annual Heating Loads = UAeff x DHH - Solar Gains

Increases in the effective UA increase the heat flows associated with a temperature differential between outdoor air temperature and the room air temperature. This results in added heat gains when it is hot outside but also works as an "unpowered economizer" when it is cool outside but internal loads require cooling due to internal gains and thermal mass storing heat from the day and releasing at night through an exterior wall section or stored in a mass floor that was exposed to solar gains.

Appendix H: Prototype Building Description

The 2022 Title 24, Part 6 update will have a strong emphasis on multifamily buildings. To ensure accurate energy savings estimates and accurate Standard Design, the Statewide CASE Team conducted analysis and development of new and revised prototypes. These prototypes better align with multifamily new construction trends, as demonstrated in this report.

The Statewide CASE Team proposes four multifamily prototypes:

- Low-Rise Garden Style: a two-story, eight-unit building with dwelling unit entry from the building exterior
- Loaded Corridor: a three-story, 36-unit building with dwelling unit entry off of an interior corridor, common laundry, gym, and business center
- Mid-Rise Mixed-Use: a 96-unit building with one story of retail and common area spaces under four stories of residential space.
- High-Rise Mixed-Use: a 108-unit building with one story of retail and common area space under nine stories of residential space.

Note that the proposed prototypes are not a suggestion of delineation between low-rise and high-rise buildings types. The Statewide CASE Team aims to harmonize Title 24, Part 6 requirements for low-rise and high-rise multifamily buildings through requirements based on system or assembly type, rather than number of stories. System type and assembly selection are often based on fire safety and mechanical limitations associated with building height. The harmonization effort therefore indirectly aligns with the Benningfield Group suggestion to delineate by building height instead of number of stories, as stated in the December 2016 report, Multifamily: Energy Code Compliance Challenges.

Table 92 summarizes the building characteristics of the four prototypes.

Table 92: Table Summary of Proposed Prototype Characteristics

	Low-Rise Garden Style	Low-Rise Loaded Corridor	Mid-Rise Mixed-Use	High-Rise Mixed-Use
Stories	2	3	5 (1 commercial, 4 residential)	10 (1 commercial, 9 residential)
No. Dwelling Units	8 2 1-bedroom 2 2-bedroom	36 6 studio 12 1-bedroom 12 2-bedroom 6 3-bedroom	88 8 Studios 40 1-bedroom 32 2-bedroom 8 3-bedroom	117 18 Studios 54 1-bedroom 45 2-bedroom
Conditioned Floor Area	7,320	39,372	113,700	125,400
Foundation	Slab on grade	Slab on grade	Concrete podium with underground parking	Concrete podium with underground parking
Wall Assembly	Wood frame	Wood frame	Wood frame over a first floor concrete podium	Steel frame
Roof Assembly	Low slope attic roof	Flat roof	Flat roof	Flat roof
Window-to-wall ratio	15 percent	25 percent	25 percent	40 percent
Space heating and Cooling	Individual ducted split heat pump	Individual ducted split heat pump	Individual ducted split heat pump	Four-pipe fan coil
Ventilation	Exhaust only	Exhaust only	Exhaust only	Central supply ventilation ducted to corridors and units
Domestic Hot Water	Individual gas instantaneous	Gas storage serving multiple units	Gas storage serving whole building	Gas storage serving whole building

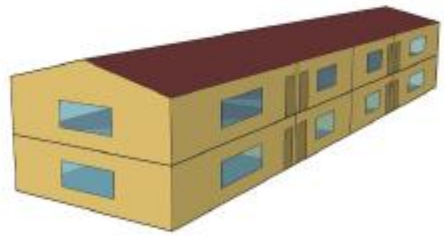

Figure 34: Low-rise garden style isometric view.

