DOCKETED

Docket Number:	19-BSTD-03
Project Title:	2022 Energy Code Pre-Rulemaking
TN #:	232909
Document Title:	Statewide Utility Codes and Standards Enhancement Team Comments - MF IAQ_Draft CASE Report_Statewide CASE Team
Description:	N/A
Filer:	System
Organization:	Statewide Utility Codes and Standards Enhancement Team
Submitter Role:	Public
Submission Date:	5/5/2020 5:40:44 PM
Docketed Date:	5/6/2020

Comment Received From: Statewide Utility Codes and Standards Enhancement Team
Submitted On: 5/5/2020
Docket Number: 19-BSTD-03

MF IAQ_Draft CASE Report_Statewide CASE Team

Additional submitted attachment is included below.

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

Multifamily Indoor Air Quality

2022-MF-IAQ-D | Multifamily HVAC | May 2020

DRAFT CASE REPORT

Prepared by TRC

Please submit comments to info@title24stakeholders.com by June 12, 2020

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
Authors:	Marian Goebes, Robert Grindrod, Gwen McLaughlin, Mia Nakajima, Neil Perry (TRC); David Springer, Alea German, Josh Peralta (Frontier Energy); Nelson Dichter, Curtis Harrington (UC Davis); Nick Young (Association for Energy Affordability)
Prime Contractor:	TRC
Project Management:	California Statewide Utility Codes and Standards Team: Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric Company, Sacramento Municipal Utility District, Los Angeles Department of Water and Power.

Table of Contents

List of Tables

List of Figures

Executive Summary

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this draft report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in August 2020. The Statewide CASE Team is particularly interested in feedback on the proposed requirements and high-level comments on the technical rationale for the proposed requirements at this time.

Email comments and suggestions to info@title24stakeholders.com *by* ***June 12, 2020****. 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 Efficiency Building Standards (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 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 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. Submeasure C addresses sealing of central ventilation ducts; it primarily provides IAQ benefits, but also results in statewide energy savings. While all relate to multifamily 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 which 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 HERS Rater or ATT using product specification sheets or product databases:

    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/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(c), and include a bypass function whereby the intake air bypasses the heat exchanger and the equipment functions similar to an economizer.

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 and 1.2 W/cfm for central ERVs/HRVs, for all climate zones.

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. One of the requirements in ASHRAE Standard 62.2 is that non-enclosed kitchens include intermittent kitchen exhaust with an airflow of at least 100 cubic feet per minute (cfm) and a sound rating of less than or equal to three sones. The proposed requirement maintains the existing requirement and adds a new requirement for range hoods to better ensure that an exhaust system can adequately remove cooking-related pollution. Specifically, the proposal builds upon recent research from Lawrence Berkeley National Laboratory (LBNL) indicating that at least 75 percent range hood capture efficiency is needed to maintain fine particulate matter (PM2.5) and nitrogen dioxide (NO_2, for natural gas-fueled range hoods) at acceptable levels specified by the U.S. Environmental Protection Agency standards. Both pollutants – and particularly PM2.5 – 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 has found a relationship between airflow and capture efficiency (i.e., a higher airflow generally results in a higher capture efficiency). As additional background, manufacturers are moving towards 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

[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.

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 minimum capture efficiency of 70 percent using ASTM Standard E3087-18 at nominal installed airflow (defined as the intersection of the range hood's fan curve and a defined system curve) or
2. A vented range hood with a minimum airflow of 250 cfm or higher at 0.1 inches w.c. (25 Pa) or higher, or
3. A vented downdraft kitchen exhaust fan with a minimum airflow of 300 cfm at 25 Pa (0.1 inches w.c.) or higher, or
4. A continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour for enclosed kitchens only (an enclosed kitchen is defined as a kitchen whose permanent openings to interior adjacent spaces does not exceed a total 60 square feet (6 square meters).

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 9162. 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 Pascals (Pa), (0.2 inches w.c.) for

---

[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.

central ventilation duct serving more than six dwelling units, and does not exceed 6 percent of the central fan airflow rate at 25 Pascals (Pa), (0.1 inches w.c.) for central 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 Draft 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 would be verified by the HERS Rater or ATT.
- Submeasure B: Kitchen exhaust minimum capture - All kitchen exhaust systems must either meet a minimum capture efficiency or minimum airflow. For both enclosed and non-enclosed kitchens, if a range hood is chosen, the range hood must either provide a minimum capture efficiency of 70 percent or provide airflow of at least 250 cfm at nominal installed airflow. Kitchen exhaust systems may also consist of a downdraft kitchen exhaust with a minimum airflow of at least 300 cfm at 0.1 inches w.c. (25 Pa) fan for both enclosed and non-enclosed

kitchens, or a continuous exhaust system with a minimum airflow of at least 5 air changes per hour for enclosed kitchens only.

- 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 can be done by either Home Energy Rating System (HERS) Raters or Acceptance Testing Technicians (ATTs). The HERS Rater or 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) for central ventilation ducts serving more than six units and at 25 Pa (0.1 inches) for those serving six or fewer units, and the HERS Rater or ATT can use sampling for the field verification.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents 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 altered.

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
HRV/ERV	Prescriptive	120.1(b)2Aivb and 140.X for high-rise, 150.0(o)E, 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 and 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	120.5(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 either balanced ventilation or air tightness ("compartmentalization") for all new

[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.

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 range hoods are frequently installed in new construction multifamily units. 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) to 250 cfm, based on research conducted as part of this research which indicates that at least 250 cfm is needed to achieve 70 percent capture efficiency. The alternative pathway of 250 cfm enables projects 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 analysis of products in the Home Ventilating Institute (HVI) database and found that the 73 percent of listed products met the minimum airflow requirement of 250 cfm[4]. In addition, the proposed requirement retains two other compliance options (in 2019 Title 24, Part 6 by reference to ASHRAE 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 (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

---

[4] This is based on undercabinet range hoods and microwave-range hood combination products, since those are more commonly installed in multifamily units due to space constraints, and assumes vertical discharge, based on feedback from the stakeholder meeting that this is much more common than horizontal. Note that the discharge configuration refers to only the connection of the ductwork with the hood: A hood that connects to a short vertical piece of duct through a cabinet that then transitions to a horizontal run-out to a wall is a vertical configuration.

HERS Raters and ATTs 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 altered.

- 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, including the requirement for Quality Insulation Installation (QII) for low rise multifamily buildings in 2019 Title 24, Part 6 and a proposed version of QII for high-rise multifamily buildings for 2022 Title 24, Part 6. Consequently, the Statewide CASE Team does not need to show that the measure is cost effective. However, based on a comparison of a sample of ranges that do and do not comply with the proposed minimum airflow requirement for range hoods (at least 250 cfm), the Statewide CASE Team found no statistical difference in prices between products that would and would not comply.
- 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 HERS Raters or 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 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 HRV/ERV 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 2 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 calculated by the Statewide CASE Team. Section 4 contains details on the per-unit energy savings calculated by the Statewide CASE Team.

Table 2 does not include energy savings for the kitchen exhaust minimum capture proposed code change, because the primary purpose of this measure is to improve IAQ. As described in Section 2.3.3, cooking pollution includes PM2.5, and (from gas-fired stoves) NO_2, 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 2: 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)	-3.26	1.59	0.46	79.92
New Construction	-3.26	1.59	0.46	79.92
Additions and Alterations	N/A	N/A	N/A	N/A
Submeasure C: Central Ventilation Duct Sealing (Total)	0.03	0.09	0.02	7.26
New Construction	0.03	0.09	0.02	7.26
Additions and Alterations	N/A	N/A	N/A	N/A

Table 3 presents the estimated avoided GHG emissions associated with the proposed code change for the first year the standards are in effect. Avoided GHG emissions are measured in metric tonnes of carbon dioxide equivalent (Metric Tonnes 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 3: First-Year Statewide GHG Emissions Impacts

Measure	Avoided GHG Emissions (Metric TonnesCO2e/yr)	Monetary Value of Avoided GHG Emissions ($2023)
Submeasure A: ERV/ HRV (Total)	1,209	$36,274
Submeasure C: Central Ventilation Duct Sealing (Total)	2,614	$78,431
Total	2,846	$84,400

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 is described in Section 2.3.5. Impacts that the proposed measure would have on market actors are described in Sections 0, 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 HERS verifications.
  - If an ERV or HRV is required
    - The project team chooses and installs qualifying equipment, including equipment with the minimum sensible recovery efficiency (SRE)[5] 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.
- Submeasure B: Kitchen exhaust minimum capture
  - The project team specifies a kitchen exhaust system that complies with the requirement based on either its capture efficiency or its sound rating and

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

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.
  - The ATT or HERS Rater 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. HERS 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 or HERS Rater 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 or HERS Rater 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 is a draft report. There are some sections that do not include content, due in part to the delay in the release of updated software. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this draft report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in July 2020. For this report, the Statewide CASE Team is requesting high-level comments on the proposed requirements and underlying analysis.

Email comments and suggestions to info@title24stakeholders.com *by* ***June 12, 2020****. Comments will not be released for public review or will be anonymized if shared with stakeholders.*

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update California's Energy Efficiency Building Standards (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 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 a public stakeholder workshop that the Statewide CASE Team held on August 22, 2019; a second meeting is scheduled for March 26, 2020. Notes from the first stakeholder meeting 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 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 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

2. Measure Description

This Draft 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

A heat recovery ventilator (HRV) captures outgoing energy (both sensible and latent) in exhausted air and transfers it to incoming air, thus essentially preheating or precooling incoming air. An energy recovery ventilator (ERV) does the same thing but also transfers moisture, thereby transferring more 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 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 1.2 W/cfm 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. This requirement would not affect alterations. Many existing multifamily buildings have no whole dwelling unit ventilation (e.g., 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 sensible recovery efficiency 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.

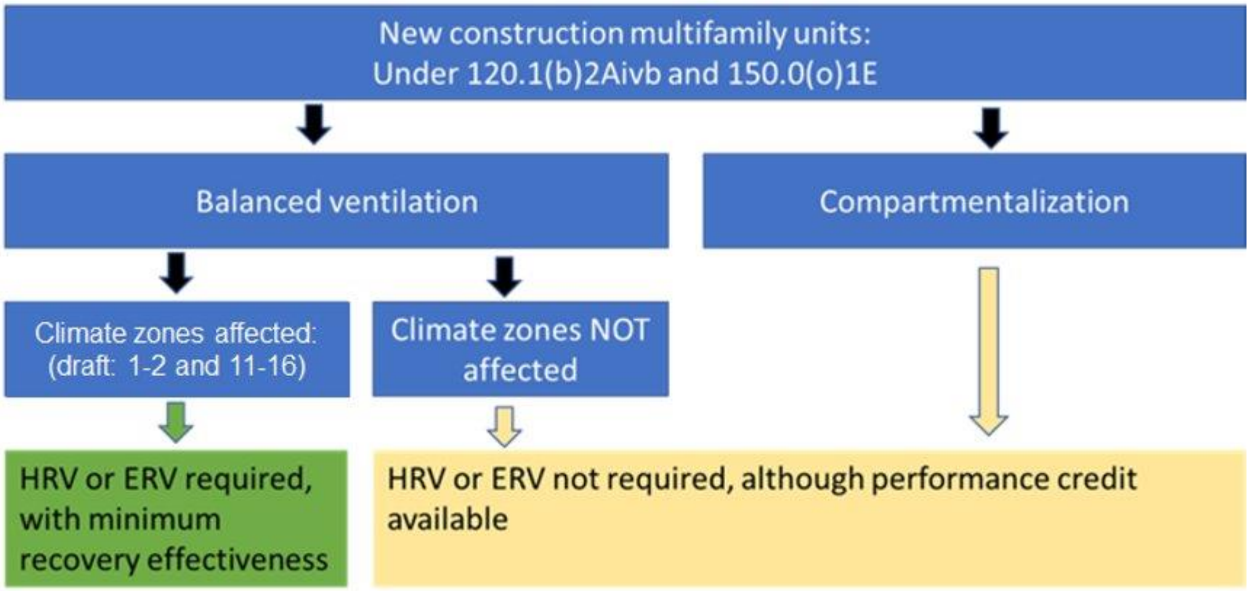

Figure 1: Overview of multifamily dwelling units affected by proposed ERV/HRV code change.

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.

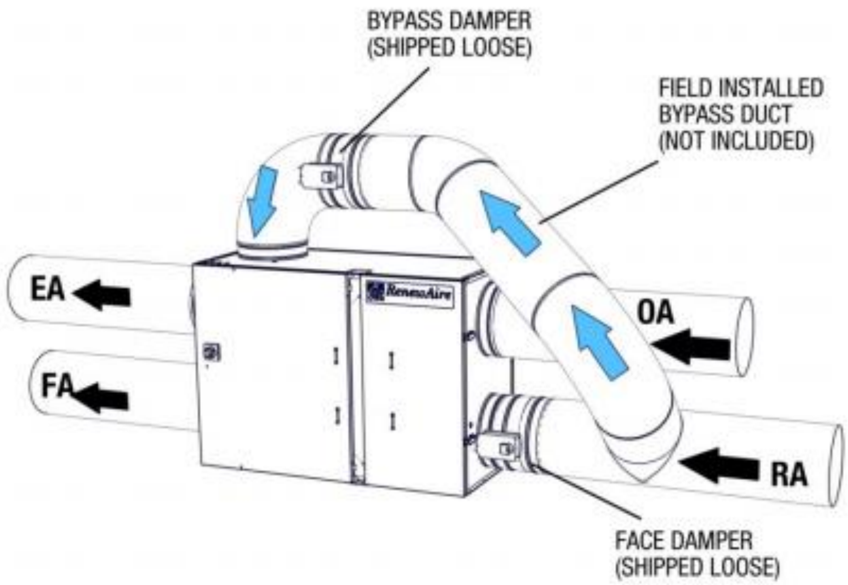

Figure 2: HRV/ERV diagram. RA = Room Air into unit. OA = Outside Air into unit. FA = Fresh Air to inside. EA = Exhaust Air to outside.

Source: RenewAire 2019.

The difference between an HRV and ERV is that while both transfer sensible energy and some latent energy, an ERV transfers additional latent energy because it also transfers humidity. During the heating season, the ERV transfers moisture from the outgoing air to the incoming airstream. Conversely, during the cooling season, the ERV removes moisture from the incoming airstream. The proposed code change would allow project teams to choose either an HRV or ERV system.

Unitary HRV and ERV equipment have a sensible recovery efficiency (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 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 a sensible recovery efficiency (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.

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 a sensible recovery *efficiency* (abbreviated as 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 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, Alternative Calculation Method (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 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 the California Energy Code 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 degrees F (0 degrees 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 degrees F (0 degrees C), fan efficacy that meets the requirements of Section 140.4(c), and a bypass function that enables it to function in an economizer mode to take advantage of free cooling.

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 need to follow the proposed requirement.

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 degrees F (0 degrees 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 degrees F (0 degrees C), fan efficacy meeting Section 140.4(c) 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 HRV/ERV 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.

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.

A HERS Rater would:

1. If an ERV/HRV is listed on the compliance forms, 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 ERV/HRV performance requirements listed on the compliance forms are met based on product databases (HVI, Association of Home Appliance Manufacturers [AHAM], or Air Conditioning, Heating,

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

2. For MF Building central ERV/HRV systems that provide ventilation for more than one dwelling unit, verify that the bypass function exists from the cut-sheet, and field verify that the bypass function exists and meets the requirements in Table 140.4(e).

RESIDENTIAL APPENDIX

RA3.4.4 HVAC System Verification Procedures (low-rise multifamily dwelling units): The proposed change will add a subsubsection: RA3.7.4.4: Rated Heat Recovery and Energy Recovery Ventilation Verification Procedures. This new subsection will 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.

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 based on product databases or from product specifications from the manufacturer.
3. For central ERV/HRV systems, verify that the bypass function exists from the cut-sheet, and field verify that the bypass function exists and is programmed to identify an outdoor temperature range where the unit should operate in bypass mode.

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 E/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 E/HRV with a fan efficacy better (less than) 0.6 W/cfm and receive energy savings, an E/HRV with a fan efficacy of 0.6 W/cfm for no energy savings, or an E/HRV with a fan efficacy between 0.6 and 1.0 W/cfm and receive an energy penalty. For central E/HRVs, the same approach would be used for the performance path except the assumed efficacy is the requirements in Section 140.4(c).
- 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,[6] 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

[6] Parking garages are not considered occupiable.

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, 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 will 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.

E/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 E/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 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 E/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 E/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 will stipulate that the HERS Rater must document the sensible recovery efficiency 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 will 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 HRV/ERV 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 (VCS), 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 HRV/ERV 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 ERVs or HRVs. 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 E/HRV should not be more difficult than the existing requirement for balanced ventilation in terms of this CMC requirement. There are some E/HRVs known as “through-wall” products, because they are installed at the wall and do not require ducting. These products would need to include some ductwork to meet this CMC requirement.

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 a pickup 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 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 the *California Energy Code.*

The Statewide CASE Team also examined whether the Nonresidental 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(c). 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 exact 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.

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[7]	NR	≥19,500	≥9000	≥5000	≥4000	≥3000	≥1500	≥120
0A, 1A, 2A, 3A, 4B, 5B[8]	≥2500	≥2000	≥1000	≥500	≥140	≥120	≥100	≥80
4A, 5A, 6A, 7, 8[9]	≥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.

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

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

[9] Does not correspond to any California Climate Zones.

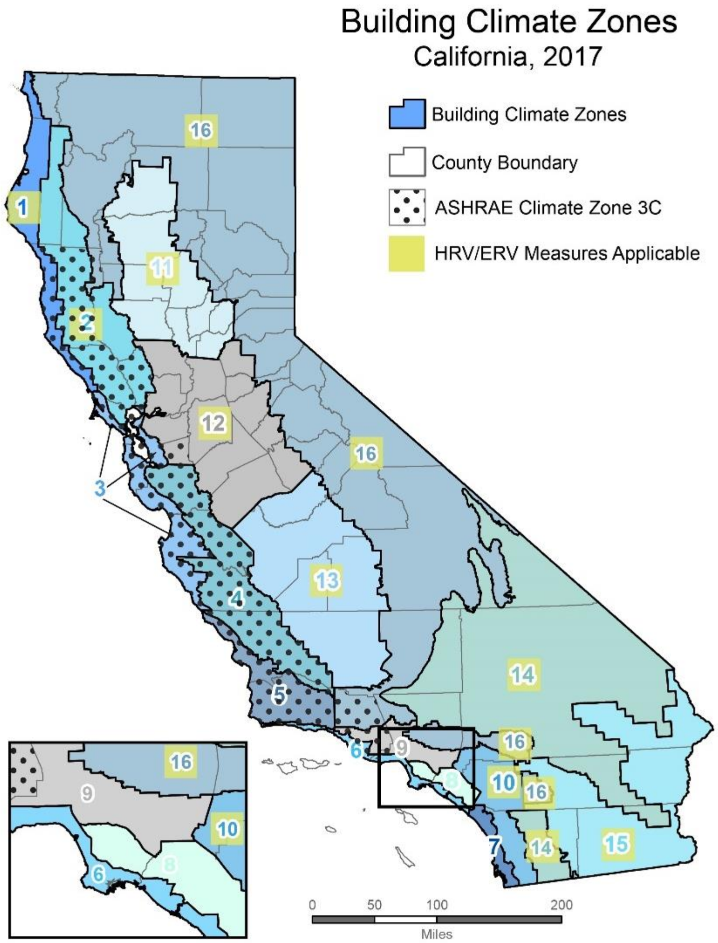

Figure 5: Map of ASHRAE Climate Zone 3C compared with California climate zones with proposed requirement.

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 HRV/ERV 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 HRV or ERV 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 HRV or ERV equipment supported by compliance documentation. Design of the ducts is submitted for approval. The plans examiner reviews the drawings and specifications to ensure the HRV or ERV 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. The HERS Rater or 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. HERS Rater/ATT would follow verification procedures and document via applicable Certificate of Verification/Acceptance NRCV/NRCA/CF3R

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. In particular, 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.

Figure 6 shows adjustments in daily average 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 nitrogen dioxide is associated with respiratory problems such as chest tightness, shortness of breath, and wheezing (United States Environmental Protection Agency n.d.).

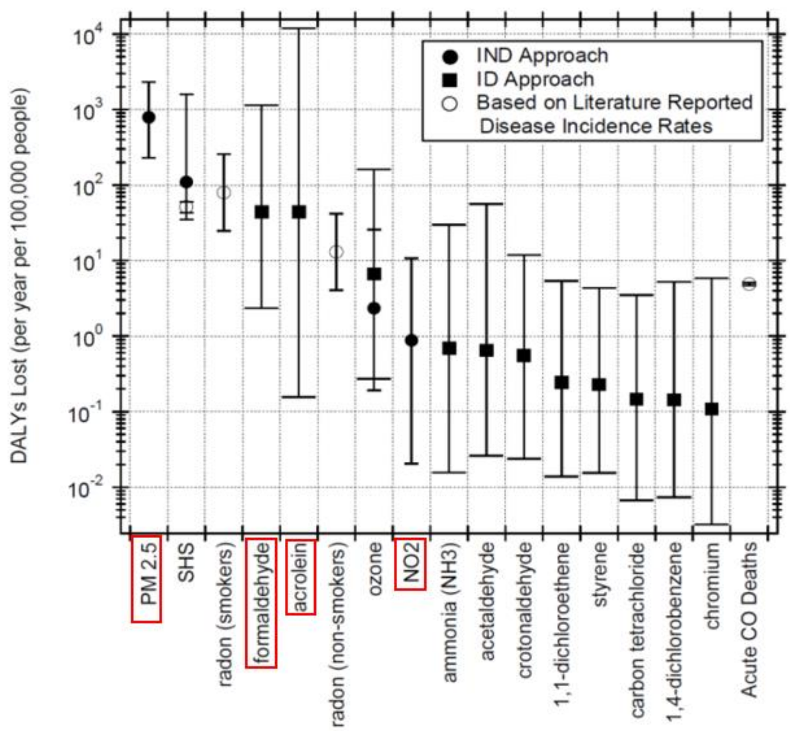

Figure 6: Estimated population averaged annual cost, in disability adjusted life years (DALYs), of twelve pollutants with highest median DALY estimates shows PM2.5 with highest median DALY estimate.

Source: Logue, et al 2011.

It is particularly important that kitchen exhaust systems effectively remove kitchen exhaust in multifamily dwelling units, since these residences can have their air degraded by both their own kitchen pollution and from transferred pollution 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 Lawrence Berkeley National Laboratory (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 nitrogen dioxide (1-h average concentration of 100ppb from California Air Resources Board 2016), and 60 percent is required to avoid unhealthy levels of PM2.5 (24-h average of 25$\mu g/m^3$ from World Health Organization 2006)[10]. 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 (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. Therefore, this analysis notes that to achieve field condition capture efficiencies of 60 percent to 70 percent, higher capture efficiencies (such as 75 percent or higher) may be needed. However, as described in this report, the proposed requirement for this code cycle is 70 percent capture efficiency, to balance IAQ needs with availability of compliant products.

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

1. A vented range hood with a minimum capture efficiency of 70 percent at nominal installed airflow, or
2. A vented range hood with a minimum airflow of 250 cubic feet per minute (cfm) at a static pressure of 0.1 inches w.c. or greater, or
3. A vented downdraft exhaust with a minimum airflow of 300 cubic feet per minute (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

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

---

[10] 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 which affect results.

For the first path, the nominal installed airflow is defined in HVI Standard 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). The HVI standard does not specify a system for system curve used in the definition. The ASHRAE 62.2 working group has been working to define a system. Once the system is published, industry should use that nominal installed airflow for consistency.

For the second path, the Statewide CASE Team has considered multiple options for minimum airflow. While the correlation of airflow and capture efficiency is not well established, the Statewide CASE Team found through laboratory testing of kitchen range hoods that a capture efficiency of 70 percent roughly corresponded to an airflow of 250 cfm. The Statewide CASE Team also found that the majority of range hood products in the HVI database comply with the proposed requirement. 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 (and therefor capture efficiency) increases as static pressure decreases.

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.

In addition to the proposed requirement above, all range hoods in multifamily dwelling units would continue to meet the existing requirement of no greater than three sones at 100 cfm for demand-controlled range hoods and no greater than one sone for continuous exhaust. Note that the proposed requirement does not have an associated sound requirement (i.e., there is no sound requirement at 70 percent capture efficiency, 250 cfm for range hoods, or 300 cfm for downdrafts). Consequently, the sound test will be conducted at a lower speed (the working speed, which is 100 cfm or higher) than the airflows required under this proposal. This is because adding a sound rating at the proposed capture efficiency and 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 that case, the new equipment would need to meet the proposed requirement.

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 multifamily building envelopes tighten under QII 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 systems, 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 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, 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,
2. A downdraft exhaust system with an airflow of at least 300 cfm, or
3. (for enclosed kitchens only[11]) continuous exhaust with an airflow of at least five kitchen air changes per hour at 50 Pascals.

Equipment must be rated by HVI (Home Ventilating Instutute 2015) to not exceed 3 sones at 100 cfm for demand-controlled equipment, or to not exceed 1 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

[11] 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).

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, 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 (United States Environmental Protection Agency 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 nitrogen dioxide 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 E3087-2018 provides a test method for capture efficiency, and HVI is currently developing the HVI Range Hood Capture 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).

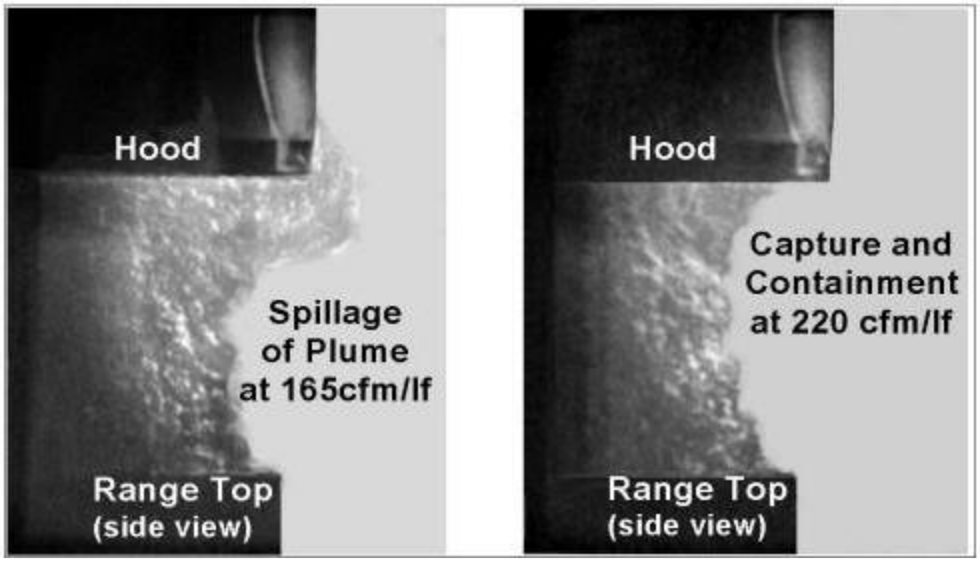

Figure 7: Illustration of range hood plume spillage at different airflow rates.

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 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 62.2 committee, range hood manufacturers as well as researchers from Lawrence Berkeley Laboratory (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 manufacturers can test equipment under the same conditions as will be required by ASHRAE 62.2 and HVI.

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 and other agencies are forthcoming within the 2022 code cycle, and requires that the ratings be verified to meet 70 percent or greater. HVI indicated capture efficiencies would be included in listings by October 2020 on a voluntary basis and would be made mandatory October 2021. The second, third, and fourth options allows verification based on a 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 and results indicate that (roughly) at least 250 cfm of airflow is required to achieve 70 percent capture efficiency

The Statewide CASE Team considered adding another requirement for a maximum sound value for the second compliance option at the 250 cfm airflow, in addition to the existing requirement for sound level. However, a sound rating at 250 cfm would require additional testing by manufacturers. In addition, the industry is currently moving to rating their equipment at higher static pressures than the traditional 0.1" w.c. (since 0.1 inch w.c. is less than what would be measured at most installed conditions), which may require re-testing. The Statewide CASE Team supports testing and reporting of products at higher static pressures to better represent field conditions, and did not want to impose the additional burden on manufacturers of testing for sound at 250 cfm at 0.1" w.c. In addition, there is little data indicating what level of sound is acceptable to consumers, making it difficult to set a minimum sound requirement.

2.2.2.5 Consumer Range Hood Behavior

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 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.

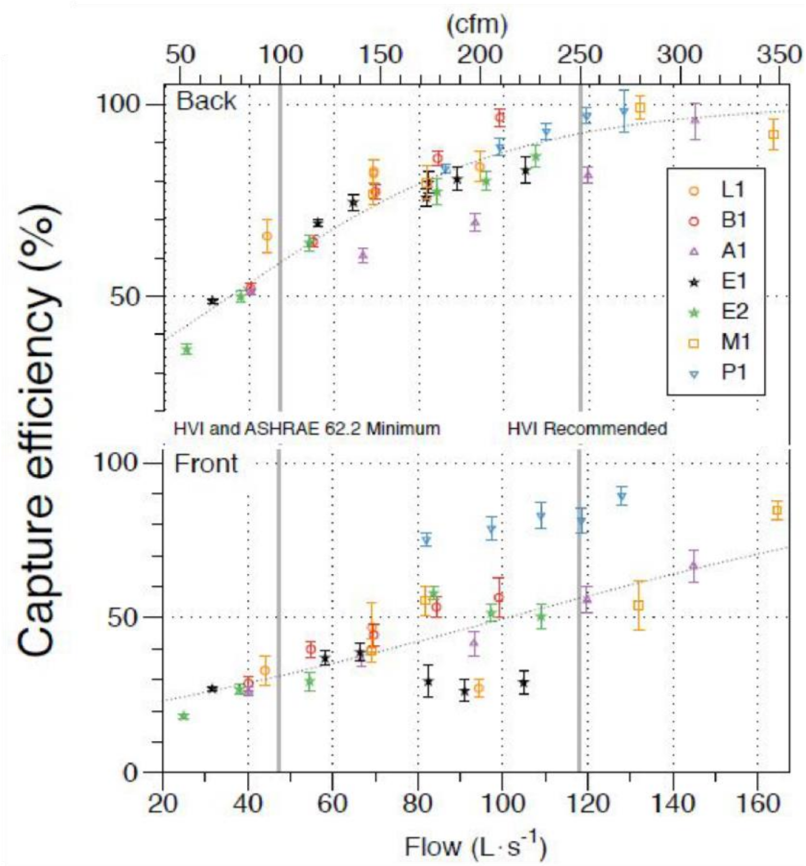

Figure 8: Capture efficiency of kitchen range hoods, as measured via "pollutant method".

Source: Effective Kitchen Ventilation for ZNE Homes with Natural Gas (Technical Advisory Committee Meeting #2 Slides).

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 our market research. LBNL conducted research on occupant range hood use as part of the Healthy, Efficient, Natural Gas Homes (HENGH) study, which collected data from 70 single family homes: 32 of which had range hoods, and 38 of which had microwave-range hood combination products. The study included field measurements and an occupant survey of range hood use.

Table 4 provides results of field testing of how often occupants used range hoods or microwave range hood combinations, commonly referred to as over-the-range microwaves (OTRs), during times when they used the cooktop. Occupants' use of their ranges was identified by a temperature sensor, and their use of a range hood was identified by using an anemometer. As shown in the "N" column, most cooking events lasted 30 minutes or less; 10 percent of occupants used their range hoods for at least part of cooking events that lasted 1 to 10 minutes; 22 percent of occupants used it at least part of the events lasting 11 to 20 minutes; and 37 percent used it at least part of the events lasting 21 to 30 minutes. Weighting the fraction of range hood use ("Any RH use") by the number of occurrences (N values), occupants use range hoods for approximately 29 percent of cooking events. Furthermore, occupants are more often likely to turn on the range hood during longer cooking events. When the range hood events are weighted by duration of cooking event (assuming the midpoint for the time: e.g., 5 minutes for an event that is 1 to 10 minutes, 15 minutes for an event that is 11 to 20 minutes), occupants used their range hoods for 42 percent of cooking events. The final column also indicates that occupants rarely use their range hood for the full duration of the cooking event.

Table 4: Range Hood Use in HENGH Homes Based On Field Measurements

Category		**N**	**Any RH use**	**Full RH use**
Total Cooktop Use		602	29%	8%
Duration of Cooking Event (minutes)	1-10	191	10%	4%
	11-20	174	22%	7%
	21-30	91	37%	12%
	31-40	41	49%	14%
	≥41	105	60%	10%
	Range hood	236	26%	8%
Type of Range Hood	OTR	366	31%	8%

Figure 9 presents 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.

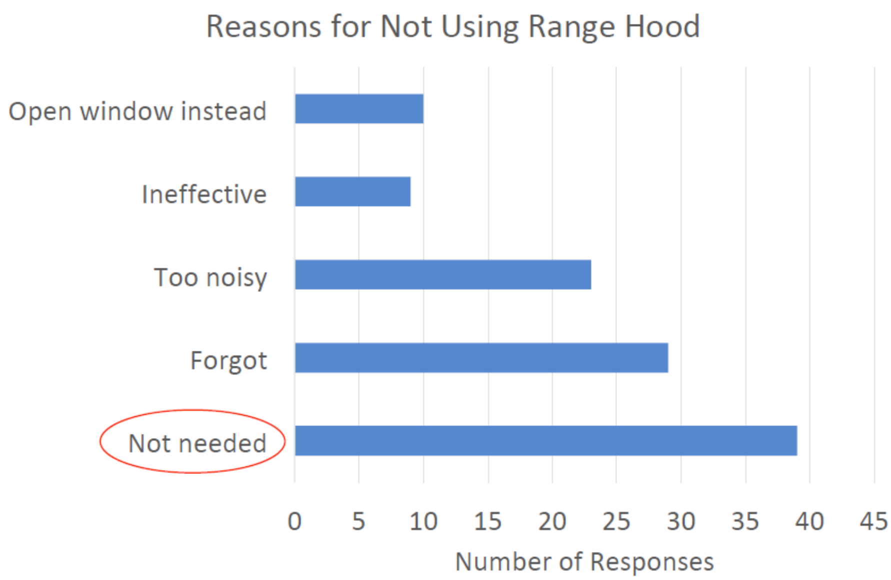

Figure 9: Reasons for not using kitchen exhaust.

Source: Effective Kitchen Ventilation for ZNE Homes with Natural Gas (Technical Advisory Committee Meeting #1 Slides).

Overall, results indicate that most consumers do use their range hood sometimes – 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. The concept of requiring the hood to turn on automatically whenever temperature sensors show that cooking is occurring could be explored in future code cycles as a means of increasing the IAQ benefits to occupants, although energy impacts should also be considered.

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 leads to lower airflow, which 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 10, 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.

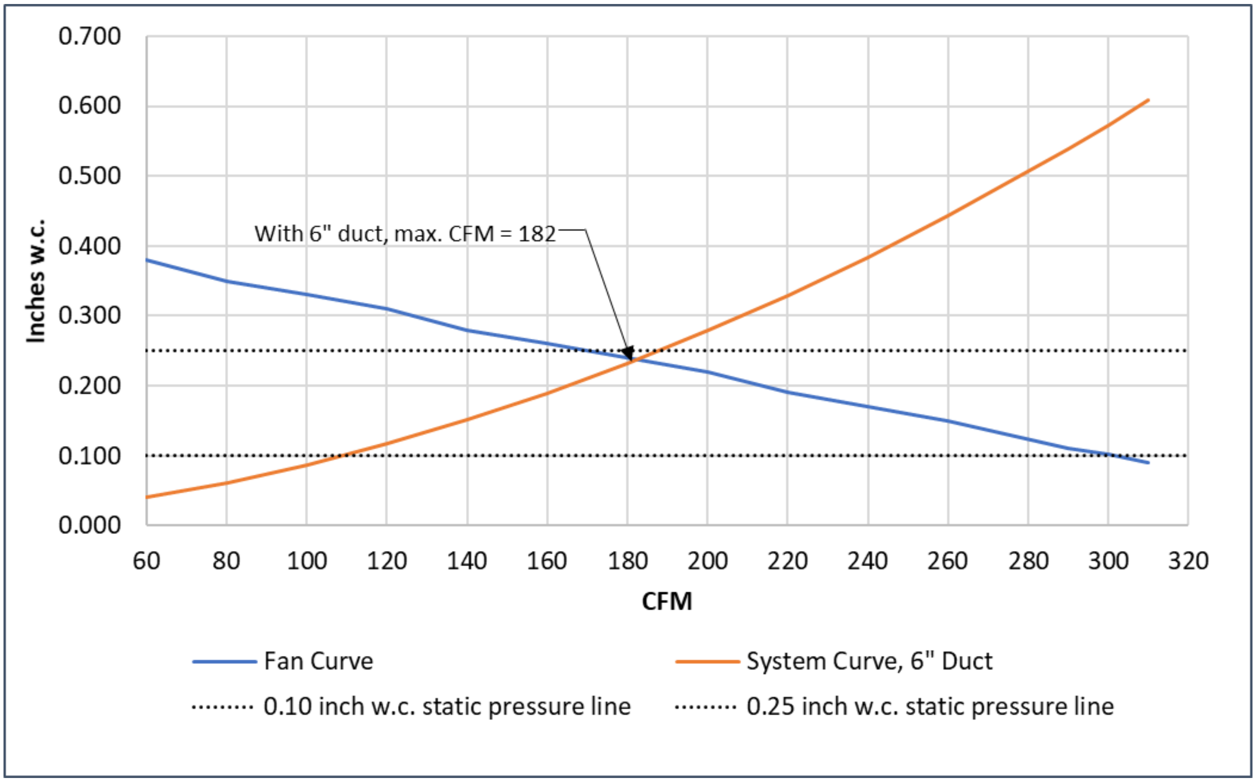

Figure 10: Typical kitchen range hood system and fan curves.

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 (NIA). The NIA is calculated from the intersection of the airflow curve and a nominal system curve (as in Figure 10). The nominal system curve is calculated using ten 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 requirements will likely provide less than 70 percent capture efficiency and 250 cfm airflow as installed, so 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.

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 the California Energy Code as shown below. See Section 7.2 of this report for marked-up code language.

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)2Avi (for high-rise dwelling units): The proposed change extends existing sound requirements for range hoods to kitchen exhaust systems and modifies requirements for kitchen exhaust systems in multifamily dwelling units that are new construction, additions, or in existing kitchen ventilation systems that are altered. The exhaust system must comply with at least one of the following:

1. A vented kitchen range hood with a minimum capture efficiency of 70 percent 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 of 250 cfm 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 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.

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 extends existing sound requirements for range hoods to kitchen exhaust systems and modifies requirements for kitchen exhaust systems in multifamily dwelling units that are new construction, additions, or in existing kitchen ventilation systems that are altered. The exhaust system must comply with one of the following:

1. A vented kitchen range hood with a minimum capture efficiency of 70 percent 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 of 250 cfm 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 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.

Section 141.0(a) Additions

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

Section 141.0(b) Alterations

Alterations 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.

No changes are needed to the language in Section 150.2 (low-rise dwelling unit additions and alterations) since 150.0(o) is already listed as a requirement. Alterations would not need to follow the proposed requirement.

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 will add a requirement that verification of the range hood include the rated capture efficiency as listed by HVI, 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 will add a requirement that verification of the range hood include the rated capture efficiency as listed by HVI, 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 will 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: Will add a description of the new requirements proposed by this submeasure.

Section 4.3.2.4 – Compliance and Enforcement: Will 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: Will summarize the requirement and add capture efficiency to certificate of compliance enforcement requirements and CF2R-MCH-01 listings.

Section 4.6.7 – Local Exhaust: Will 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: Will add a description of the new requirement.

Section 4.6.7.2 – Continuous Local Exhaust: Will 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 will have to be added.

2.2.4 Regulatory Context

2.2.4.1 Existing Requirements in the California Energy Code

There are no relevant existing requirements in the California Energy Code 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 3 sones at one or more airflow settings greater than or equal to 100 cfm. 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.

Section 150.0(o) and Section 120.1(b)2 also 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.

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.

The Statewide CASE Team investigated whether the Fan Energy Index (FEI) proposal would affect this equipment. Because that requirement is for equipment of 5 horsepower (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, and to recommend a minimum capture efficiency based on this method. The Statewide CASE Team is collaborating with this working group.