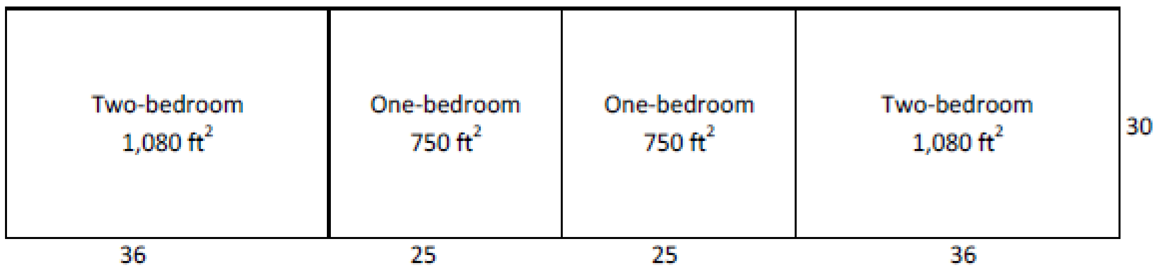

Figure 35: Low-rise garden first and second floor plan.

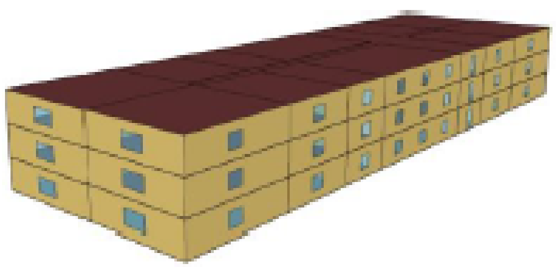

Figure 36: Low-rise loaded corridor isometric view.

Figure 37: Low-rise loaded corridor second and third floor plan.

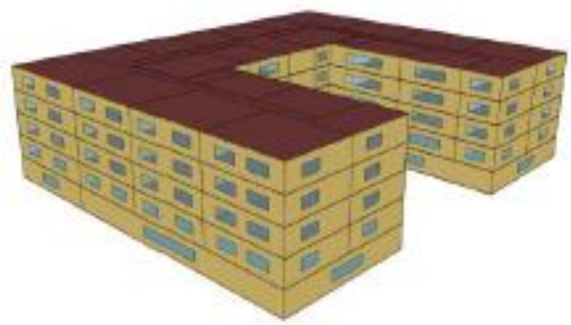

Figure 38: Mid-rise mixed use isometric view.

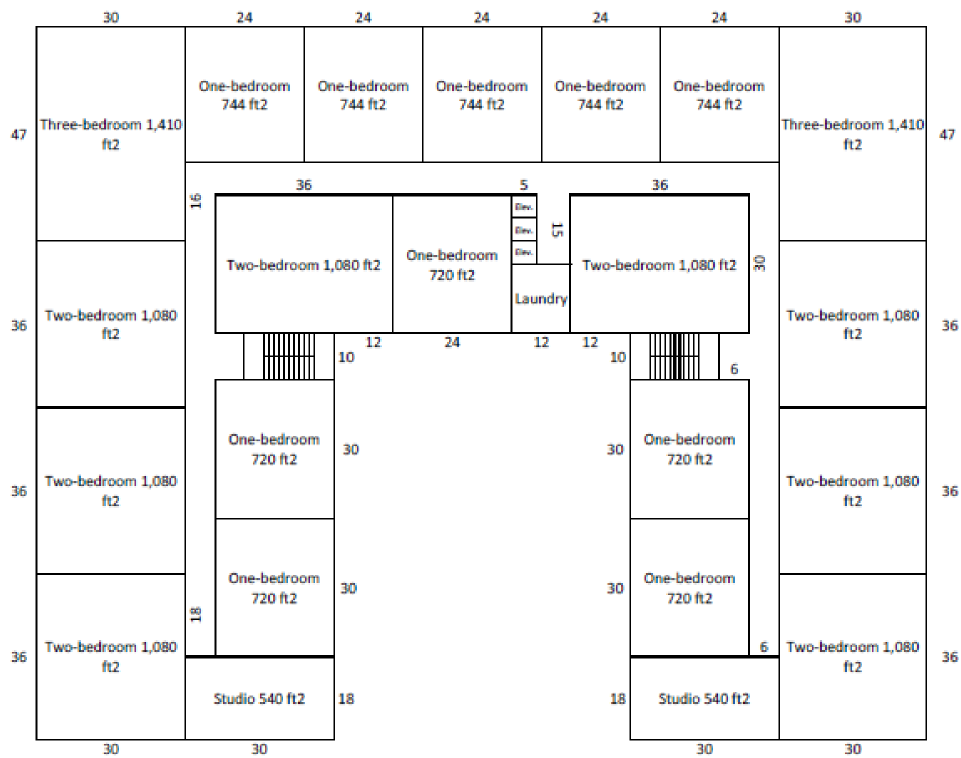

Figure 39: Mid-rise mixed use second through fifth floor plan.

Figure 40: High-rise mixed use isometric view.

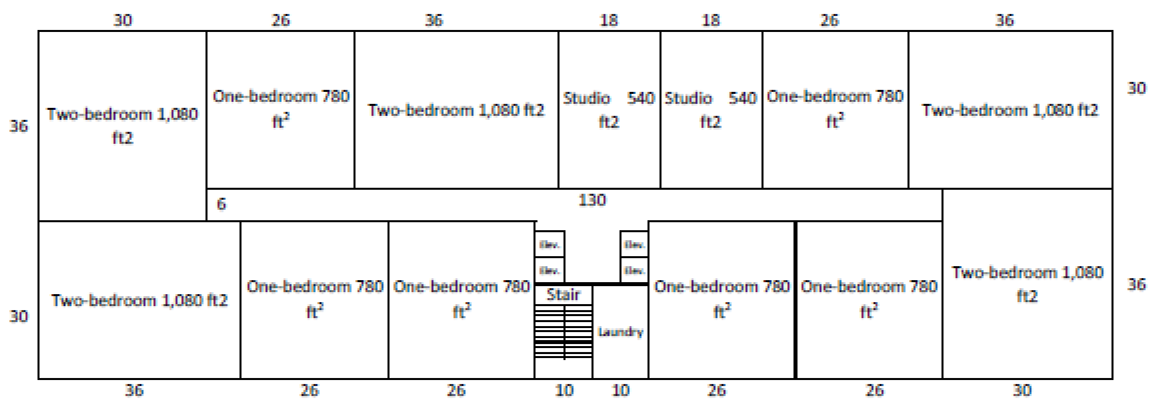

Figure 41: High-rise mixed use second through tenth floor plan.

Appendix I: Methodology for Testing Capture Efficiency for Sample of Range Hoods

Background

Under the 2019 Title 24, Part 6 code cycle, all new multifamily units (low and high-rise) are required to include kitchen range hoods that are vented to outdoors[22]. Research completed by Lawrence Berkeley National Laboratory (LBNL) has shown that pollutants generated by cooking, including NO_2, ultrafine particles (PM2.5), and acrolein can pose a significant health risk. One of LBNL's contributions was to contribute to the development of ASTM Standard E3087-18, Standard Test Method for Measuring Capture Efficiency of Domestic Range Hoods.

On other fronts, a working group of the ASHRAE Standard 62.2 committee has been developing recommendations for test conditions for range hood capture efficiency, and HVI developed HVI Publication 917, Range Hood Capture Efficiency Testing and Rating Procedure. The HVI publication adds definition to the ASTM standard and paves the way to listings of capture efficiency test results in the HVI Certified Products Directory. The Texas A&M RELLIS Energy Efficiency Laboratory (REEL), which has provided test results for HVI listings for many years, has been coordinating with HVI and has begun testing a limited number of products for capture efficiency. However, due to confidentiality requirements, REEL has not been at liberty to release results. The February 2020 release of HVI Publication 920 (Performance Certification Procedure) provides direction on determining the airflow at which capture efficiency should be measured, but testing was initiated prior to receipt of HVI Publication 920.