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 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.
- **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.
- **Construction Phase:** The project team installs the compliant kitchen hood documenting compliance documentation. 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 will 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 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

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 may 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.

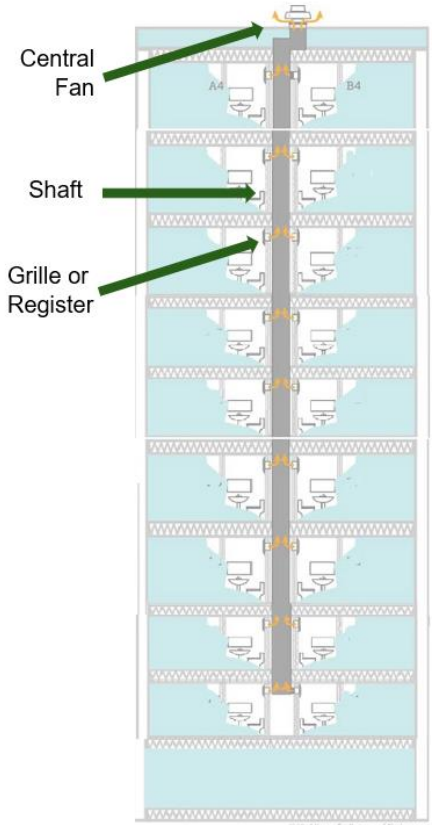

Figure 11. Diagram of central ventilation duct system components.

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)Ei 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 run 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 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.

Figure 12 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.

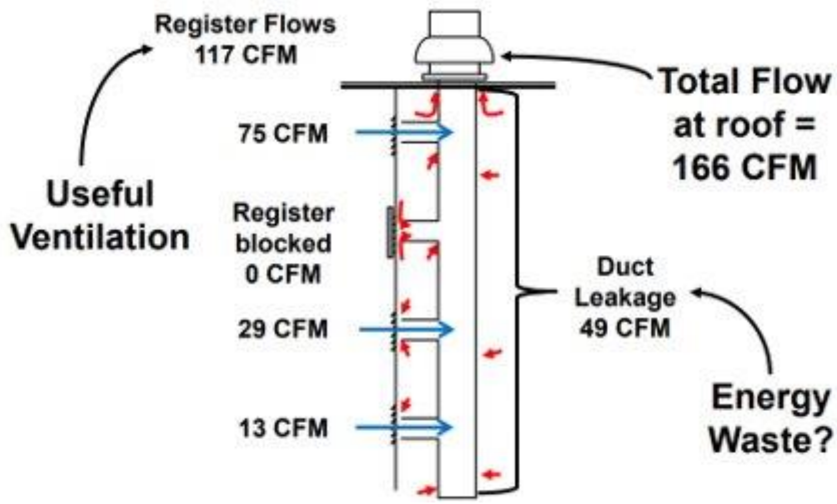

Figure 12: Ventilation duct leakage, with hypothetical flow rates.

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, a HERS rater or 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 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 or HERS Rater can use sampling for the fan pressurization test using the sampling protocols, with a higher sampling rate for this measure, presented in Section 7.3.2. In addition, the ATT or HERS Rater 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).

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 the California Energy Code as shown below. See Section 7.2 of this report for marked-up code language.

SECTION 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

Section 140.4(l): 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 6percent 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(b)2D Altered Duct Systems and Section 141.0(b)2E Altered Space-Conditioning Systems (for Alterations, Prescriptive Approach): Adds criteria in Section 140.4(l)3 to the list of criteria that would require duct sealing under certain alterations.

Additions would need to follow proposed language for new construction. No changes are needed to Section 150.2 (which covers low-rise dwelling units additions) since Sections 150.0(a) through (q) are already required.

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 a HERS Rater to test at least one in three central ventilation duct systems for verifying the requirements in Section 140.4(l)3
.

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, so no changes are needed to allow ATTs to conduct the duct leakage test in Section 140.4(l)3.

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 140.4(l)3.

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

The revised language will state that sampling can be used for duct testing following RA2.6.2 procedures. If sampling is used for this measure, a sampling group will 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.

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 inch 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 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

For the nonresidential ACM reference manual, the measure will require modifications in section 5.7 HVAC Secondary Systems. Specifically, the proposal will modify the ACM guidance on the following modeling inputs. For the fans, the team did not modify the space conditioning system but modified the outdoor air supply which tempers the air before entering the apartments. The model used in this anlaysis had a DOAS providing conditioned outdoor air to the building.

- 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. For example, assuming 6 percent leakage, a building for which dwelling units need 5,000 cfm of airflow should deliver 5,300 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 used a lower assumption (125 Pa) as a conservative estimate of energy savings. The Statewide CASE Team recommends that the Energy Commission consider adjusting the static pressure for this assumption so as not to overestimate savings from this measure.

See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

The measure will require similar modifications in the Residential ADM Manual in Section 2.4 Building Mechanical Systems.

2.3.3.4 Summary of Changes to the Residential and Nonresidential Compliance Manuals

NONRESIDENTIAL COMPLIANCE MANUAL

Section 2.2.8 – HERS 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.

RESIDENTIAL COMPLIANCE MANUAL

Section 2.5.1 – Measures Requiring HERS 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.

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.

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

- 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 B. Duct Leakage Diagnostic Test, 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 the California Energy Code

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 square feet 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 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.”

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.” Note that “in. wg” is inches water gauge, which is the same as inches w.c. 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 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 or HERS Rater 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 a public stakeholder meeting that the Statewide CASE Team held on August 22, 2019; there is a second stakeholder meeting scheduled for March 26, 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 HRVs and ERVs 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 5 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 5: Example Products of HRVs and ERVs with MERV 13 or HEPA Filter Options

Manufacturer	Product	Product Name	Flowrate (cfm)	Cost ($)	Sensible Recovery Efficiency (%)	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
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. *Sensible recovery efficiency 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 6 provides an overview of ERV and HRV strategies, and design considerations for each approach, based on interviews with three subject matter experts.

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

Table 6: 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) is located on the roof and serves multiple dwelling units, such as a vertical column of units; or located throughout the building and serve 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 13) and ERVs (Figure 14) 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.

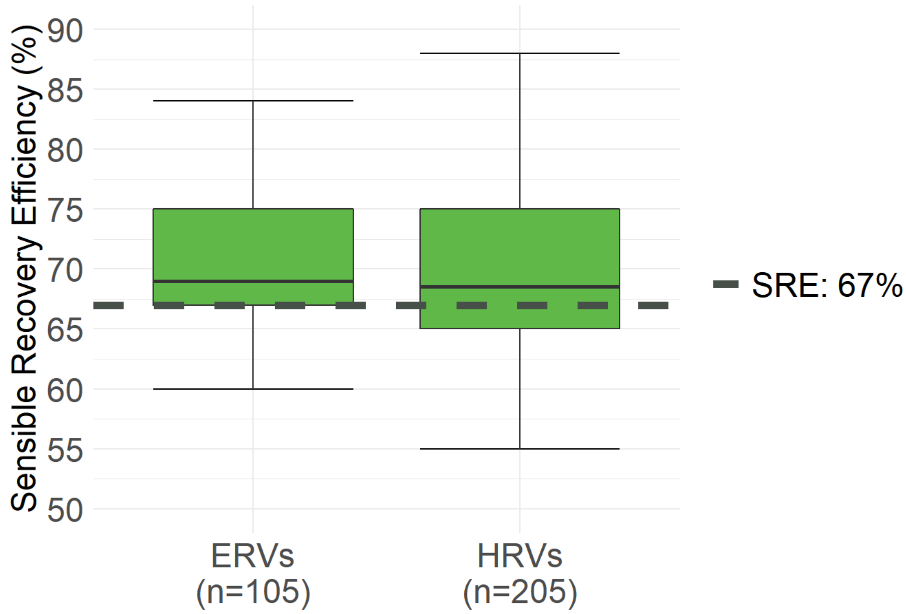

Figure 13: Boxplot of sensible recovery efficiency of ERVs and HRVs (30-100cfm) from the HVI Certified Products database.

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

The following data was compiled 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 Air Conditioning, Heating, and Refrigerating Institute (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. Sensible recovery *efficiency* (SRE) refers to recovery effectiveness of the entire E/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.

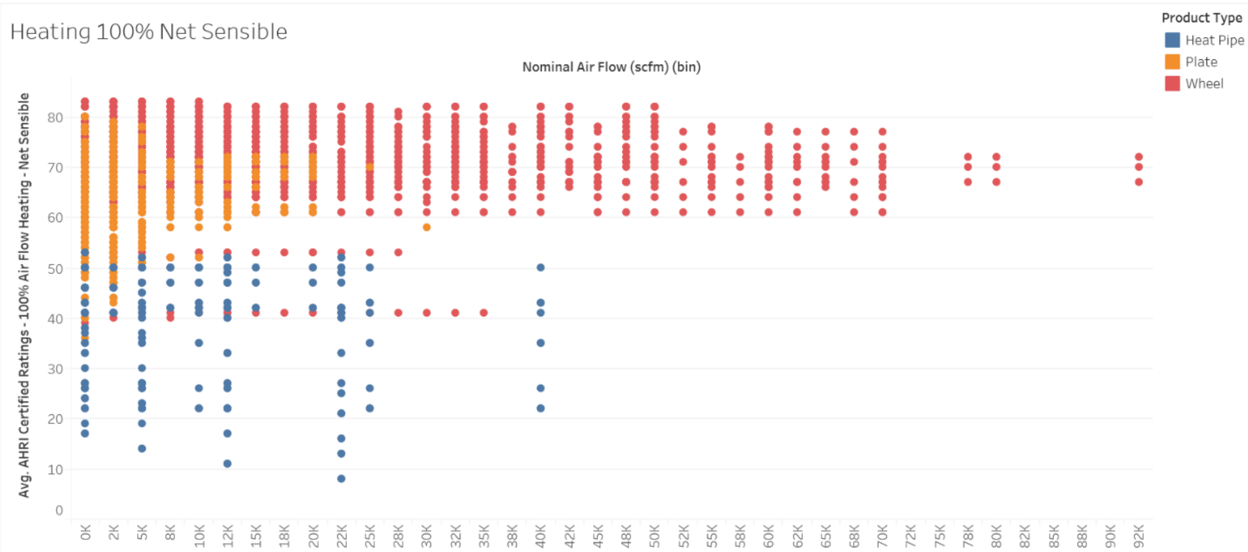

Figure 14. Net Sensible Recovery Effectiveness of E/HRVs in AHRI database (Courtesy Red Car Analytics)

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). As shown in Table 5 (above), most ERVs and HRVs with MERV 13 filtration meet the prescriptive minimum (0.6 W/cfm). As shown in the figure below, most ERVs and HRVs in the HVI database meet the mandatory minimum (1.0 W/cfm).

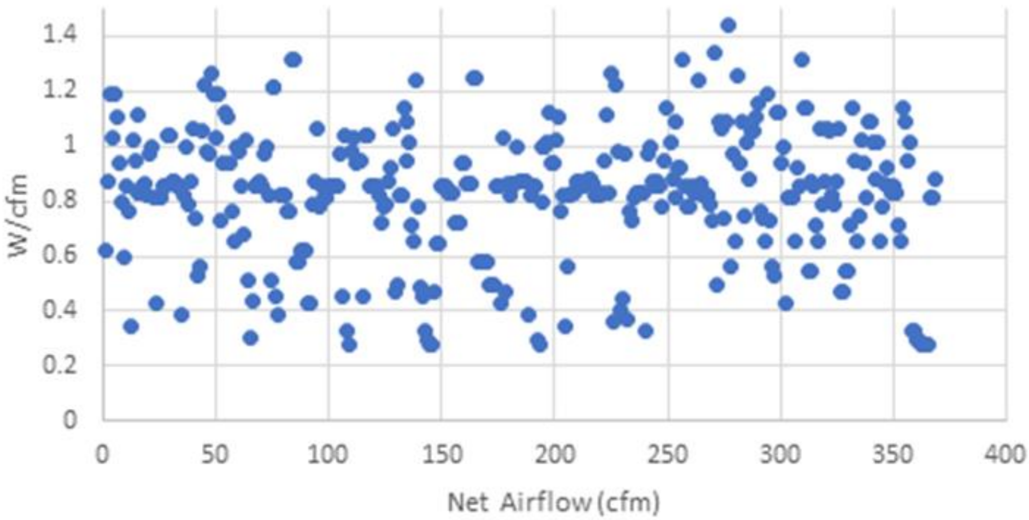

Figure 15. Fan Efficacy of HRVs and ERVs in HVI Database

For central ERVs/HRVs, the fan efficacy requirement would follow the current language in 2019 Title 24, Part 6 Section 140.4(c).

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 E/HRVs, installing central E/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 HRVs or ERVs (typically unitary) in garden-style multifamily projects, and seven of eleven respondents reported they would use HRVs or ERVs (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 E/HRVs 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 plug-and-play 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 ERVs and HRVs in high efficiency projects or as one solution to meeting San Francisco Article 38, various case studies exist that show ERVs and HRVs 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, ERVs or HRVs with low MERV (e.g., MERV 13) 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 ERVs/HRVs, 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 ERVs and HRVs, 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.

3.1.4.2 Creation or Elimination of Businesses in California

There is no expected change.

3.1.4.3 Competitive Advantages or Disadvantages for Businesses in California

There is no expected change.

3.1.4.4 Increase or Decrease of Investments in the State of California

There is no expected change.

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

There is no expected change.

3.1.4.6 Impacts on Specific Persons

There is no expected change.

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 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 (250 cfm) is based on simulations and capture efficiency measurements (using a different capture efficiency rating method than ASTM Standard E3087-18) that indicate a capture efficiency of at least 75 percent is needed to maintain acceptable levels of PM2.5 and NO_2. In order to decrease market burden, the Statewide CASE Team found the airflow corresponding to a capture efficiency of 70 percent through laboratory testing, which was about 250 cfm. In addition, market data indicates that the majority of range hoods with vertical discharge and many with horizontal discharge have an airflow of at least 250 cfm, indicating that the market is equipped to meet this measure.

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.

For products that use a range hood, products that comply with the 2019 Title 24, Part 6 requirements must have an airflow of at least 100 cfm and not exceed three sones (sound-rating). Products meeting these specifications are widely available.

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 April 2020 has not been publicly released. However, HVI plans to begin listing capture efficiencies in October 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. A review of products currently listed by HVI and included in the California Appliance Efficiency Regulations (Title 20) Modernized Appliance Efficiency Database System (MAEDBS) shows there are many products capable of delivering more than 250 cfm at 0.1 inches w.c.

As further market analysis, the Statewide CASE Team reviewed plans for eleven multifamily projects in the 2016 to 2018 CFMNH 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. 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, so 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).

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
- Three 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 range hood testing laboratory to measure capture efficiency for a sample of range hood products. It was 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 build up, wear and tear, or other factors. 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 wide 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.

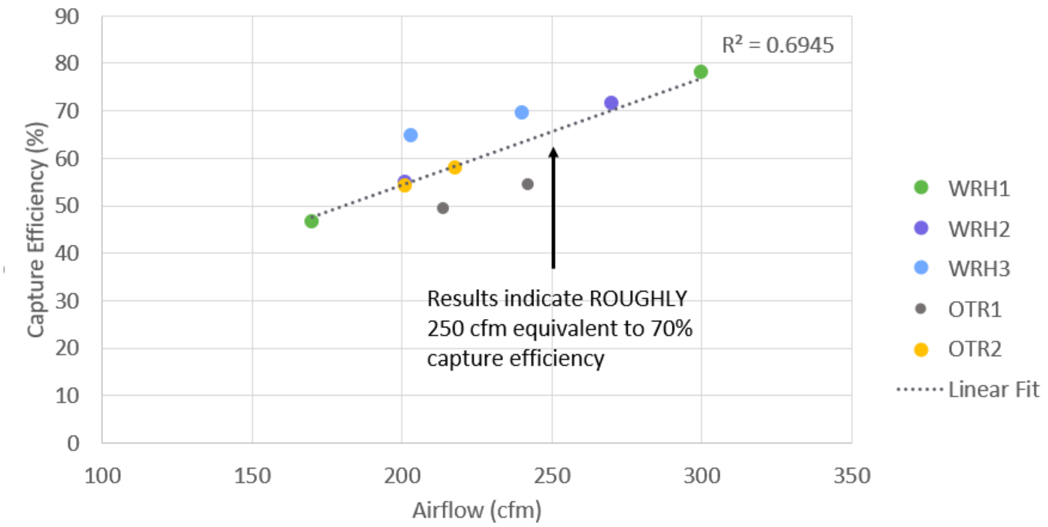

Figure 16. Capture efficiencies of example undercabinet and microwave range hoods.

Figure 16 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) a 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 0.6945) to the capture efficiency and airflow results and found that a capture efficiency of 70% corresponded to an airflow slightly greater than 250 cfm. One product, OTR1, had lower capture efficiencies relative to airflow which would make the trendline show a higher airflow needed to obtain 70% capture efficiency. OTR1 may be performing worse because OTRs may have lower capture efficiencies than undercabinet range hoods but there is currently not enough data to show this. Without the OTR1 product, the R-squared value increases to 0.87 but the trendline is not affected significantly and shows capture efficiency of 70% corresponding slightly more closely to 250 cfm.

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

Previous research (conducted using the “pollutant-method” for testing rather than ASTM Standard E3087-18) shows that capture efficiency generally increases with airflow. As described in Section 3.2.2.2 above, laboratory testing has shown that a capture efficiency of 70 percent may roughly be equivalent to an airflow 250 cfm. Consequently, the Statewide CASE Team used market availability data to investigate availability of products with an airflow of at least 250 cfm.

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 7 and Table 8 show products in the HVI database that have a minimum airflow rating of 250 cfm at a static pressure of 0.1 inches w.c. or higher. For most manufacturers, there was at least one product that complied with the proposed requirement. About 46 percent percent of microwave and undercabinet range hoods with horizontal discharge and 73 percent of those with vertical discharge in the HVI database met the proposed requirement of at least 250 cfm at a static pressure of 0.1 inches w.c. or higher. All chimney and island range hoods in the HVI database met the proposed requirement for both vertical and horizontal discharge.

Table 7: Count of Microwave and Undercabinet Range Hoods That Could Meet Proposed Requirement (Horizontal Discharge)

Range Hood Type	Models			Manufacturers	
	Total	Count	Percentage	Total	Count
Microwave & Undercabinet	129	59	46%	17	20
Microwave Only	81	23	28%	10	12
Chimney & Island Hood	3	3	100%	1	1

Table 8: Count of Microwave and Undercabinet Range Hoods That Could Meet Proposed Requirement (Vertical Discharge)

Range Hood Type	Models			Manufacturers	
	Total	Count	Percentage	Total	Count
Microwave & Undercabinet	146	106	73%	18	20
Microwave Only	84	59	70%	11	12
Chimney & Island Hood	66	66	100%	9	9

The Statewide CASE Team also investigated higher airflow minimum requirements because static air pressure in field conditions are almost always higher than test conditions. Table 9 shows the percentage of products in the HVI database that are greater than each of the airflows listed for horizontal and vertical discharge.

Table 9: Fraction of Compliant Products at Varying Minimum Airflow Levels

CFM	Percentage Compliant	
	Horizontal	Vertical
≥200	82%	92%
≥210	80%	90%
≥220	73%	79%
≥230	60%	75%
≥240	48%	75%
≥250	46%	73%
≥260	32%	62%
≥270	30%	51%
≥280	28%	49%
≥290	26%	38%
≥300	23%	31%

Figure 17 and Figure 18 shows market availability of products comparing the rated airflow and sound levels in the HVI database for products with a rated airflow of less than 600 cfm. This analysis included range hoods up to 600 cfm, although the Statewide CASE Team expects that project teams would typically install a range hood of 400 cfm or less in a multifamily kitchen. The yellow dotted box outlines products that would be compliant under the proposed requirement of having a minimum airflow of 250 cfm at 0.1 inches w.c. or higher. Statewide CASE Team noted that:

- The HVI directory lists over 1,000 individual models that were tested at 0.25 inches w.c. but corresponding sone ratings are not reported.
- Data points with similar values in the scatter plot only showing microwave range hood combination products are “jittered”: i.e., spread out slightly so they can be distinguished from one other.