Given the progress that has been made in this area over the past several years and the importance to maintaining indoor air quality, the Statewide CASE Team proposed a measure to ensure the effectiveness of range hoods for capturing and removing pollutants associated with cooking by including capture efficiency requirements in Title 24, Part 6 that, in the 2022 code cycle, would apply only to multifamily buildings.

Need for and Purpose of Testing

There has been no publicly available information on the capture efficiency of typical kitchen hoods that can be used to support the proposed code change. Also, LBNL's correlations between capture efficiency and pollutant exposure were developed using a different test method than used by the ASTM standard.

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[22] Under the adopted ASHRAE 62.2 standard, continuous ventilation, an alternative to intermittently operated kitchen range hoods, is only permitted for enclosed kitchens which are rarely used in multifamily buildings.

Purpose of Testing

As an overview, the purposes of the testing were:

1. Identify capture efficiency for a sample of products, to allow a comparison of these values to the proposed capture efficiency requirements
2. Investigate the airflow associated with these capture efficiency values, to inform a minimum airflow needed to meet the proposed capture efficiency

Supporting #1: At present there is no publicly available information on the capture efficiency of typical kitchen hoods that can be used to support the proposed code change.

Supporting #2: Given the current lack of capture efficiency data, the Statewide CASE Team proposed an alternate means of compliance, which (for the Draft CASE Report) required that hoods be rated to exhaust at least 250 cfm at a static pressure of 0.1 inches w.c. Initially, limitations to sound ratings were considered, but in consultation with Energy Commission staff it was determined that a maximum sone rating would eliminate too many products. Lacking test data, the relationship between capture efficiency and airflow rate, and hence the potential IAQ impact cannot be estimated. Testing by the REEL lab will yield information on the capture efficiency of a representative sample of range hoods and combination microwave-range hood products (known as OTRs) that can be used to support this code change proposal.

Product Selection and Test Methods

Five products were chosen for testing from amongst hundreds of model numbers listed in the HVI Product Directory. Consistent with typical range hoods used in multifamily buildings, the selected products are all designed to be mounted under cabinets, have a 30-inch width, and accommodate vertical connections to vent ducting. Other selection criteria included airflows ranging from 200 to 300 cfm (at 0.1 inches w.c.), a cross-section of brands, and low to medium price range. The selected products are listed in the table below. Airflows are all at high speed settings and at 0.1 inches w.c. static pressure. The Statewide CASE Team removed the manufacturer name and model number for anonymity, per CASE Report requirements.

Table 93: Range Hood Products Tested

Type	Anonymized Product Number	Ducting	CFM	Sones
Undercabinet	WRH1	7"	300	5.5
Undercabinet	WRH2	3 1/4" X 10"	270	4
Undercabinet	WRH3	7"	230	6
Microwave	OTR1	3 1/4" X 10"	210	5
Microwave	OTR2	3 1/4" X 10"	250	7

Much consideration was given to the static pressure and corresponding airflow that should be used for the tests. Though airflow is related to static pressure, the ASTM standard only provides for testing at airflows specified by the manufacturer. Various parties have expressed concern that the field-installed static pressure can be much greater than the common rating point of 0.1 inches w.c. Currently, the vast majority of listings in the HVI Product Directory do not include higher pressures that may be more representative of installed conditions. Use of the intersection of the fan curves for the selected products with a specific system curve was considered but abandoned in favor of testing at airflows corresponding to 0.1 and 0.25 inches w.c.

It is an unfortunate matter of timing that HVI released Publication 920 after testing was initiated because it includes a method for calculating the Nominal Installed Airflow (NIA). This method applied the same strategy proposed by the ASHRAE 62.2 working group which determines the flow-pressure curve of a duct that is the same size as the kitchen hood duct connection, has a length of ten feet, two elbows, and a duct termination. Thus, the Statewide CASE Team directed each product to be tested at the following test points:

1. A static pressure of 0.1” w.c., to allow comparison of results with how products are currently listed in the HVI database
2. A static pressure of 0.25” w.c., to better reflect field conditions.

Fan curve data provided by manufacturers was used to calculate the airflows to be used for testing listed in the table below.

Table 94: Target Airflows for Capture Efficiency Testing

Anonymized Product Number	Target Airflows (cfm)	
	0.1"	0.25"
WRH1	298	170
WRH2	272	201
WRH3	240	203
OTR1	218	201
OTR2	242	214

The height of the hood above the cooking surface affects capture efficiency. A review of manufacturer installation recommendations led to using a mounting height of 24 inches for range hoods and 18 inches for OTRs.

Appendix J: Range Hood Capture Efficiency Test Results

The following range hood capture efficiency test results were provided in a report by the Rellis Energy Efficiency Laboratory (REEL) at Texas A&M University.

TRC Capture Efficiency Test Summary

Contract number: 20-1159

1. Project Overview

The Rellis Energy Efficiency Laboratory at Texas A&M University tested the capture efficiency of five kitchen range hood units, including three wall-mounted range hoods (WRHs) and two over-the-counter combination microwave units (OTRs). Testing was completed in accordance with ASTM E3087-18 (*Standard Test Method for Measuring Capture Efficiency of Domestic Range Hoods*) and HVI Publication 917 (*Range Hood Capture Efficiency Testing and Rating Procedure*). TRC, representing the California Statewide Codes and Standards Team, selected the hoods to be tested and identified the airflows to be used and the heights of the hoods above the countertops. All products are 18 inches wide.

Tests of each hood were conducted at high speed settings and at two airflows. Test airflows were determined from fan system curves and were based on the air volume the hoods are capable of exhausting at static pressures of 0.1” inch w.c. (25 Pa) and 0.25” (62.3 Pa) inch w.c. The WRH products were mounted 24 inches above the test chamber countertop and the OTR products were 18 inches above the countertop.

2. Test apparatus and procedure

The capture efficiency testing chamber built at REEL complies with ASTM E3087-18. It consists of a cubic room of 3.5 m length, 2.5 m width and 3.0 m height. Figure 42 and Figure 43 present a side and front view of the chamber setup.

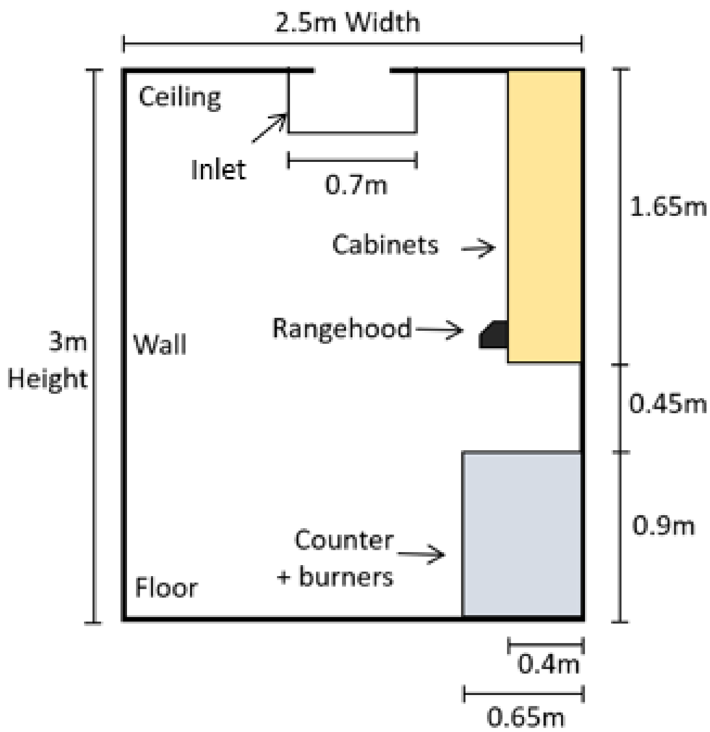

Figure 42: Test chamber side view with dimensions.