As shown in the below figures, the proposed minimum requirement of 250 cfm for range hoods would cause several products that currently comply with the 2019 Title 24, Part 6 requirement of at least 100 cfm to no longer comply, but most would. Most stakeholders reported in the March 25, 2020 that their projects install range hoods using a vertical configuration[13] in multifamily units, so the vertical configuration values are more applicable to market practice.

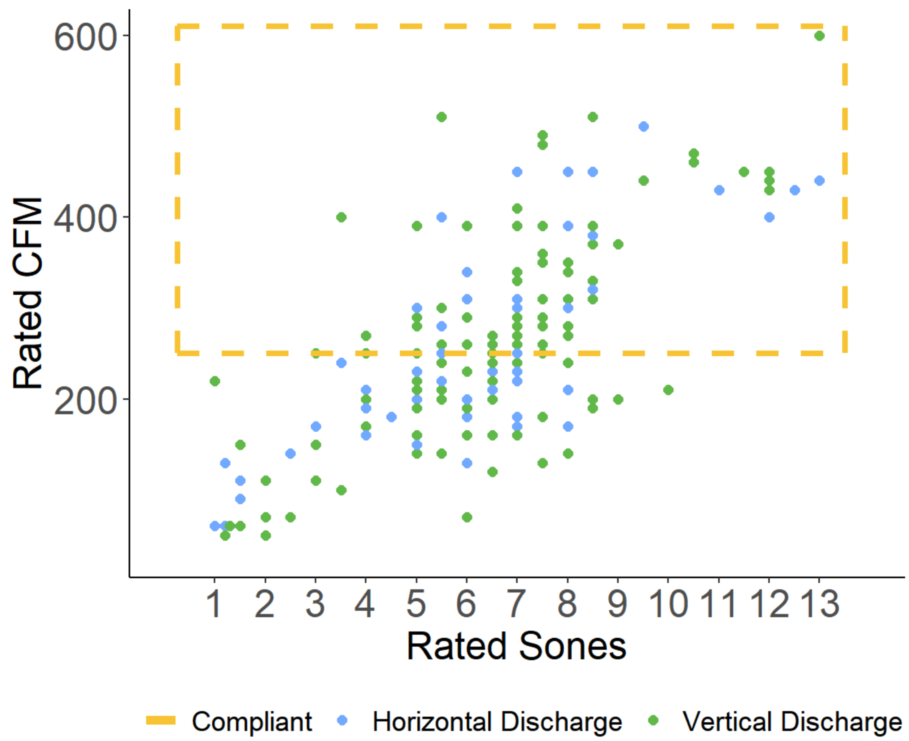

Figure 17: Range hood market availability under compliance pathway.

Source: Home Ventilating Institute 2019.

[13] Vertical configuration refers to how the ductwork interfaces with the range hood immediately at the point of connection with the range hood. An installation that uses a short vertical duct to connect the range hood to a horizontal run-out (for through-wall exhaust) is still considered a vertical configuration.

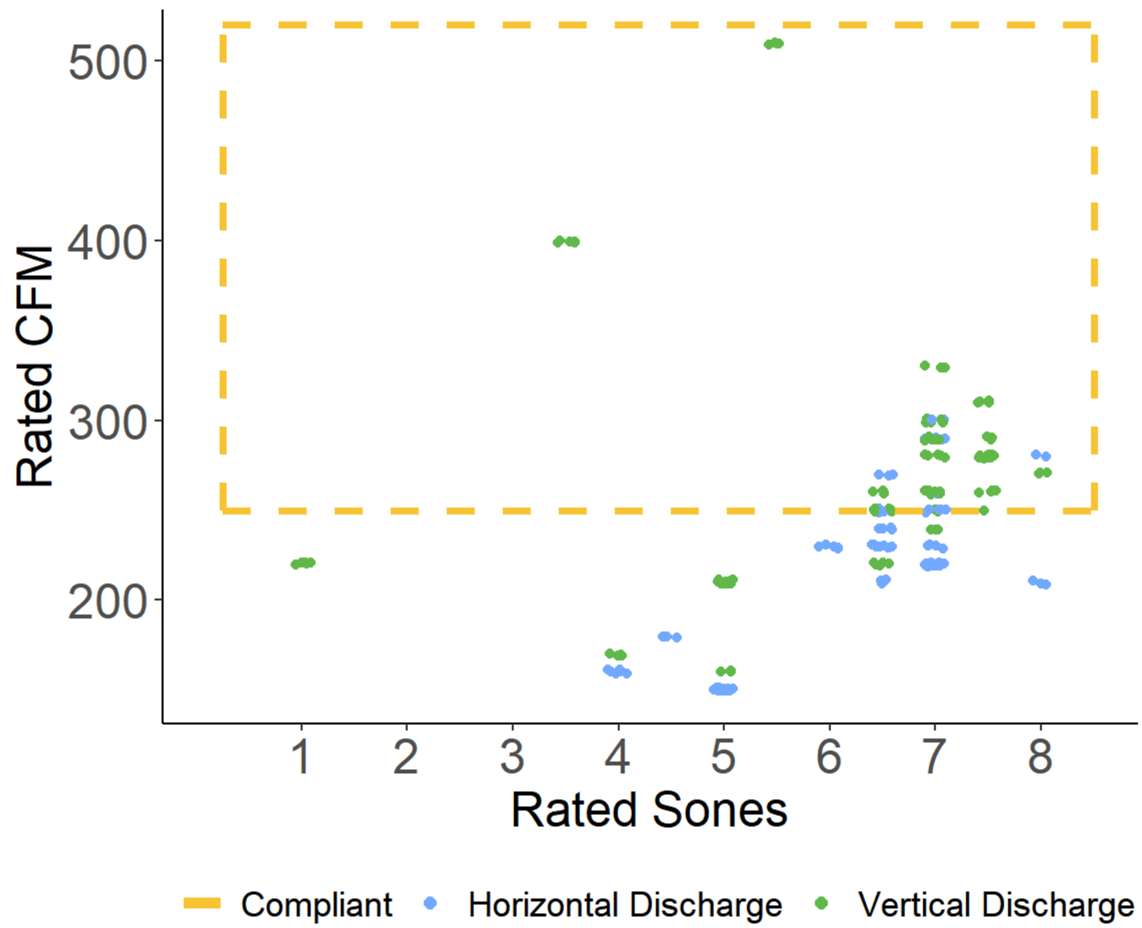

Figure 18: Microwave range hood combination market availability under compliance pathway.

Source: Home Ventilating Institute 2019.

3.2.3 Market Impacts and Economic Assessments

3.2.3.1 Impact on Builders

Builders will need to identify 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 path. Because the compliance paths for downdraft exhaust systems and continuous kitchen exhaust (in non-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 requirement for a minimum of 250 cfm airflow and found no statistical difference in price.

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 will provide improved IAQ to occupants, because it increases the amount of pollutants removed through the kitchen range hood. Section 2.3.2 describes pollution from cooking and gas ranges, and related health impacts.

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 3 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 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 listing by reviewing a few more fields in the HVI 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 product that meets proposal (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.

3.2.4.2 Creation or Elimination of Businesses in California

There is no expected change.

3.2.4.3 Competitive Advantages or Disadvantages for Businesses in California

There is no expected change.

3.2.4.4 Increase or Decrease of Investments in the State of California

There is no expected change.

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

There is no expected change.

3.2.4.6 Impacts on Specific Persons

There is no expected change.

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. 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.

Figure 19: 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 or HERS Rater 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 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 (or their HERS Rater or ATT) 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 or HERS Rater to conduct leakage testing for all or a sample of central ventilation ducts. Builders are accustomed to working with HERS Raters to test duct leakage for 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 a HERS Rater or ATT conduct the duct leakage testing, there will be little impact on building inspectors. Although ATTs and HERS Raters conduct duct leakage testing on some types of commercial and low-rise residential ductwork systems, there may be a learning curve for HERS Raters of 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.

3.3.4.4 Increase or Decrease of Investments in the State of California

There is no expected change.

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

There is no expected change.

3.3.4.6 Impacts on Specific Persons

There is no expected change.

4. Energy Savings

4.1 Submeasure A: ERV/HRV

4.1.1 Key Assumptions for Energy Savings Analysis

As of the Draft CASE Report's date of publication, the Energy Commission has not released the final 2022 TDV factors that are used to evaluate TDV energy savings and cost effectiveness. 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.

When the Energy Commission releases the final TDV factors, the Statewide CASE Team will consider the need to re-evaluate energy savings and cost-effectiveness analyses using the final TDV factors for the results that will be presented in the Final CASE Report.

The Energy Commission is developing a source energy metric (energy design rating or EDR 1) for the 2022 code cycle. As of the date this Draft CASE Report was published, the source energy metric has not been finalized and the Energy Commission has not provided guidance on analyses they would like to see regarding the impact of proposed code changes relative to the source energy metric. Pending guidance from the Energy

Commission, the Final CASE Reports may include analyses on the source energy metric.

Project teams could meet the proposed ERV/HRV requirement using different strategies, including unitary ERVs or HRVs (i.e., one ERV or HRV for each dwelling unit) or central ERVs or HRVs (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 would enable smaller capacity heating and cooling systems to be installed. 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. In reality, projects may see a lower incremental cost than what is shown here, due to heating and cooling downsizing from the ERV/HRV.

4.1.1.1 Unitary ERV for Low-rise Prototypes

For energy savings analysis, the Statewide CASE Team assumed one ERV per dwelling unit (a "unitary ERV" 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 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 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 central ventilation (a dedicated outdoor air system, or DOAS).

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

Prototype Name	Number of Stories	Floor Area (square feet)	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	4-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

[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.

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.

Table 12 presents precisely which parameters were modified and what values were used in the Standard Design and Proposed Design. Specifically, 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 12 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.

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 HRV/ERV 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. It also reduces this by 75 percent at all hours to account for building pressurization when the HVAC system is operational. The Statewide CASE Team conducted analysis of HRV savings for Climate Zone 12 using the midrise prototype under different 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 E/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 11: 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 12: 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/sf-ext-wall (0.000536 m3/s-m2-ext-wall)	0.106 CFM/sf-ext-wall (0.000536 m3/s-m2-ext-wall)	0.0448 CFM/sf-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

	ZoneInfiltration:DesignFlowRate Flow per Exterior Surface Area (EnergyPlus object)	0.0665 CFM/sf-ext-wall (0.000338 m3/s-m2-ext-wall)	0.0665 CFM/sf-ext-wall (0.000338 m3/s-m2-ext-wall)	0.0448 CFM/sf-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 EnergyPlus calculates whole-building energy consumption for every hour of the year measured in kilowatt-hours per year (kWh/yr) and therms per year (therms/yr). The software then applies the 2022 time dependent valuation (TDV) factors to calculate annual energy use in kilo British thermal units per year (TDV kBtu/yr) and annual peak electricity demand reductions measured in kilowatts (kW). CBECC-Res and EnergyPlus 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. 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 13: 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 14: 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
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 15: 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 (or the commercial version of EnergyPlus), differences between the prototype buildings, or other reasons.

Table 16: 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	-58	0	36	7,336
2	-112	0	20	3,738
3	-97	0	18	2,399
4	-104	0	13	2,023
5	-135	0	15	172
6	-141	0	6	(1,662)
7	-174	0	4	(3,358)
8	-140	0	5	(1,358)
9	-109	0	7	375
10	-105	0	8	664
11	9	0	23	8,245
12	-68	0	19	4,922
13	-15	0	16	5,827
14	5	0	20	7,090
15	95	0	4	5,333
16	-47	0	40	9,672

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 17: 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	0	0	35	8,840
2	12	0	26	8,212
3	0	0	12	3,601
4	17	0	13	4,938
5	-2	0	16	4,085
6	5	0	4	1,628
7	1	0	2	671
8	26	0	4	2,749
9	35	0	6	3,982
10	48	0	12	5,448
11	76	0	24	10,181
12	44	0	21	8,492
13	90	0	19	9,629
14	67	0	27	10,398
15	225	0	4	9,510
16	2	0	52	13,738

As shown, for the climate zones where the measure is proposed (Climate Zones 1, 2, and 11-16), 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 of the Draft CASE Report's date of publication, the Energy Commission has not released the final 2022 TDV factors that are used to evaluate TDV energy savings and cost effectiveness. 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.

When the Energy Commission releases the final TDV factors, the Statewide CASE Team will consider the need to re-evaluate energy savings and cost-effectiveness analyses using the final TDV factors for the results that will be presented in the Final CASE Report.

The Energy Commission is developing a source energy metric (energy design rating or EDR 1) for the 2022 code cycle. As of the date this Draft CASE Report was published, the source energy metric has not been finalized and the Energy Commission has not provided guidance on analyses they would like to see regarding the impact of proposed code changes relative to the source energy metric. Pending guidance from the Energy Commission, the Final CASE Reports may include analyses on the source energy metric.

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 the 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 used their kitchen exhaust systems regularly, 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 all range hoods from the HVI database 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.

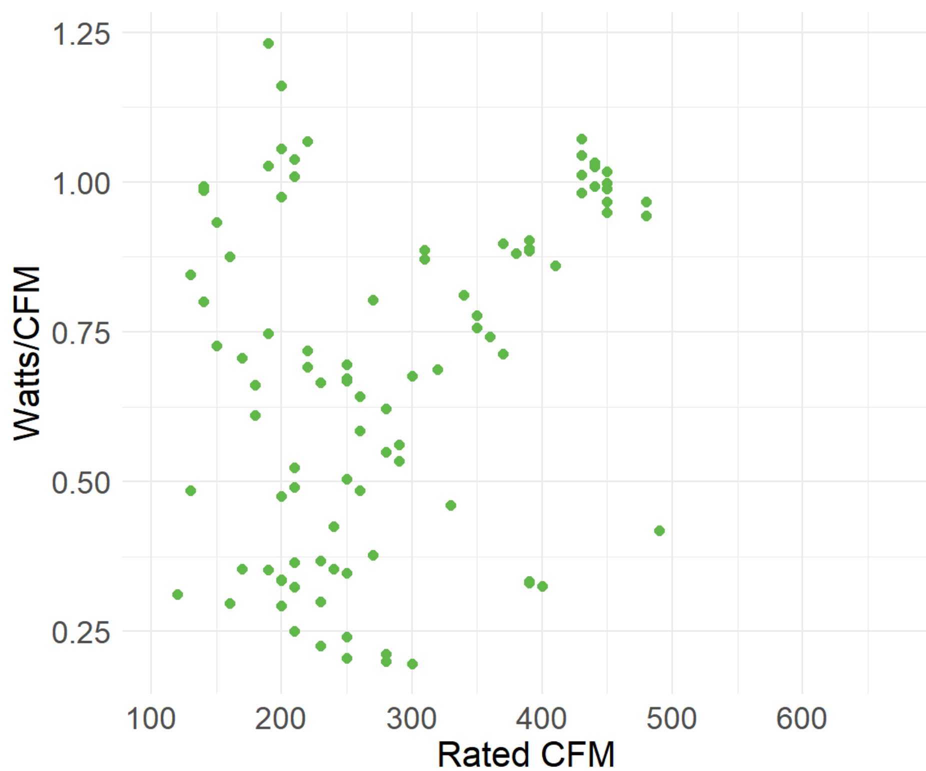

Figure 22: Kitchen range hood power per unit of flow.

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 (not compliant with proposed requirement) and products with air flow of 250 to 400 cfm (compliant with proposed requirement). The analysis found a statistically significant difference (p-value < 0.1) in the watts/cfm of the compliant and non-compliant products. The range hoods with airflow of 100 to 250 cfm (non-compliant) had a *higher* average W/cfm than range hoods with an airflow of 250 to 400 cfm (compliant) indicating worse average fan performance of non-compliant range hoods. This indicates that the proposed requirement should not significantly impact energy and may slightly decrease energy usage.

4.3 Submeasure C: Central Ventilation Duct Sealing

4.3.1 Key Assumptions for Energy Savings Analysis

As of the Draft CASE Report's date of publication, the Energy Commission has not released the final 2022 TDV factors that are used to evaluate TDV energy savings and cost effectiveness. 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.

When the Energy Commission releases the final TDV factors, the Statewide CASE Team will consider the need to re-evaluate energy savings and cost-effectiveness analyses using the final TDV factors for the results that will be presented in the Final CASE Report.

The Energy Commission is developing a source energy metric (energy design rating or EDR 1) for the 2022 code cycle. As of the date this Draft CASE Report was published, the source energy metric has not been finalized and the Energy Commission has not provided guidance on analyses they would like to see regarding the impact of proposed code changes relative to the source energy metric. Pending guidance from the Energy Commission, the Final CASE Reports may include analyses on the source energy metric.

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

Prototype Name	Number of Stories	Floor Area (square feet)	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

[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 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.

4.3.2.2 Submeasure C: Central Ventilation Duct Sealing

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

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

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 is 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 19 summarizes key modeling assumptions used for this measure.

Table 19: 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 leaks17 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/sf, infiltration 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

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 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). Note that, 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. The Statewide Construction Forecasts estimate new construction that will occur in 2023, the first year

[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.

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 20 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 20: 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 21 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 21: 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.

Field measurements from retrofitted buildings illustrate that this measure can significantly reduce fan flow rate, which in turn results in significant energy savings. The Association for Energy Affordability (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.

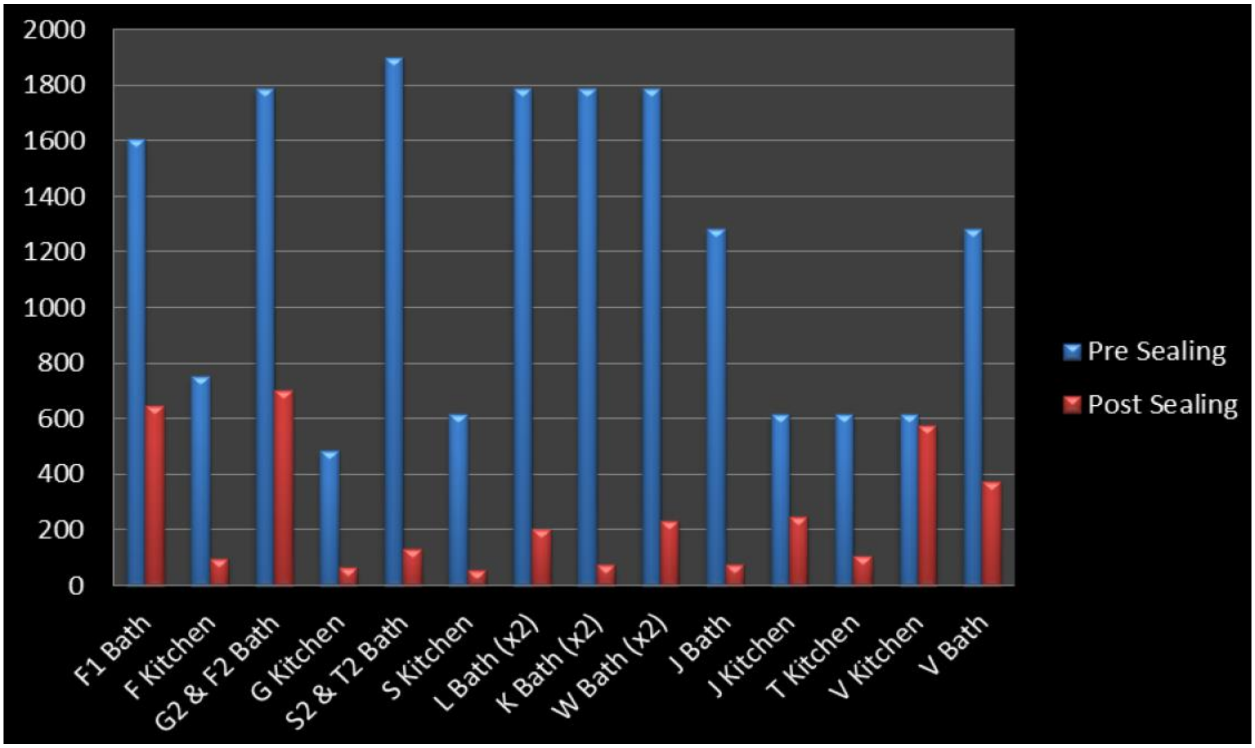

Figure 23: Central fan flow rates (cfm) pre- and post-sealing of central ventilation shafts in retrofitted multifamily building.

Source: AEA 2012

Because of the high energy savings predicted, the Statewide CASE Team used simple 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)

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) 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%), which supports the modeling result for natural gas savings. The team did not have a similar engineering estimate for electricity 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 roughly 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 highrise 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 22 and Table 23 below.