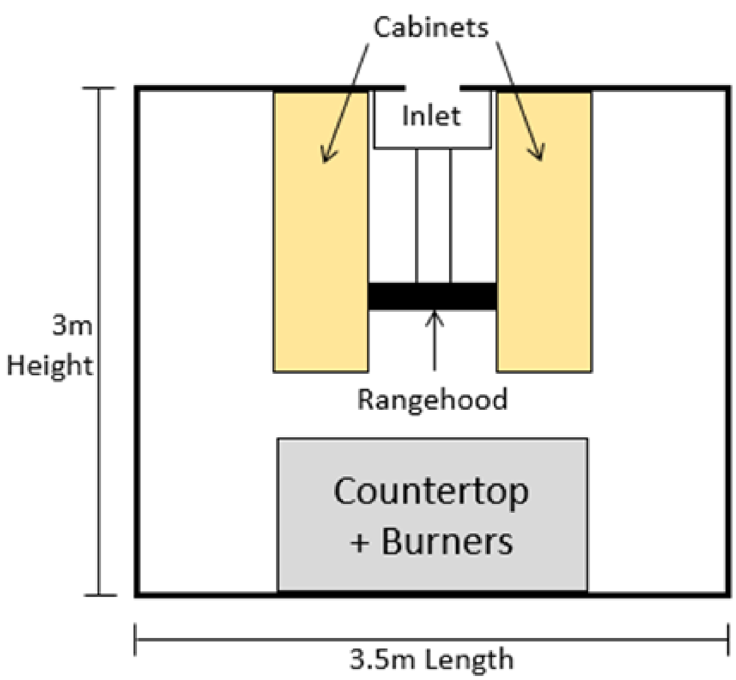

Figure 43: Test chamber front view with dimensions.

A countertop and two heating elements are installed following the ASTM standard, which specifies that the range hood units tested should be placed between cabinetry and above heating elements that simulate a cook top. Each heating element is topped by a plume diffusion emitter assembly that has one large hole for tracer-gas (CO_2) to feed in and several smaller holes for CO_2 to flow out, thus simulating cooking contaminants generated uniformly over a stove top while cooking. The flow of tracer-gas is controlled by using a CO_2 mass flow controller. Pictures in Figure 42 through Figure 43 show typical test setups.

Units are tested under steady state conditions, which means that the data-taking process can only start after CO_2 has been injected for a certain period of time (at least 4 air changes), which ensures that the concentration of tracer gas is constant in the chamber. When the conditions are satisfied then the CE is constant and steady state is achieved. CO2 concentration is recorded at the inlet, inside the chamber and at the exhaust and the capture efficiency is calculated from measured concentration as followed in Equation 1.

$$CE = \frac{C_{exhaust} - C_{chamber}}{C_{exhaust} - C_{inlet}} \qquad Eq. 1$$

3. Equipment and Calibration data

Table 95 presents a list of the instruments and equipment used in the range hood capture efficiency testing and their calibrations status. The calibration status is displayed and shows the calibration date along with the due date for the next calibration.

Table 95: Equipment List and Calibration Status

	Identification			Calibration Status			
	Equipment ID	Description	Manufacturer/ Model No	Calibration Service Provider	Cert. #	Calibration Date	Calibration Due
1	CETC-L1	Thermocouple, K (Left Burner)	McMaster Carr/6445T68	Cal Lab	2062198	Jan. 8 2020	Jan. 8 2021
2	CETC-R1	Thermocouple, K (Right Burner)	McMaster Carr/6445T68	Cal Lab	2062199	Jan. 8 2020	Jan. 8 2021
3	161904	CO2 Mass Flow Controller	Cole-Parmer/32907-75	Integrated Service Solution	161904_899_152_0221	Feb. 11 2020	Feb. 11 2021
4	5297	CO2 Sensor	PP Systems/SBA-5	PP Systems	101623	Dec. 5 2019	Dec. 5 2020
5	8134644	Pressure Transducer (0-1 inch w.c.)	Setra/264	Cal Lab	2062197	Jan. 6 2020	Jan. 6 2021
6	8420844	Pressure Transducer (0-3 inch w.c.)	Setra/264	Cal Lab	2059397	Sep. 19 2019	Sep. 19 2020
7	CE 00829	Digital Weather Station	Acurite/00829-RX	Cal Lab	2059398	Sep. 20 2019	Sep. 20 2020

Additional equipment that do not need calibration were used and those include:

- 2 burners operated alongside 2 variable auto-transformers.
- 2 adjustable speed in-line fans

4. Test Results and Discussion

Table 95 presents results obtained for this contract. Each fan was tested at high speed and at the heights and exhaust airflows listed in the table. ASTM E3087-18 does not provide for measurement of static pressure during the tests, only airflow.

Table 96: Capture Efficiency Results Recorded at Two Static Pressure for Each Fan

Fan ID	Exhaust	Contract number	Height (in)	Static Pressure (inch w.c.)	Airflow (cfm)	Capture Efficiency (%)
WR H1	Vertical Round 7"	20-1159A	24	0.1	300	78.0
	Vertical Round 7"	20-1159B	24	0.25	170	46.7
WR H2	Vertical rectangular, 3¼ " x 10"	20-1159C	24	0.1	270	71.6
	Vertical rectangular 3¼ " x 10"	20-1159D	24	0.25	201	54.9
WR H3	Vertical Round 7"	20-1159E	24	0.1	240	69.5
	Vertical Round 7"	20-1159F	24	0.25	203	64.8
OTR 1	Vertical rectangular	20-1159G	18	0.1	242	54.4
	Vertical rectangular	20-1159H	18	0.25	214	49.4
OTR 2	Vertical rectangular	20-1159I	18	0.1	218	61.4
	Vertical rectangular	20-1159J	18	0.25	201	58.0

The measured capture efficiency ranged from 54.4 to 78.0 percent at airflows corresponding to 0.1 inches w.c. static pressure, and from 46.7 to 64.8 inches w.c. at airflows corresponding to 0.25 inches w.c. Results show that increased airflow generally correlates with increased capture efficiency.

Results also show that products that exhibit high capture efficiency at low static pressures do not necessarily produce higher capture efficiency at higher static pressures. For example, WH1 had the highest capture efficiency at 0.1 inches w.c. but the lowest capture efficiency at 0.25 inches w.c. As described above, higher airflow is correlated with higher capture efficiency. In addition, higher static pressure is correlated with lower airflow. Consequently, an increase in static pressure generally leads to a decrease in capture efficiency. However, the correlation between static pressure and capture efficiency is not consistent across products, due to their different fan curves.

5. Pictures of Test Set-up

Figure 44**: WRH1**

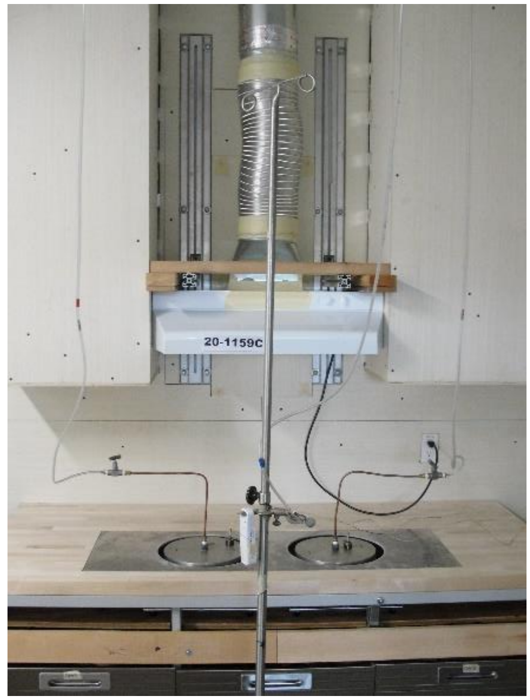

Figure 45: WRH2

Figure 46: WRH3

Figure 47: OTR2

Appendix K: Nominal TDV Energy Savings

Per-unit energy cost savings for newly constructed buildings that are realized over the 30-year period of analysis are presented in 2023 dollars in the figures below. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Below are energy savings estimates at the dwelling unit level in nominal cost savings for the different prototypes from the ERV/HRV measure.