Table 22: 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

[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 23: 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
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 984.1.2. 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, particularly garden-style buildings. This is because central systems, such as ERV serving multiple dwelling units, will require penetration of party walls. In addition, interviews with six multifamily raters and mechanical engineers indicated that unitary ERVs and HRVs are more common than a centralized approach in low-rise buildings, even those with common corridors.

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).

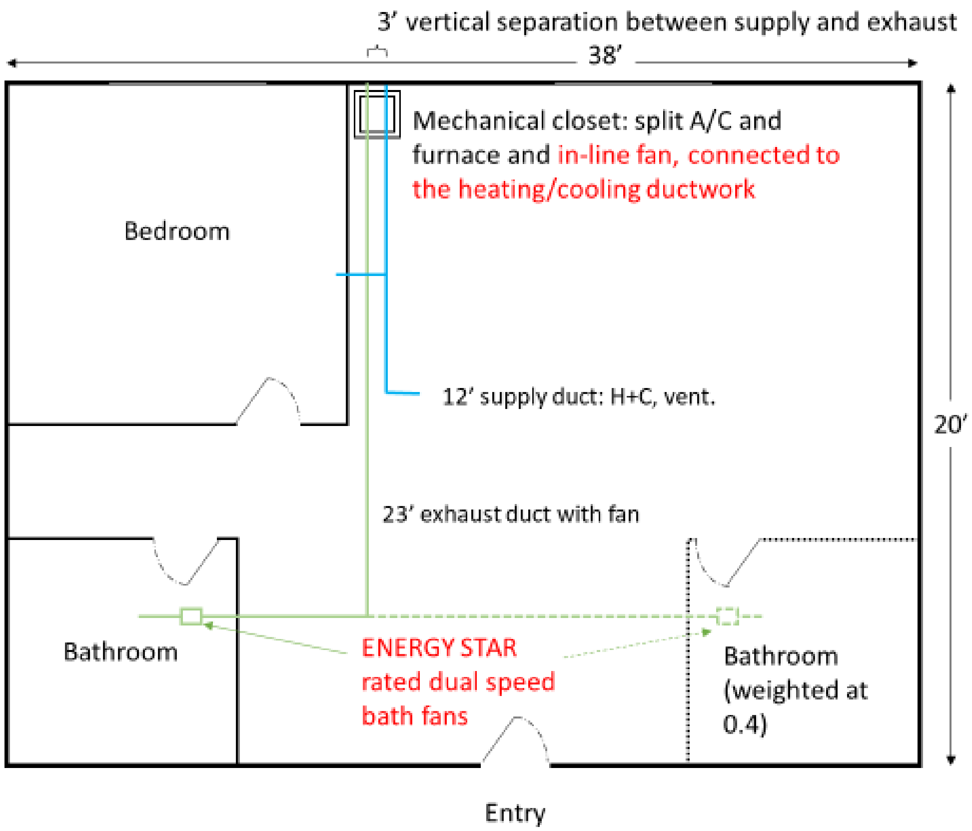

Figure 24: Base case: discrete supply in-line fan.

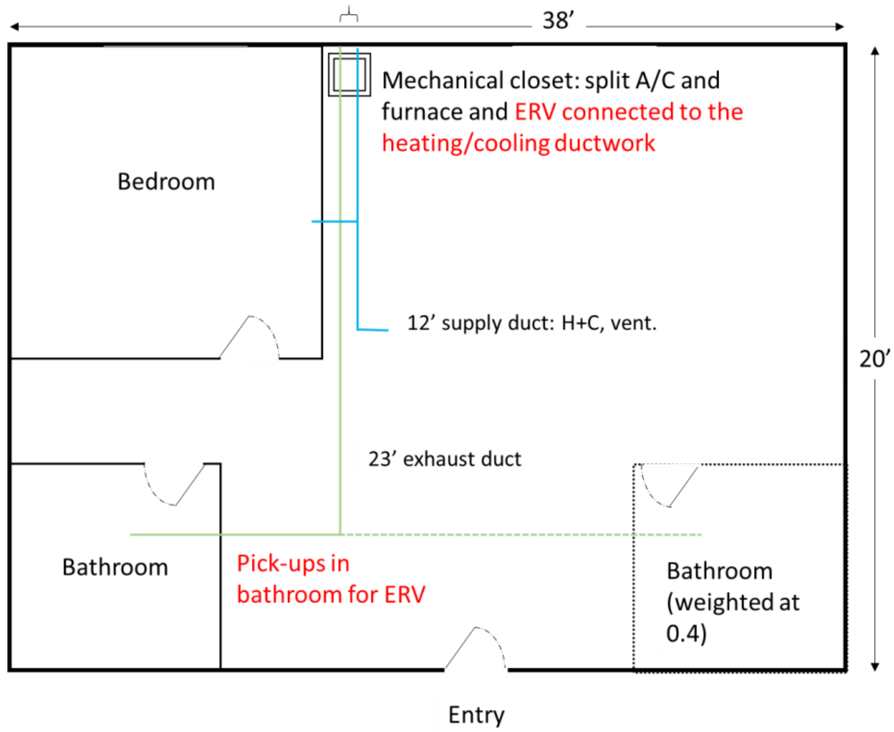

Figure 25: ERV proposed case.

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 systems (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. Note that, because the high-rise prototype assumes that the bottom floor is commercial space, the ERV does not serve this floor.

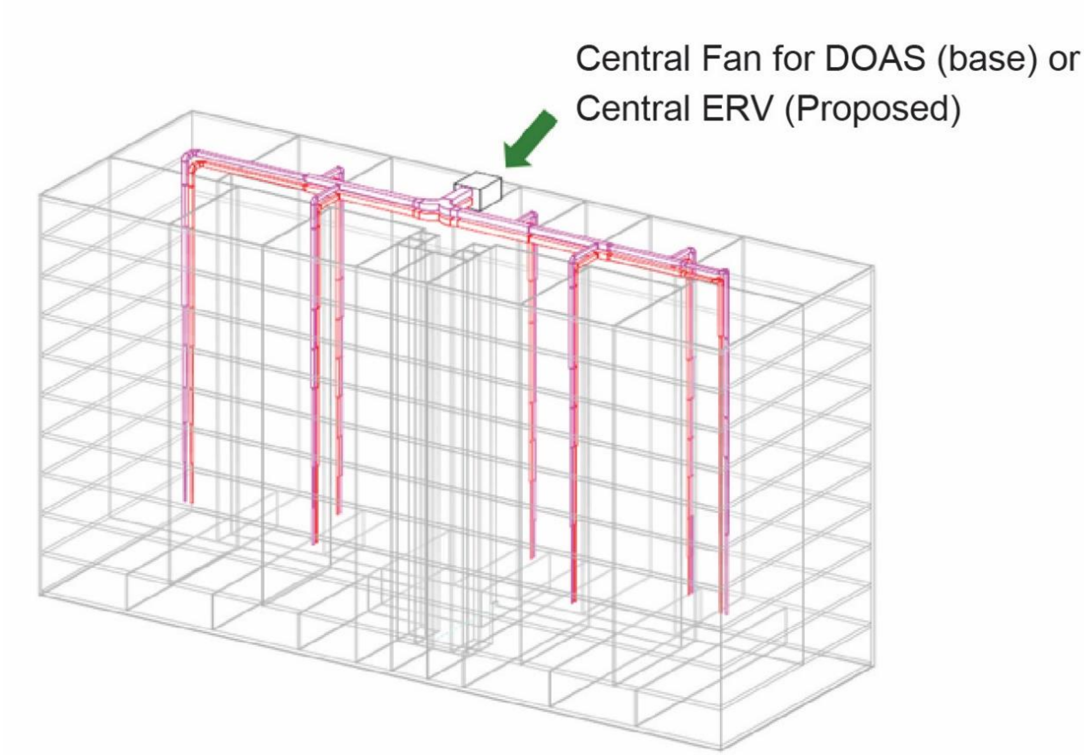

Figure 26: Central ERV strategy for high-rise mixed-use prototype.

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.

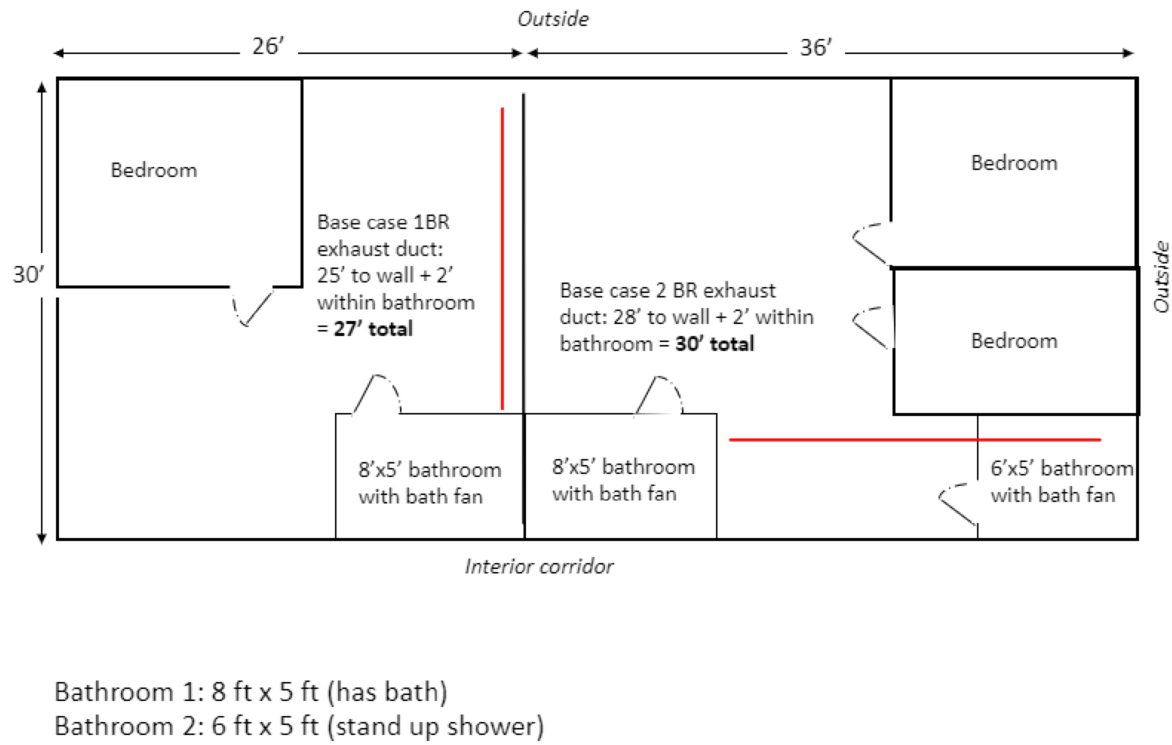

Figure 27: Floor plan of base case for in-unit exhaust ducting.

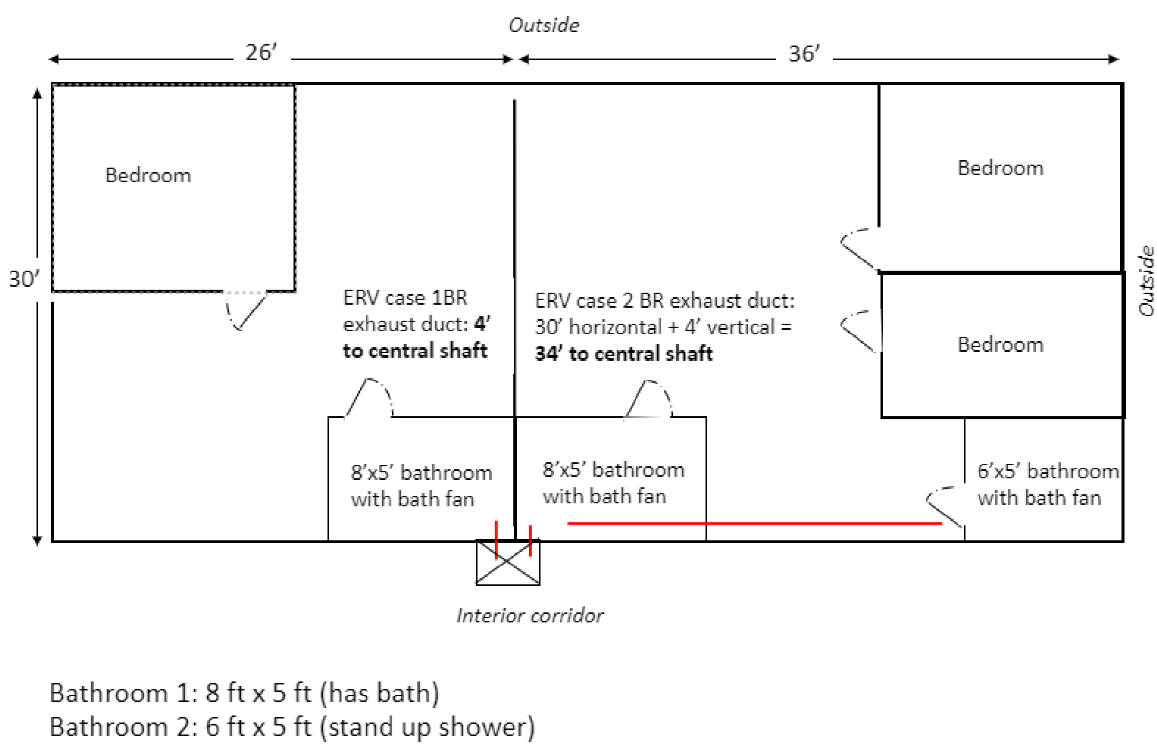

Figure 28: Floor plan of proposed (central ERV) case for in-unit exhaust ducting.

5.1.1.3 Impact of ERV/HRV on Dwelling Unit Square Footage

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

1. For ERVs/HRVs installed in dwelling units with ducted heating/cooling systems, such as those assumed for our assumed system in this report, the E/HRV is installed in the mechanical closet. The E/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 E/HRV into the heating/ cooling system ductwork. Thus, the E/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 ERVs/HRVs installed in dwelling units with non-ducted heating/cooling systems (mini-splits, electric resistance heaters), the E/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 E/HRV in the soffit. The E/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 E/HRV used this strategy.

For the central ERV, both the base case (DOAS ventilation) and proposed ERV 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 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

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 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.

Table 24 shows results for low-rise garden-style units.

Table 24: 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 25: 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
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 26: 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	-$266	$1,396	$1,130
2	-$258	$834	$576
3	-$338	$708	$369
4	-$218	$529	$312
5	-$576	$602	$27
6	-$490	$234	-$256
7	-$676	$159	-$517
8	-$402	$193	-$209
9	-$238	$296	$58
10	-$243	$345	$102
11	$326	$944	$1,270
12	-$29	$787	$758
13	$234	$663	$897
14	$250	$842	$1,092
15	$669	$152	$821
16	-$105	$1,595	$1,489

Table 27: 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	$1	$1,360	$1,361
2	$222	$1,043	$1,265
3	$51	$504	$555
4	$246	$515	$760
5	-$3	$632	$629
6	$81	$169	$251
7	$23	$81	$103
8	$241	$182	$423
9	$344	$269	$613
10	$350	$489	$839
11	$576	$992	$1,568
12	$429	$879	$1,308
13	$690	$793	$1,483
14	$495	$1,106	$1,601
15	$1,314	$151	$1,465
16	$19	$2,097	$2,116

Table 27 shows results for the high-rise dwelling units as assumed here – i.e., with bypass. For comparison, the following results in Table 28 shows results that do not include 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). 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 5. 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 28: 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

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 29: Cost Multipliers by Climate Zone

Climate Zone	Material	Equipment	Labor
1	96.4	97.1	130.6

Climate Zone	Material	Equipment	Labor
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 30 and Table 31.

Table 30: 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 31: 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 32: 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 21 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 to develop costs for each case:

- 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 and 75 degrees Fahrenheit.
- 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.
- 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.
- There is no difference in design fee between the proposed and base cases.

Table 33: Cost of Base (Supply Fans) and Proposed Case (Central ERVs)

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 sf			$39,500	5,700 sf			$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 34 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 33 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 34: 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 $(1/1+0.03)^{15}$

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 scenario. 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 $(1/1+0.03)^{15}$ = $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 35: 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	$-		$26	$-	
Proposed	Appliance: ERV*	$889	$125	$1,053	$571	$80	$676
	Filter: MERV13	$39	$-		$25	$-	
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 36: 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 ERVs, 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 37: 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 Exhaust Fans	$106	164	$24,570	328	$59,296				
ERVs	$106					1	$40,000	8	$40,848
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
Startup, Balancing, & Commissioning	$104			144	$15,018			144	$15,018
Insulation Budget		1,600 sf			$32,000	3,200 sf			$64,000
Electrical Budget					$10,000				$10,000
		Mark Up		**Rate**		**Mark Up**		**Rate**	
		Taxes for material cost only (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 replacement 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 34) with the IMC replacement Cost in 2023 ($).

Table 38: Incremental Measure Cost (IMC) for Replacement by Climate Zone – Central ERV

Climate Zone	Incremental Equipment	Incremental Materials	Incr. Labor	Incr. Markups	IMC Replacement	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 measures are not proposed for alterations, 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 39 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 ERVs, 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.

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 39: 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

Table 40: 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

Table 41: 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	$1,130	$618	1.8
2	$576	$557	1.0
3	$369	$594	0.6
4	$312	$581	0.5

5	$27	$619	0.0
6	$(256)	$616	(0.4)
7	$(517)	$661	(0.8)
8	$(209)	$635	(0.3)
9	$58	$604	0.1
10	$102	$626	0.2
11	$1,270	$619	2.1
12	$758	$640	1.2
13	$897	$620	1.4
14	$1,092	$622	1.8
15	$821	$715	1.1
16	$1,489	$619	2.4

Table 42: 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	$1,361	$917	1.5
2	$1,265	$1,003	1.3
3	$555	$1,008	0.6
4	$760	$1,006	0.8
5	$629	$918	0.7
6	$251	$915	0.3
7	$103	$943	0.1
8	$423	$941	0.4
9	$613	$916	0.7
10	$839	$940	0.9
11	$1,568	$941	1.7
12	$1,308	$943	1.4
13	$1,483	$940	1.6
14	$1,601	$915	1.8
15	$1,465	$929	1.6
16	$2,116	$919	2.3

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 not affect alterations. 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).

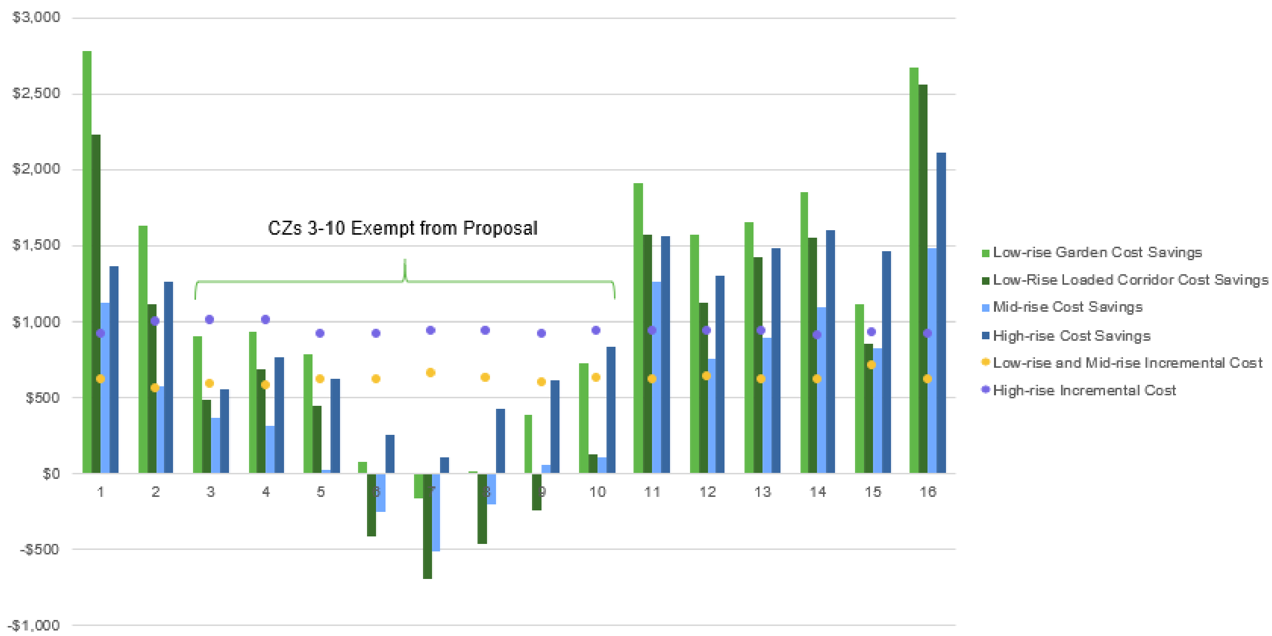

Figure 29. HRV/ERV Cost – Benefit Analysis Summary

5.2 Submeasure B: Kitchen Exhaust Minimum Capture

5.2.1 Cost Impact Investigation Methodology

The code change proposal will not modify the stringency of the existing California Energy Code, so the Energy Commission does not need a complete cost-effectiveness analysis to approve the proposed change. Section 5 of CASE Reports typically presents a detailed cost-effectiveness analysis. For this proposed change, 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.