Table 97: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis - Per Dwelling Unit – ERV/HRV in Low-Rise Garden-style New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$1,272	$4,411	$5,683
2	$743	$2,594	$3,337
3	$300	$1,555	$1,855
4	$391	$1,510	$1,901
5	$188	$1,408	$1,596
6	($257)	$418	$160
7	($576)	$244	($332)
8	($163)	$187	$24
9	$240	$546	$786
10	$517	$956	$1,473
11	$1,591	$2,329	$3,919
12	$1,026	$2,189	$3,216
13	$1,503	$1,879	$3,382
14	$1,539	$2,248	$3,787
15	$2,249	$46	$2,294
16	$1,221	$4,242	$5,463

Table 98: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis - Per Dwelling Unit – ERV/HRV in Low-Rise Loaded Corridor New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$935	$3,628	$4,563
2	($94)	$2,373	$2,279
3	($359)	$1,341	$982
4	($289)	$1,679	$1,390
5	($490)	$1,406	$916
6	($1,209)	$366	($843)
7	($1,428)	$12	($1,416)
8	($1,081)	$133	($947)
9	($879)	$372	($507)
10	($291)	$536	$245
11	$1,015	$2,196	$3,211
12	$172	$2,131	$2,303
13	$950	$1,967	$2,917
14	$954	$2,227	$3,182
15	$1,758	$0	$1,758
16	$961	$4,275	$5,236

Table 99: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis - Per Dwelling Unit – ERV/HRV in Mid-Rise Mixed-Use New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$43	$1,889	$1,932
2	($52)	$1,097	$1,045
3	($177)	$893	$715
4	($99)	$675	$575
5	($402)	$764	$362
6	($387)	$285	($101)
7	($600)	$196	($404)
8	($347)	$228	($119)
9	($171)	$349	$179
10	($95)	$476	$380
11	$424	$1,137	$1,561
12	$125	$1,007	$1,132
13	$333	$887	$1,220
14	$337	$1,035	$1,372
15	$674	$179	$854
16	$39	$1,888	$1,926

Table 100: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis - Per Dwelling Unit – ERV/HRV High-Rise Mixed-Use New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$3	$3,117	$3,120
2	$511	$2,390	$2,901
3	$117	$1,154	$1,271
4	$566	$1,180	$1,745
5	($6)	$1,448	$1,442
6	$187	$388	$575
7	$52	$185	$237
8	$555	$418	$973
9	$793	$616	$1,409
10	$806	$1,121	$1,927
11	$1,327	$2,273	$3,599
12	$988	$2,014	$3,002
13	$1,588	$1,817	$3,406
14	$1,141	$2,535	$3,675
15	$3,026	$345	$3,371
16	$43	$4,806	$4,849

The following table shows nominal savings from the Central Ventilation Duct Sealing measure.

Table 101: Nominal TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – Central Ventilation Duct Sealing - High-Rise Mixed Use New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (Nominal $)	30-Year TDV Natural Gas Cost Savings (Nominal $)	Total 30-Year TDV Energy Cost Savings (Nominal $)
1	$226	$2,679	$2,905
2	$7,840	($2,707)	$5,133
3	($77)	$1,377	$1,299
4	$402	$1,403	$1,805
5	($195)	$1,532	$1,337
6	($138)	$664	$526
7	($401)	$284	($117)
8	$193	$545	$738
9	$710	$729	$1,439
10	$755	$873	$1,628
11	$1,372	$1,715	$3,087
12	$1,026	$1,748	$2,774
13	$1,337	$1,571	$2,908
14	$1,161	$1,714	$2,875
15	$2,390	$391	$2,781
16	$271	$2,987	$3,258