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 with a minimum airflow of 250 cfm at 0.1'' w.c. static pressure or greater), with those that comply with the current requirement but not proposed requirement (“noncompliant” products: vented range hood with airflow between 100 and 250 cfm at 0.1” w.c.). 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 of 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.

Sample sizes were fifteen and products were added (through random sampling) after preliminary cost collection to increase precision of the estimates as needed. Precision of estimates were all under 20 percent.

Because capture efficiency is not available for range hoods 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 with minimum capture efficiency of 70 percent). 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

Table 43 and Table 44 below show the average prices found for a sample of products that would be compliant and non-compliant with the proposed requirement. On average, compliant products were found to be cheaper than non-compliant products for both range hood types. However, using the Welch’s t-test, the Statewide CASE Team found that average price differences were not significant at the 10 percent significance level, since p-values were greater than 0.1.

Table 43: Sampled Costs of Microwave Range Hood Products

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (one-tailed)
Microwave Range Hood Non-Compliant: 100-250 cfm	$453	$168	15%	15	86	0.42
Microwave Range Hood	$464	$167	14%	16	79	

Compliant: ≥250 cfm						

Table 44: Sampled Costs of Undercabinet Range Hood Products

	Average Price	Standard Deviation	Precision	Products Sampled	Total Products	p-value (one-tailed)
Undercabinet Range Hood Non-Compliant; 100-250 cfm	$585	$282	16%	19	64	0.19
Undercabinet Range Hood Compliant; ≥250 cfm	$508	$253	14%	20	42	

Figure 30 and Figure 31 show the costs collected for each of the range hood types. The figures show that prices of the range hoods vary widely and that the price ranges for both compliant and non-compliant products are in the same range.

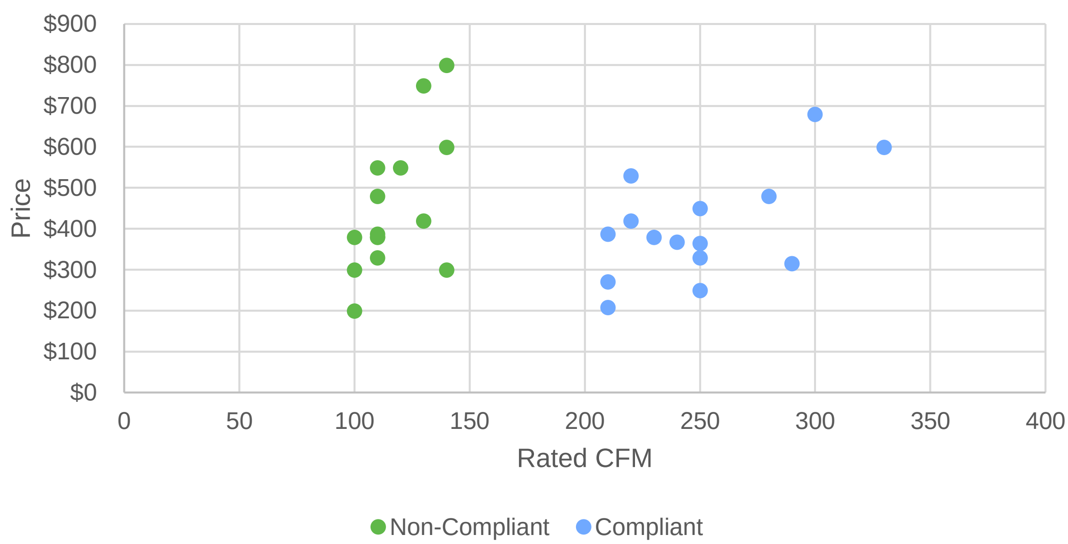

Figure 30: Prices of compliant and non-compliant over-the-range microwaves.

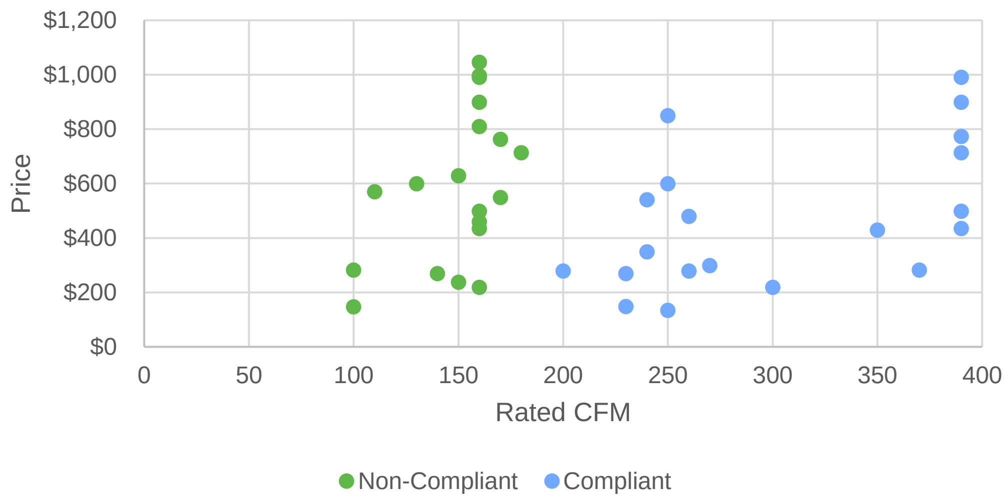

Figure 31: Prices of compliant and non-compliant undercabinet range hoods.

Based on this analysis, the Statewide CASE Team found no statistical difference in prices for range hoods that would comply with the proposed requirement, and those that comply with the current requirement but would not comply with the proposed requirement.

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-Comm 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 highrise multifamily buildings at 125 to 250 Pa (0.5 to 1 inch 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.

Table 45 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 45: 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

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 46: 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) 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) = 3.14SF 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 47.

Table 47: 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/gal
Coverage – square feet (SF) per gallon – 125 linear feet x 3/12 ft wide	31 SF/gal
Coverage per shaft – vertical seams plus connection seams Length of seam from Table 48/ 125 LF/gal. = 262/125=	2.1 gal./ shaft
Cost per shaft – branches Area of branch from Table 48 / 31 SF/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) = 26.4 x 1.1	21 Gallons
Gallon cost (web pricing)	$35.95/gal
Total for all 7 shafts in building	$734
Cost per dwelling unit – 1015/117	**$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 Square Foot (SF) 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 (LF) per RS Means reference number 099113800120.
- Labor time for area application of sealant = 0.012 hour/square foot (SF) per RS Means reference number 099113601800

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

Table 48: 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 SF
Surface area of branches per shaft with 1 branch/floor 3.14 x 1 per floor x 9 floors	28.3 SF
Surface area of branches on shafts with 2 branches/floor 3.14 x 2 per floor x 9 floors	56.6 SF
labor time, 1 branch/floor shafts 262 LF / shaft x 0.013 hr. per linear foot coated = 3.4 hours 28.3 sf of branch per 1-branch shaft x .012 hr./SF = 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 sf of branch per 2-branch shaft x .012 hr./SF. = 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	$3145.65
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.

5.3.3.2 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 in three 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 fairly inexpensive, 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 HERS Rater or 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 49: 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 50: 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

Costs with Sampling	Count	Labor (hours) each	Total hours	Labor rate per hour	Labor ($) each	Total labor
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, CA city index (Q1 2020) of 131.4 applied. For the testing labor we assumed a crew of one senior field engineer and one junior field engineer would be adequate for the task.

Table 51. 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

5.3.3.3 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 52 compares sealing and testing costs as estimated by this 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 CASE report.

Table 52: 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 are not proposed for alterations, 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 53: 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

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 – 9, so these climate zones will not be affected by this proposed requirement.

Table 54 presents the first-year statewide energy and energy cost savings from newly constructed buildings by climate zone.

Table 55 presents first-year statewide savings from newly constructed buildings by climate zone.

Table 54: 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 (million 2023 PV$)
1	212	(0.001)	0.04	0.01	$0.33

2	1,258	(0.08)	0.11	0.03	$1.05
3	6,104	(0.41)	0.22	0.09	$2.67
4	3,180	(0.22)	0.17	0.04	$1.53
5	565	(0.05)	0.01	0.01	$0.13
6	2,696	(0.32)	(0.07)	0.01	-$0.72
7	2,898	(0.42)	(0.14)	0.01	-$1.53
8	3,790	(0.47)	(0.08)	0.01	-$0.96
9	8,899	(0.81)	0.04	0.05	-$0.02
10	3,144	(0.24)	0.12	0.02	$0.53
11	898	0.03	0.14	0.02	$1.27
12	5,068	(0.18)	0.54	0.09	$4.77
13	1,479	0.02	0.21	0.02	$1.67
14	672	0.02	0.10	0.01	$0.87
15	438	0.05	0.05	0.001	$0.38
16	271	0.0003	0.05	0.01	$0.52
TOTAL	41,573	(3.09)	1.49	0.44	$12.50

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

Table 55: 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)
New Construction	(3.09)	1.49	0.44	77.46
TOTAL	(3.09)	1.49	0.44	77.46

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 United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. The electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard goal of 33 percent renewable electricity generation by 2020.[20] 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.

Table 56 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 232 metric tonnes of carbon dioxide equivalents (Metric Tonnes CO2e) will be avoided.

Table 56: First-Year Statewide GHG Emissions Impacts: ERV/HRV

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a] (Metric Tonnes CO2e)	Natural Gas Savings[a] (million therms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tonnes CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tonnes CO2e)
ERV/HRV	-3.09	-743	0.44	2,378	1,635
TOTAL	-3.09	-743	0.44	2,378	1,635

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 ERVs or HRVs 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.

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

---

[20] When evaluating the impact of increasing the Renewable Portfolio Standard from 20 percent renewables by 2020 to 33 percent renewables by 2020, the California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The incremental emissions were calculated by dividing the difference between California emissions in the CARB high and low generation forecasts by the difference between total electricity generated in those two scenarios.

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 ERVs 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 57 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 57: 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 58 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 58: 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		-1,886
Supply fan (2500-8500 cfm)	494		-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 59: 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 20 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 will provide increased thermal comfort, because it will 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 the team estimates there will 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 team estimates there will be no significant difference in energy use from the proposed requirement.

6.2.3 Statewide Water Use Impacts

The proposed code change will not result in water savings.

6.2.4 Statewide Material Impacts

The proposed measure will 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 will provide significant IAQ benefits. As detailed throughout this report, the kitchen exhaust minimum capture measure will 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 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 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 60: 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 (million 2023 PV$)
1	78	0.003	(0.001)	0.003	$0.10
2	461	0.010	0.024	0.011	$1.03
3	2,237	(0.008)	0.013	0.037	$1.27
4	1,165	0.014	0.050	0.020	$0.92
5	207	(0.001)	(0.002)	0.004	$0.12
6	988	(0.022)	0.043	0.008	$0.23
7	1,062	(0.047)	0.018	0.004	-$0.05
8	1,389	(0.006)	0.110	0.009	$0.45
9	3,262	0.084	0.251	0.028	$2.04
10	1,152	0.040	0.108	0.012	$0.82
11	329	0.027	0.032	0.007	$0.44
12	1,857	0.102	0.181	0.039	$2.24
13	542	0.045	0.045	0.010	$0.69
14	246	0.018	0.026	0.005	$0.31
15	160	0.028	0.023	0.001	$0.19
16	99	0.002	0.003	0.004	$0.14
TOTAL	15,236	0.289	0.923	0.200	$10.93

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

Table 61: 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)
New Construction	0.29	0.92	0.20	71.0
TOTAL	0.29	0.92	0.20	71.0

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 United States Environmental Protection Agency (U.S. EPA) Emissions & Generation Resource Integrated Database (eGRID) for the Western Electricity Coordination Council California (WECC CAMX) subregion. The electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard goal of 33 percent renewable electricity generation by 2020.[21] 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.

Table 57 presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 2,579 metric tonnes of carbon dioxide equivalents (Metric Tonnes CO2e) will be avoided.

Table 62: First-Year Statewide GHG Emissions Impacts

Measure	Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings[a]	Natural Gas Savings[a] (million therms/yr)	Reduced GHG Emissions from Natural Gas Savings[a] (Metric Tonnes CO2e)	Total Reduced CO_2e Emissions[a,b] (Metric Tonnes CO2e)

[21] When evaluating the impact of increasing the Renewable Portfolio Standard from 20 percent renewables by 2020 to 33 percent renewables by 2020, the California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The incremental emissions were calculated by dividing the difference between California emissions in the CARB high and low generation forecasts by the difference between total electricity generated in those two scenarios.

		(Metric Tonnes O2e)			
Central Ventilation	289,283	70	0.20	1,092	1,162
TOTAL	289,283	70	0.20	1,092	1,162

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 will 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 47. 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 63: 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 will provide IAQ benefits. The central ventilation duct sealing measure will 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 will help ensure that central ventilation ducts carrying exhaust air will 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, Alternative Calculation Method (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 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. 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 standard ventilation system will have a heat recovery ventilator (HRV) or energy recovery ventilator (ERV) that meets the requirements in either 140.X(a) or 140.X(b):

a. An ERV or HRV serving one individual dwelling unit shall have 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 have 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(c), 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).

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

…

Alterations would not need to follow the proposed requirement, unless newly installed ventilation equipment is installed. The Statewide CASE Team proposes to add "ventilation" system in the new multifamily chapter to the list of newly installed equipment that must meet requirements.

141.0(b) Alterations

(b) **Alterations.** Alterations to components of existing nonresidential, high-rise residential, hotel/motel, or relocatable public school buildings, including alterations made in conjunction with a change in building

occupancy to a nonresidential, high-rise residential, or hotel/motel occupancy shall meet item 1, and either Item 2 or 3 below:

1. **Mandatory Requirements**. Altered components in a nonresidential, high-rise residential, or hotel/motel building shall meet the minimum requirements in this Section.

   …

2. **Prescriptive approach.** The altered components of the envelope, or space conditioning, ventilation, lighting, electrical power distribution and water heating systems, and any newly installed equipment serving the alteration, shall meet the applicable requirements of Sections 110.0 through 110.9, Sections 120.0 through 120.6, and Sections 120.9 through 130.5.

   …

   3. Performance approach.

   A. The altered envelope, space–conditioning system, ventilation, lighting and water heating components, and any newly installed equipment serving the alteration, shall meet the applicable requirements of Sections 110.0 through 110.9, Sections 120.0 through 120.6, and Sections 120.9 through 130.5.

Draft language for low-rise multifamily buildings:

Section 150.0(o)E

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)E in Climate Zones 1, 2, and 11-16, the standard ventilation system will have a heat recovery ventilator (HRV) that meets one of the following

   a. An ERV or HRV serving one individual dwelling unit shall have 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 have 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(c), 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).

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

				Climate Zone															
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
HVAC SYSTEM	**Balanced Venti-lation***	**Unitary (serving one dwelling unit)**	**Sensory Recovery Efficiency**	067	0.67	NR	NR	NR	NR	NR	NR	NR	NR	0.67	0.67	0.67	0.67	0.67	0.67
			Fan Efficacy (W/cfm)	0.6	0.6									0.6	0.6	0.6	0.6	0.6	0.6
		Central (serving multiple dwelling units)	**Sensory Recovery Efficiency or Effective-ness**	067	0.67									0.67	0.67	0.67	0.67	0.67	0.67
			Bypass Function	Req	Req									Req.	Req.	Req.	Req.	Req.	Req.

*Requirements only apply when using Balanced Ventilation to meet 150.0(o)E.7

…

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 not need to follow the proposed requirement.

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

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)2Avi~~i~~: 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. Single family dwelling unit exhaust system shall meet the requirements of ASHRAE 62.2. Multifamily exhaust systems in non-enclosed kitchens must meet 1, 2, or 3 below, and multifamily 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 of 70 percent, in accordance with ASTM Standard E3087-18, measured at nominal installed airflow described in HVI Standard 920; or

2. A vented range hood with at least one speed setting with a minimum airflow of ~~100~~ 250 cfm 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.

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

…

Alterations would not need to follow proposed requirement..

Draft 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 and ii below.

i. Kitchen exhaust systems ~~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 exhaust systems ~~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. Single family dwelling unit exhaust system shall meet the requirements of ASHRAE 62.2. Multifamily exhaust systems in non-enclosed kitchens must meet a, b, or c below, and multifamily exhaust systems in enclosed kitchens must meet a, b, c, or d below:

a. A vented range hood with at least one speed setting with a minimum capture efficiency of 70 percent, in accordance with ASTM Standard E3087-18, measured at the nominal installed airflow described in HVI Standard 920; or

b. A vented range hood with at least one speed setting with a minimum airflow of ~~100~~ 250 cfm at 25 Pa (0.1 inches w.c.) or higher; or

c. 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

d. Continuous exhaust system with a minimum airflow equal to five kitchen air changes per hour.

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 would not need to follow proposed requirement.

7.2.3 Submeasure C: Central Ventilation Duct Sealing

Draft high-rise multifamily building requirements. The proposed language states that leakage must be confirmed by HERS Rater verification, but the Nonresidential Appendix Section 1.9.1 states that duct leakage verification can be confirmed by an Acceptance Test Technician.

Section 140.4(l). Air Distribution System Duct Leakage Sealing. Duct systems shall be sealed in accordance with 1, ~~or~~ 2, or 3 below:

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.

1. Duct systems serving healthcare facilities shall be sealed in accordance with the California Mechanical Code.

3. Ventilation ducts in multifamily buildings shall meet duct sealing requirements in the California Mechanical Code Section 603.10 and confirmed by HERS Rater verification 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.

Additions would need to follow proposed language for new construction.

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

Alterations would not need to follow the requirements.

Draft 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 by HERS Rater verification 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 RA3.1.4.3at 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.

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 not need to meet the proposed requirement.

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]

For verifying requirements in 140.X, a HERS Rater will determine if an energy recovery ventilator (ERV) or heat recovery ventilator (HRV) is needed based on whether it follow the balanced ventilation path in 120.1(b)Aiv and if it is in Climate Zone 1, 2, or 11 through 16. If so, the HERS Rater 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 140.X 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. Field verify that the bypass function exists and meets the requirements of Table 140.4(e).

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. For verifying requirements in 150.1, a HERS Rater will determine if an energy recovery ventilator (ERV) or heat recovery ventilator (HRV) is needed based on whether it follow the balanced ventilation path in 150.0(o)E and if it is in Climate Zone 1, 2, or 11 through 16. If so, the HERS Rater 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 150.1 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. Field verify that the bypass function exists and meets the requirements of Table 140.4(e).

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 or another directory of certified product performance ratings approved by the Energy Commission for determining compliance. 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 or another directory of certified product performance ratings approved by the Energy Commission for determining compliance. 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.

7.3.2 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 HERS Rater 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. For the leakage requirements in Section 140.4(l)3, a HERS Rater shall identify a group of up to three central ventilation duct systems in the building from which a sample will be selected. 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.

…

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 with the exception of requirements in Section 140.4(l)3.

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 specify that the test be conducted at 50 Pa (0.2 inches w.c.), and language will be revised so that it applies to ventilation duct systems as opposed to space conditioning duct systems.

The revised language will also state that sampling can be used for duct testing following NA1.6 procedures. If sampling is used for this measure, a sampling group will 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 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, and a HERS Rater shall identify a group of up to three central ventilation duct systems in the building from which a sample will be selected.

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 or altered duct system. 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% 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% and a fan power index of 0.6 W/cfm. In all other climates zones the Standard Design is a balanced ventilation system without heat recovery and a fan power index of 0.6 W/cfm. If the Proposed Design is a central ventilation system serving more than one apartment, the Standard Design is also a central ventilation system. 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 to lock out the heat exchanger when outdoor temperatures are cool. In all other climate zones the Standard Design does not have a heat recovery system.
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.

7.4.3 Submeasure C: Central Ventilation Duct Sealing

Section 2.3.3.3 provides a description of proposed changes to the ACM. The Statewide CASE Team will develop marked up language for the final CASE report.

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 will include language that summarizes the requirement. The manual will provide an overview of strategies to meet the requirement, including unitary HRVs or ERVs, 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 will 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.

E/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 E/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 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 E/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 E/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 will stipulate that the HERS Rater must document the sensible recovery efficiency 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 will 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.

7.6 Compliance Documents

Several compliance documents will 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 will 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 will need what changes to cover the new requirements. For this Draft CASE Report, the Statewide CASE Team has not specified exact language for the document updates, but rather highlighted the sections where final language, requirements, and procedures will need to be included.

Table 64: Proposed Changes to Compliance Forms – CF1R

Form Group	Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
CF1R	2019-CF1R-NCB-01-E-PrescriptiveNewly ConstructedBuilding.pdf	Energy consultant	-Ventilation Cooling section will need to adapted to include references to HRV w/ bypass (free cooling)		N/A

Table 65: Proposed Changes to Compliance Forms – CF2R

Form Group	Compliance Form	Who completes?	HRV/ERV	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 packaged balanced systems like HRV/ERV -**G. Other Requirements** will need to reflect HRV/ERV requirements -**H. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**F. Other Requirements** will need to kitchen exhaust requirements	-**H. Air Moving Equipment** will need to reflect central shaft sealing requirements
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 packaged balanced systems like HRV/ERV -**G. Other Requirements** will need to reflect HRV/ERV requirements -**H. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**F. Other Requirements** will need to reflect kitchen exhaust requirements	-**H. Air Moving Equipment** will need to reflect central shaft sealing requirements

Form Group	Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
CF2R	2019-CF2R-MCH-27c-SingleFamilyAndMultifamilyScheudledandRealTimeControl.pdf	Installing Contractor or HERS Rater	-**B. Other Requirements** will need to reflect HRV/ERV requirements -**C. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**B. Other Requirements** will need to reflect kitchen exhaust requirements	-**C. Air Moving Equipment** will need to reflect central shaft sealing requirements
CF2R	2019-CF2R-MCH-27c-SingleFamilyAndMultifamilyScheudledandRealTimeControl.pdf	Installing Contractor or HERS Rater	-**B. Other Requirements** will need to reflect HRV/ERV requirements -**C. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**B. Other Requirements** will need to reflect kitchen exhaust requirements	-**C. Air Moving Equipment** will need to reflect central shaft sealing requirements
CF2R	2019-CF2R-MCH-30-VentilationCooling.pdf	Installing Contractor or HERS Rater	-**A. Central Fan Ventilation Cooling System (VCS) Equipment Information** and **B. Additional Requirements** will need to be reconfigured to document HRV/ERV w/ bypass -Maybe easier to create separate form	N/A	N/A
CF2R	2019-CF2R-MCH-30-VentilationCooling.pdf	Installing Contractor or HERS Rater	-**A. Central Fan Ventilation Cooling System (VCS) Equipment Information** and **B. Additional Requirements** will need to be reconfigured to document HRV/ERV w/ bypass -Maybe easier to create separate form	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** will need to be reconfigured to document HRV/ERV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to add any new kitchen exhaust requirements	N/A

Form Group	Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
				-**C. Kitchen Exhaust System** will need to include fields for any new requirements	
CF2R	2019-CF2R-MCH-32-LocalMechanicalExhaust.pdf	Installing Contractor or HERS Rater	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to be reconfigured to document HRV/ERV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to add any new kitchen exhaust requirements -**C. Kitchen Exhaust System** will need to include fields for any new requirements	N/A

Table 66: Proposed Changes to Compliance Forms – CF3R

Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
2019-CF3R-MCH-27b-Multifamily.pdf	HERS Rater	-Many locations: references to "mechanical supply system, exhaust system, or combination thereof" should be updated to include packaged balanced systems like HRV/ERV -**G. Other Requirements** will need to reflect HRV/ERV requirements -**H. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**F. Other Requirements** will need to reflect kitchen exhaust requirements	-**H. Air Moving Equipment** will need to reflect central shaft sealing requirements

2019-CF3R-MCH-27c-SingleFamilyAndMultifamilyScheudledandRealTimeControl.pdf	HERS Rater	-**B. Other Requirements** will need to reflect HRV/ERV requirements -**C. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**B. Other Requirements** will need to reflect kitchen exhaust requirements	-**C. Air Moving Equipment** will need to reflect central shaft sealing requirements
2019-CF3R-MCH-32-LocalMechanicalExhaust.pdf	HERS Rater	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to be reconfigured to document HRV/ERV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to add any new kitchen exhaust requirements -**C. Kitchen Exhaust System** will need to include fields for any new requirements	N/A

Table 67: Proposed Changes to Compliance Forms – NRCC

Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
2019-NRCC-MCH-E.pdf	Energy Consultant	-Any new NRCI & NRCA forms will need to be added	-Any new NRCI & NRCA forms will need to be added	-Any new NRCI & NRCA forms will need to be added
2019-NRCC-PRF-01-E.pdf	Energy Consultant	-Information about HRV/ERV SRE, bypass will need to be displayed on form	N/A	-Forms will need to indicate whether central shafts requiring sealing verification are present.

Table 68: Proposed Changes to Compliance Forms – NRCA

Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
2019-NRCA-MCH-02-A Outdoor Air.pdf	ATT	-**A. Construction Inspection** will need AT procedure for HRV/ERV verification	N/A	N/A

2019-NRCA-MCH-04a-H-AirDistributionDuctLeakage.pdf	ATT/HERS Rater	N/A	N/A	-**A. Construction Inspection** will need to include requirements for central shafts that is distinct from heating/cooling systems. -**B. Functional Testing** will need procedure for testing central shafts that is distinct from existing procedure for recirculating systems.
2019-NRCA-MCH-04b-A-AirDistributionDuctLeakage.pdf	ATT/HERS Rater	N/A	N/A	-**A. Construction Inspection** will need to include requirements for central shafts that is distinct from heating/cooling systems. -**B. Functional Testing** will 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** will need to include new HRV/ERV requirements.	-**A. Construction Inspection** will need to include new kitchen exhaust requirements. -**B. Functional Testing** will need procedure for range hoods.	-**A. Construction Inspection** will need to include requirements for central shafts that is distinct from heating/cooling systems. -**B. Functional Testing** will need procedure (and requirements) for testing central shafts that is distinct from existing procedure for recirculating systems.

Table 69: Proposed Changes to Compliance Forms – NRCV

Form Group	Compliance Form	Who completes?	HRV/ERV	Kitchen Exhaust	Central Shaft Sealing
NRCV	2019-NRCV-MCH-04a-DuctLeakageTest-NewConst.pdf	ATT/HERS Rater	N/A	N/A	-**A. System Information** will need to include parameters for central shafts that is distinct from heating/cooling systems. -**B. Duct Leakage Diagnostic Test – HCH-04-a – Completely New Duct System** will need inputs for tesing central shaft that are different

					than those for heating/cooling systems.
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 packaged balanced systems like HRV/ERV -**H. Other Requirements** will need to reflect HRV/ERV requirements -**I. Air Moving Equipment** will need to reflect HRV/ERV requirements	-H. **Other Requirements** will need to reflect kitchen exhaust requirements	-I**. Air Moving Equipment** will need to reflect central shaft sealing requirements
NRCV	2019-NRCV-MCH-27c-HighriseResidentialHighriseResidScheduledRealTimeControl.pdf	HERS Rater	-**C. Other Requirements** will need to reflect HRV/ERV requirements -**D. Air Moving Equipment** will need to reflect HRV/ERV requirements	-**C. Other Requirements** will need to reflect kitchen exhaust requirements	-**D. Air Moving Equipment** will need to reflect central shaft sealing requirements
NRCV	2019-NRCV-MCH-32-LocalMechanicalExhaust.pdf	HERS Rater	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to be reconfigured to document HRV/ERV w/ bypass, or add separate section	-**B. Local Mechanical Exhaust System – Fan Selection and Duct Design for Compliance** will need to add any new kitchen exhaust requirements -**C. Kitchen Exhaust System** will need to include fields for any new requirements	N/A

8. Bibliography

n.d. http://bees.archenergy.com/Documents/Software/CBECC-Com_2016.3.0_SP1_Prototypes.zip.

2018 American Community Survey. n.d. *1-Year Estimates.* https://data.census.gov/cedsci/.

Amazon. 2019. *Panasonic FV-10VE1 Intelli-Balance 100 Balanced Air Solution, 50 to 100 CFM - Ceiling or Wall Mount ERV.* https://www.amazon.com/Panasonic-FV-10VE1-Intelli-Balance-Balanced-Solution/dp/B071D6RPFL.

American Aldes. 2018. *H280-SRG Heat Recovery Ventilator.* https://aldes.us/wp-content/uploads/2018/06/h280-srg_spec.pdf.

—. 2014. "FAK-II." https://www.hvacquick.com/catalog_files/Aldes_FAK-II_Specs.pdf.

ASHRAE. 2011. *2011 ASHRAE Handbook - HVAC Applications.*

—. 2019b. *ANSI/ASHRAE/IES Standard 90.1-2019 -- Energy Standard for Buildings Except Low-Rise Residential Buildings.*

Association, National Energy Assistance Directors. 2011. "2011 National Energy Assistance Survey Final Report." Accessed February 2, 2017. http://www.appriseinc.org/reports/Final%20NEADA%202011%20Report.pdf.

ASTM International. 2018. "Standard Test Methods for Determining Air Leakage of Air Distribution Systems by Fan Pressurization." West Conshohocken, PA.

BW Research Partnership. 2016. *Advanced Energy Jobs in California: Results of the 2016 California Advanced Energy.* Advanced Energy Economy Institute.

Calcs Plus. 2013. *U.S. Department of Energy.* https://basc.pnnl.gov/images/heat-recovery-ventilator-hrv-or-energy-enthalpy-recovery-ventilator-erv.

California Air Resouces Board. 2019. "Global Warming Potentials." https://www.arb.ca.gov/cc/inventory/background/gwp.htm#transition.

California Air Resources Board. 2019. *Global Warming Potentials.* https://www.arb.ca.gov/cc/inventory/background/gwp.htm#transition.

California Department of Water Resources. 2016. "California Counties by Hydrologic Regions." Accessed April 3, 2016. http://www.water.ca.gov/landwateruse/images/maps/California-County.pdf.

California Energy Commission. 2015. *2016 Building Energy Efficiency Standards: Frequently Asked Questions.* http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/2016_Building_Energy_Efficiency_Standards_FAQ.pdf.

—. 2019. "2019 Workshops and Meetings." October 17. https://ww2.energy.ca.gov/title24/2022standards/prerulemaking/documents/.

—. 2017. "California Energy Maps." *CA.gov.* https://ww2.energy.ca.gov/maps/renewable/BuildingClimateZonesMap.pdf.

—. 2022. "Energy Code Data for Measure Proposals." *energy.ca.gov.* https://www.energy.ca.gov/title24/documents/2022_Energy_Code_Data_for_Measure_Proposals.xlsx.

—. 2022. "Energy Code Data for Measure Proposals." *energy.ca.gov.* https://www.energy.ca.gov/title24/documents/2022_Energy_Code_Data_for_Measure_Proposals.xlsx.

—. 2019. "Housing and Commercial Construction Data - Excel." https://ww2.energy.ca.gov/title24/documents/2022_Energy_Code_Data_for_Measure_Proposals.xlsx.

—. 2018. "Impact Analysis: 2019 Update to the California Energy Efficiency Standards for Residential and Non-Residential Buildings." *energy.ca.gov.* June 29. https://www.energy.ca.gov/title24/2019standards/post_adoption/documents/2019_Impact_Analysis_Final_Report_2018-06-29.pdf.

California Public Utilities Commission (CPUC). 2015b. "Water/Energy Cost-Effectiveness Analysis: Revised Final Report." Prepared by Navigant Consulting, Inc. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5360.

California Public Utilities Commission. 2015a. "Water/Energy Cost-Effectiveness Analysis: Errata to the Revised Final Report." Prepared by Navigant Consulting, Inc. . http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5350.

Center for Energy and Environment. 2016. "Multifamily Ventilation Assessment and Retrofit Guide." https://www.cards.commerce.state.mn.us/CARDS/security/search.do?method=showPoup&documentId=%7BDB45217D-CD15-483D-87EE-E657487CAA7F%7D&documentTitle=282726&documentType=6.

Center for Energy and Environment. 2019. "Preliminary Air Leakage Results for 16 Common Entry Multi-unit Dwellings." Publication pending. Accessed October 3, 2019.

Chan, Wanyu R., Kumar Sangeetha, Alexandra Johnson, and Brett C. Singer. 2020. *Simulations of Short-Term Exposure to NO2 and PM2.5 to Inform Capture Efficiency Standards.* Berkeley: LBNL.

David Bailey, Dale Herron and Alexander Zhivov. 2012. "U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes." Illinois.

Depot, Home. n.d. *16 in. x 8 in. x 4 ft. Half Section Rectangular Duct.*

Emmerich, Steven J., Tim McDowell, and Wagdy Anis. 2005. *Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use.* National Institute of Standards and Technology. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860985.

Energy + Environmental Economics. 2016. "Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2019 Time Dependent Valuation (TDV) Data Sources and Inputs." Prepared for the California Energy Commission. July. http://docketpublic.energy.ca.gov/PublicDocuments/16-BSTD-06/TN212524_20160801T120224_2019_TDV_Methodology_Report_7222016.pdf.

Eskatel, Daniel Santiago. 2011. *An Experimental Study and Analysis on Vent Cap Performance.* Austin, TX: Office of Graduate Studies, Texas A&M Univertity.

Ettenson, Lara , and Christa Heavey. 2015. *California's Golden Energy Efficiency Opportunity: Ramping Up Success to Save Billions and Meet Climate Goals.* Natural Resources Defense Council & Environmental Entrepreneurs (E2).

fantech. 2019. *HERO 120H Fresh Air Appliance.* https://shop.fantech.net/en-US/pdfGenerator/p402009.

n.d. "Ferguson." https://www.ferguson.com/product/4-ft-26-ga-galvanized-steel-round-duct-pipe-shmp2614p/_/A-ProdFamily-210495.

Goldman, Charles, Merrian C. Fuller, Elizabeth Stuart, Jane S Peters, Marjorie McRay, Nathaniel Albers, Susan Lutzenhiser, and Mersiha Spahic. 2010. *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth.* Lawrence Berkeley National Laboratory.

Gowri, K., D. Winiarski, and R. Jarnagin. 2019. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis.* Pacific Northwest National Laboratory. https://efiling.energy.ca.gov/GetDocument.aspx?tn=65229 .

n.d. "Home Depot ." https://www.homedepot.com/p/16-in-x-8-in-x-4-ft-Half-Section-Rectangular-Duct-RD16X8X48/100199671.

Home Depot. 2019. *Intelli-Balance MERV 13 Filter (8-Pack).* https://www.homedepot.com/p/Panasonic-Intelli-Balance-MERV-13-Filter-8-Pack-FV-FL1310VE1-8PK/310332977.

Home Ventilating Institute. 2019. *HVI Certified Products Directory.* December 20. https://www.hvi.org/hvi-certified-products-directory/section-i-complete-product-listing/.

—. 2020. "HVI Publication 920 - Product Performance Certification Procedure." https://www.hvi.org/HVIORG/document-server/?cfp=HVIORG/assets/File/public/ratings/Publication_920_rev_022820.pdf.

—. 2017. "HVI Tested/Certified Heat Recovery Tentilators and Energy Recovery Ventilators (HRV/ERV)." December 29. https://www.hvi.org/HVIORG/document-server/?cfp=HVIORG/assets/file/public/CPD_files/Sec3_cover.pdf.

Home Ventilating Instutute. 2015. "HVI Publication 916 - Airflow Test Procedure." https://www.hvi.org/HVIORG/document-server/?cfp=HVIORG/assets/File/public/ratings/Publication_916_09292015.pdf.

2019. "Housing and Commercial Construction Data - Excel." https://ww2.energy.ca.gov/title24/documents/2022_Energy_Code_Data_for_Measure_Proposals.xlsx.

International Code Council. 2012. "U.S. Department of Energy." *IECC climate zone map.* https://basc.pnnl.gov/images/iecc-climate-zone-map.

Logue, Jennifer M., Phillip N. Price, Max H. Sherman , and Brett C. Singer. 2011. *A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences.* Berkeley: LBNL.

National Energy Assistance Directors' Association. 2011. *2011 National Energy Assistance Survey Final Report.* http://www.appriseinc.org/reports/Final%20NEADA%202011%20Report.pdf.

National Energy Assitance Directors' Assocation. 2011. *2011 National Energy Assistance Survey Final Report.* http://www.appriseinc.org/reports/Final%20NEADA%202011%20Report.pdf.

Pacific Gas and Electric. 2003. *Nonresidential Duct Sealing and INsulation Code Change Proposal.* Codes and Standards Enhacement Report, Pacific Gas and Electric Company.

Panasonic. 2019. *Intelli-Balance 100 Balanced Air Solution, Cold Climate ERV, 50 to 100 CFM.* https://na.panasonic.com/us/home-and-building-solutions/ventilation-indoor-air-quality/energy-recovery-ventilators/intelli-0.

RCD. 2008. "#8 Product Data Sheet." *RCD Mastics.* Accessed 2020. https://www.nikro.com/media/27401/PDS%20Ductmastic.pdf.

RDH. 2014.

—. 2017. "Air Leakage Control in Multi-Unit Residential Buildings." https://www.rdh.com/wp-content/uploads/2017/07/Air-Leakage-Control-in-Multi-Unit-Residential-Buildings.pdf.

RenewAire. 2019. "Bypass Economizer." Accessed February 26, 2019. https://www.renewaire.com/wp-content/uploads/2017/05/BypassMan_138283_002_JUL19.pdf.

Richardson, David. 2014. "The News." *Archr News .* July 7. https://www.achrnews.com/articles/127038-duct-sealing-side-effects-you-need-to-know.

Rojas, Gabriel, Iain Walker, and Brett Singer. 2017. "Comparing extracting and recirculating residential kitchen range hoods for the use in high energy efficient housing." September. Accessed 2020 30, Jan. https://eta-publications.lbl.gov/sites/default/files/walker_i_-_comparing_extracting_and_recirculating_residential_kitchen_range_hoods_for_the_use_in_high_energy_efficient_housing.pdf.

San Francisco Department of Public Health. n.d. *Article 38 of the San Francisco Health Code.* https://www.sfdph.org/dph/EH/Air/Article38.asp.

Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA). 2005. "HVAC Duct Construction Standards - Metal and Flexible 3rd Ed., 2005." Chantilly, VA: SMACNA.

Singer, Brett C., William W. Delp, and Michael G. Apte. 2012. *Natural Gas Variability in California: Environmental Impacts and Device Performance - Experimental Evaluation of Installed Cooking Exhaust Fan Performance.* Berkeley: LBNL.

Singer, Brett, and Rengie Chan. 2018. "Effective Kitchen Ventilation for ZNE Homes with Natural Gas."

—. 2019. "Effective Kitchen Ventilation for ZNE Homes with Natural Gas."

Springer, David, and Marian Goebes. 2017. "Residential Indoor Air Quality - Final Report." *California Energy Codes & Standards.* September. Accessed February 2019. https://title24stakeholders.com/measures/cycle-2019/res-indoor-air-quality/.

State of California, Employment Development Department. n.d. https://www.labormarketinfo.edd.ca.gov/cgi/dataanalysis/areaselection.asp?tablename=industry .

Steven Winter and Associates. 2013. *Ventilation in Multifamily Buildings.* https://www.energy.gov/sites/prod/files/2013/12/f5/carb_ventilation_webinar.pdf.

Stone, Nehemiah, Jerry Nickelsburg, and William Yu. 2015. *Codes and Standards White Paper: Report - New Home Cost v. Price Study.* Pacific Gas and Electric Company. Accessed February 2, 2017. http://docketpublic.energy.ca.gov/PublicDocuments/Migration-12-22-2015/Non-

Regulatory/15-BSTD-01/TN%2075594%20April%202015%20Codes%20and%20Standards%20White%20Paper%20-%20Report%20-%20New%20Home%20Cost%20v%20Price%20Study.pdf.

Stratton, J. Christ, and Brett C. Singer. 2014. "Addressing Kitchen Contaminants for Health, Low-Energy Homes." January. https://eta.lbl.gov/sites/all/files/publications/lbnl-6547e.pdf.

The Energy Conservatory. 2014. https://energyconservatory.com/wp-content/uploads/2014/07/Duct-Blaster-Manual-Series-B-DG700.pdf.

Thornberg, Christopher, Hoyu Chong, and Adam Fowler. 2016. *California Green Innovation Index - 8th Edition.* Next 10.

TRC. 2019. "Multifamily Prototypes."

TruTech Tools. n.d. Accessed 2020. https://www.trutechtools.com/.

U.S. Census Bureau, Population Division. 2014. "Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2014." http://factfinder2.census.gov/bkmk/table/1.0/en/PEP/2014/PEPANNRES/0400000US06.05000.

U.S. Department of Commerce. 2018. "Characteristics of New Housing." *United States Census Bureau.* Accessed February 2019. https://www.census.gov/construction/chars/.

U.S. EPA (United States Environmental Protection Agency). 2011. "Emission Factors for Greenhouse Gas Inventories." Accessed December 2, 2013. http://www.epa.gov/climateleadership/documents/emission-factors.pdf.

United States Environmental Protection Agency. n.d. *Adsorption-based Treatment Systems for Removing Chemical Vapors from Indoor Air.*

United States Environmental Protection Agency. 1995. "AP 42, Fifth Edition Compilation of Air Pollutant Emissions Factors, Volume 1: Stationary Point and Area Sources." https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors#5thed.

—. 1995. "AP 42, Fifth Edition Compilation of Air Pollutatnt Emissions Factors, Volume 1: Stationary Point and Area Sources." https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors#5thed.

United States Environmental Protection Agency. 2018. "Emissions & Generation Resource Integrated Database (eGRID) 2016." https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

—. 2018. "Emissions & Generation Resource Integrated Database (eGRID) 2016." https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

—. n.d. *How Does PM Affect Human Health?* https://www3.epa.gov/region1/airquality/pm-human-health.html.

Venmar. 2019. *Venmar Evo5 700 HRV HEPA.* https://www.venmar.ca/DATA/DOCUMENT/212_3_en~v~specification-sheet.pdf.

Western Cooling Efficiency Center. 2014. "Multifamily Ventilation Code Change Proposal - Final Report." Prepared for the California Energy Commission.

Wholesale Radon Distributors. 2019. *HERO 120H Fresh Air Appliance.* https://www.wholesaleradon.com/product/hero-120h-fresh-air-appliance/.

Zabin, Carol, and Karen Chapple. 2011. *California Workforce Education & Training Needs Assessment: For Energy Efficiency, Distributed Generation, and Demand Reponse.* University of California, Berkeley Donald Vial Center on Employment in the Green Economomy. Accessed February 3, 2017. http://laborcenter.berkeley.edu/pdf/2011/WET_Appendices_ALL.pdf.

Zehnder. 2019. *Zehnder ComfoAir Q600 ST.* https://zehnderamerica.com/wp-content/uploads/2019/05/Zehnder_ComfoAir_Q600_Specification_2019.05.13.pdf.

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 70 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 not applicable to alterations. Due to cost-effectiveness results, the Statewide CASE Team is proposing this measure in all climate zones except Climate Zone 3 through Climate Zone 9.

Table 70: 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%	6,104	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	80%	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**	**26%**	**13,440**	**4,310,108**	**0%**	**0**

The kitchen exhaust minimum capture efficiency measure is applicable to all new construction buildings in all climate zones but not alterations. Consequently, 100 percent of new construction multifamily buildings will be impacted by the measure.

Table 71: 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 Complete d 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 72 summarizes these assumptions.

Table 72: 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 73.

Table 73: 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 (United States Environmental Protection Agency 2018). This ensures consistency between state and federal estimations of potential environmental impacts. The electricity emissions factor calculated from the eGRID data is 240.4 metric monnes 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 tonnes/GWh.

Avoided GHG emissions from natural gas savings attributable to sources other than utility-scale electrical power generation are calculated using emissions factors specified in Chapter 1.4 of the U.S. EPA's Compilation of Air Pollutant Emissions Factors (AP-42) (United States Environmental Protection Agency 1995). The U.S. EPA's estimates of GHG pollutants that are emitted during combustion of one million standard cubic feet of natural gas are: 120,000 pounds of CO_2 (Carbon Dioxide), 0.64 pounds of N_2O (Nitrous Oxide) and 2.3 pounds of CH_4 (Methane). The emission value for N_2O assumed that low Nox burners are used in accordance with California air pollution control requirements. The carbon equivalent values of N_2O and CH_4 were calculated by multiplying by the global warming potentials (GWP) that the California Air Resources Board used for the 2000-2016 GHG emission inventory, which are consistent with the 100-year GWPs that the Intergovernmental Panel on Climate Change used in the fourth assessment report (AR4). The GWP for N_2O and CH_4 are 298 and 25, respectively. Using a nominal value of 1,000 Btu per standard cubic foot of natural gas, the carbon equivalent emission factor for natural gas consumption is 5,454.4 metric tonnes 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 – \$40/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 (SRE).
- 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. And
- 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 highrise 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[22]; 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. This will encourage tighter duct construction than what is required.

[22] 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 74, Table 75, and Table 76 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 74: Roles of Market Actors in the Proposed Compliance Process – HRV/ERV

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 HRV/ERV equipment to meet filtration, flowrate, SRE, and (if central) bypass requirements. • Layout ductwork for HRV/ERV 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.

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 75: 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. • 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 could indicate which kitchen ventilation pathway 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.
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 • 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.

Table 76: 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.	• 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.	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.

	• Coordinate with commissioning agent/ATT as necessary.	• Easily identify inappropriate substitutions. • Minimize coordination during construction.		
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
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.
HERS Rater/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 Draft CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

This appendix summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the recommendations presented in this report.

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2022 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

- Proposed code changes
- Draft code language
- Draft assumptions and results for analyses
- Data to support assumptions
- Compliance and enforcement, and
- Technical and market feasibility

The Statewide CASE Team hosted one stakeholder meeting for MF IAQ via webinar and has a second meeting scheduled. Please see below for dates and links to event pages on Title24Stakeholders.com.

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/

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 April 2020 and provided updated details on proposed code changes. The second round of meetings introduced early results of energy, cost-effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

Utility-sponsored stakeholder meetings were open to the public. For each stakeholder meeting, two promotional emails were distributed from info@title24stakeholders.com One email was sent to the entire Title 24 Stakeholders listserv, totaling over 1,900 individuals, and a second email was sent to a targeted list of individuals on the listserv depending on their subscription preferences. The Title 24 Stakeholders' website listserv is an opt-in service and includes individuals from a wide variety of industries and trades, including manufacturers, advocacy groups, local government, and building and energy professionals. Each meeting was posted on the Title 24 Stakeholders' LinkedIn page[23] (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,

[23] Title 24 Stakeholders' LinkedIn page can be found here: https://www.linkedin.com/showcase/title-24-stakeholders/.

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.

Table 77: 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 78: 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

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 79: 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 Draft 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 NRACM 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 sf 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 sf 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).

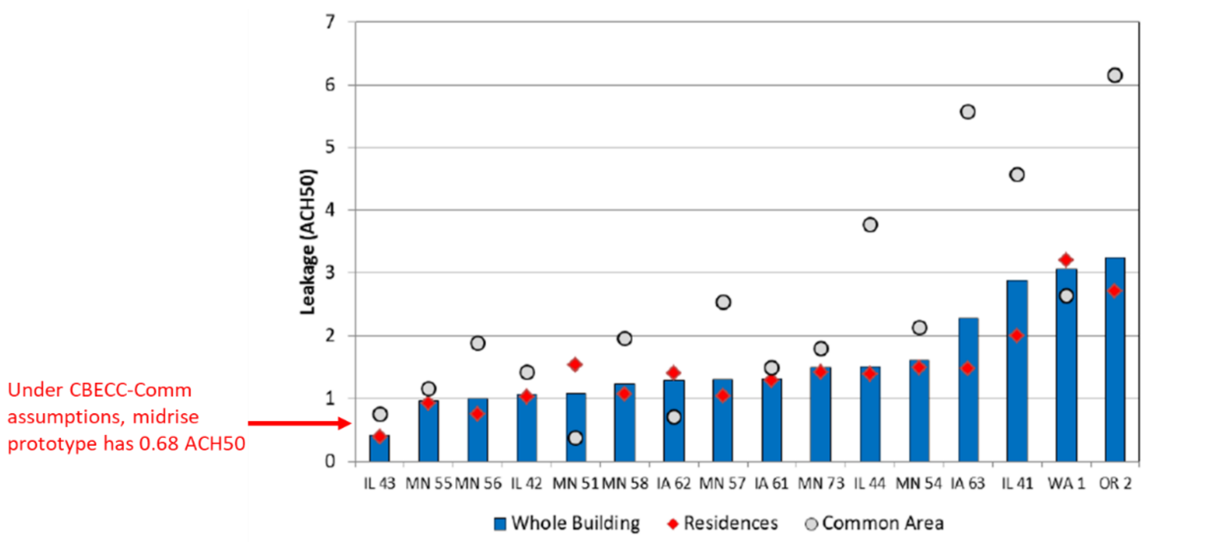

Figure 32: Multifamily leakage (measured at the whole building level) compared to CBECC-Comm infiltration assumption

Source: (Center for Energy and Environment 2019)

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.

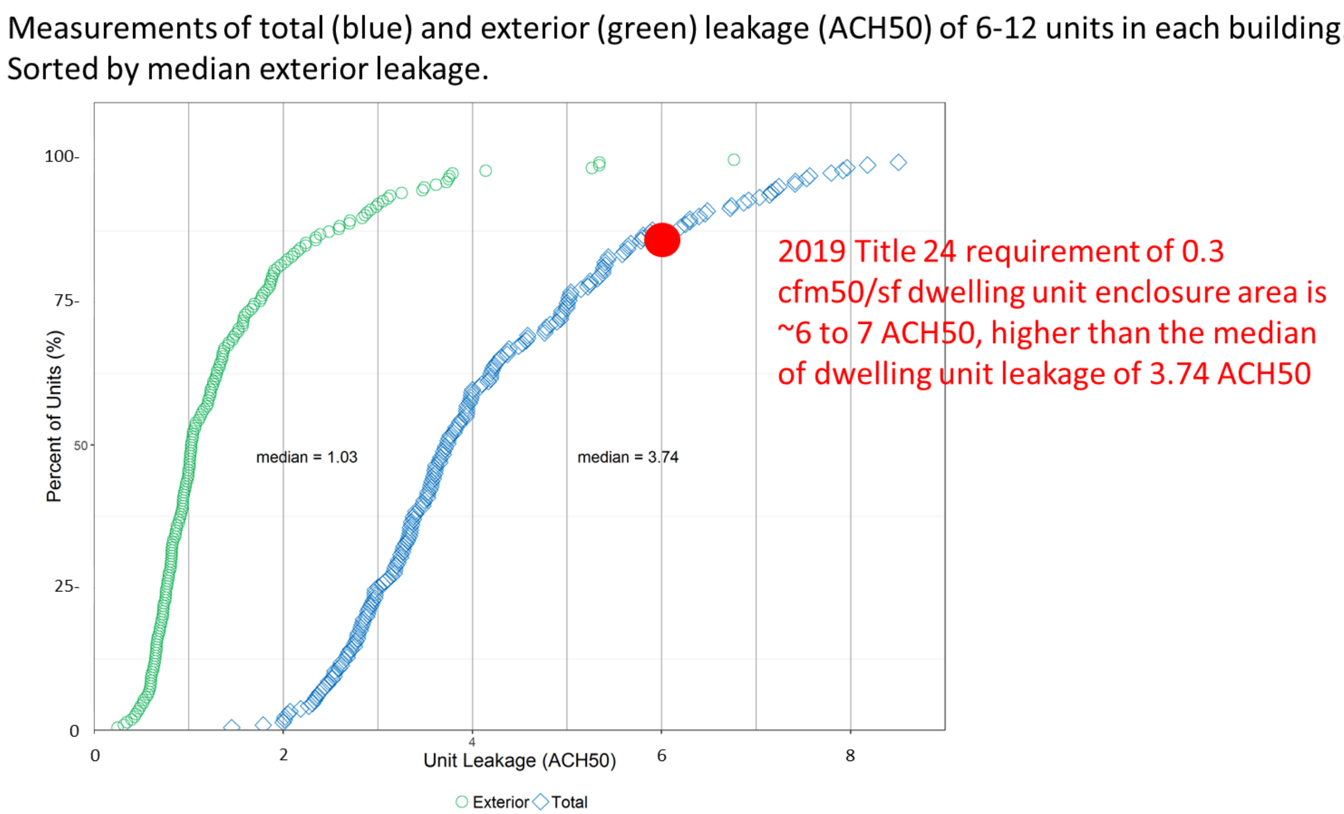

Figure 33: Leakage results in multifamily dwelling units: Total envelope leakage and exterior leakage only

Source: (Center for Energy and Environment 2019)

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.

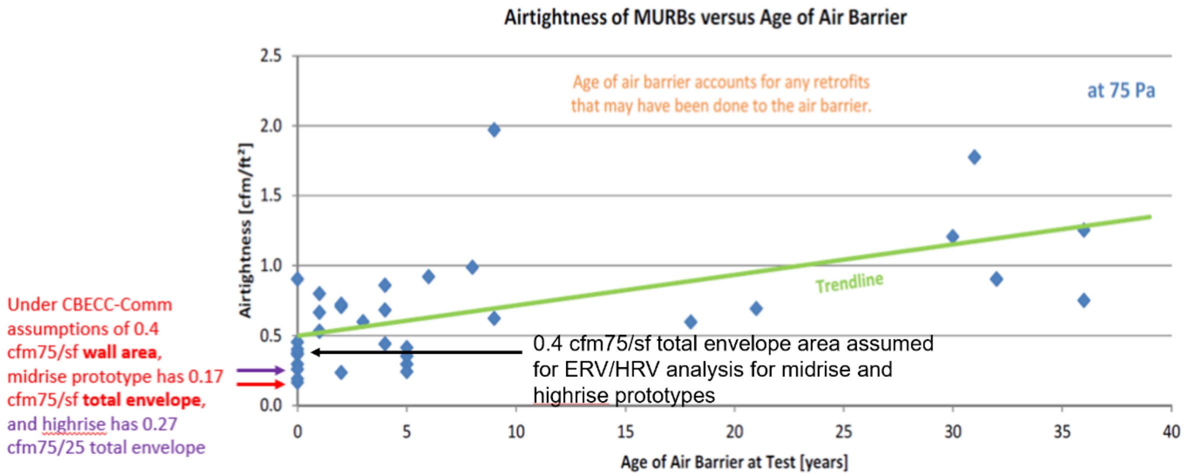

Figure 34: Airtightness of multifamily buildings versus age of air barrier

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).

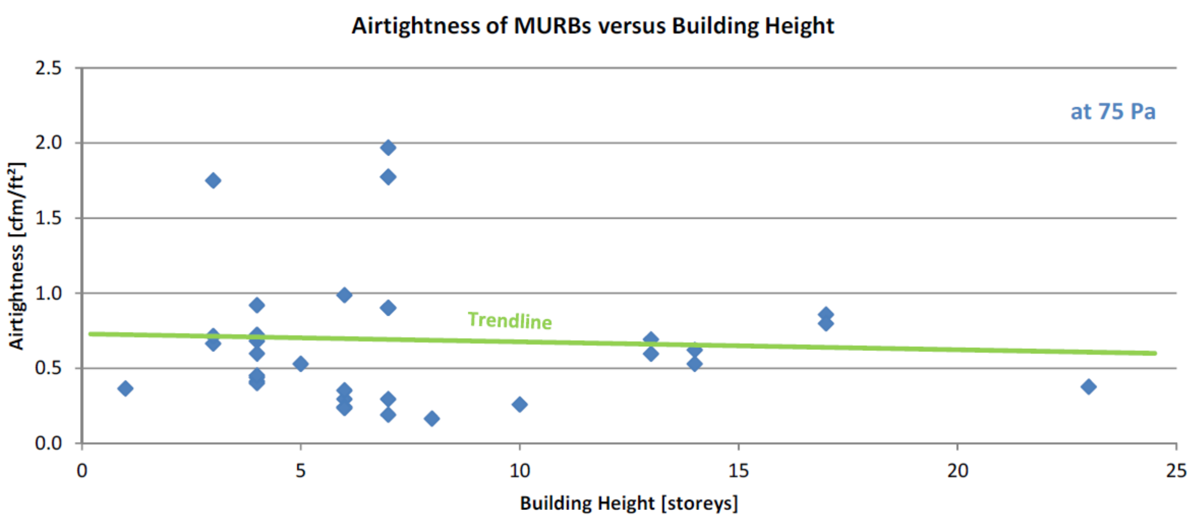

Figure 35: Airtightness of multifamily buildings versus building height

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).

2. Approach for CASE analysis for ERV/HRV and high performance walls and future considerations
    - The Statewide CASE Team plans to temporarily adjust the infiltration assumption for the midrise and high-rise prototypes as follows: Multiply the current Nonresidential ACM Reference Manual Idesign assumption of 0.0448 cfm/ft^2 by the ratio of building envelope area to exterior wall area.
        - These ratios are 2.4 for midrise, and 1.5 for highrise, for Idesign values of 0.106 cfm/ft^2 for the midrise prototype and 0.0665 cfm/ft^2 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, the Team does 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 increase the effective UA (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 80 summarizes the building characteristics of the four prototypes.

Table 80: 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	88 8 Studios 40 1-bedroom 32 2-bedroom 8 3-bedroom	117 18 Studios 54 1-bedroom 45 2-bedroom

		12 2-bedroom 6 3-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

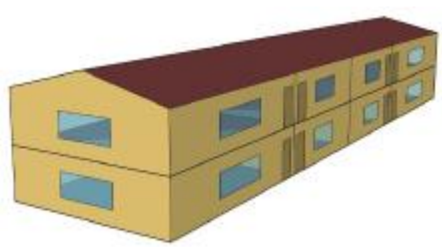

Figure 36: Low-rise garden style isometric view.

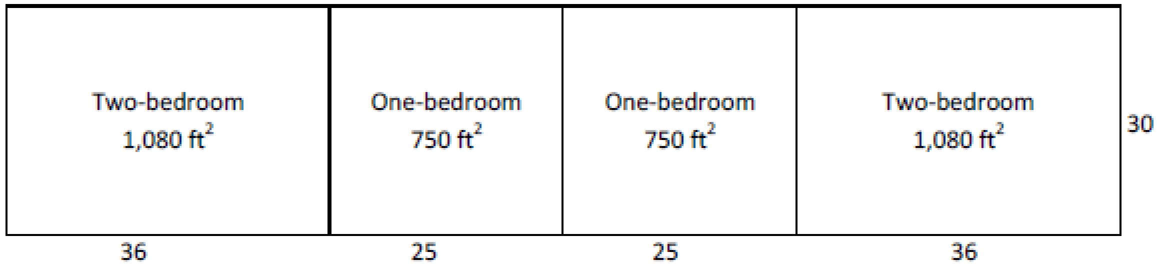

Figure 37: Low-rise garden first and second floor plan.

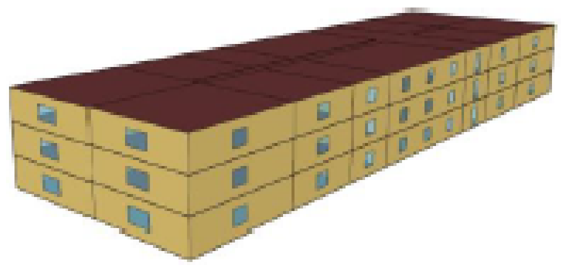

Figure 38: Low-rise loaded corridor isometric view.

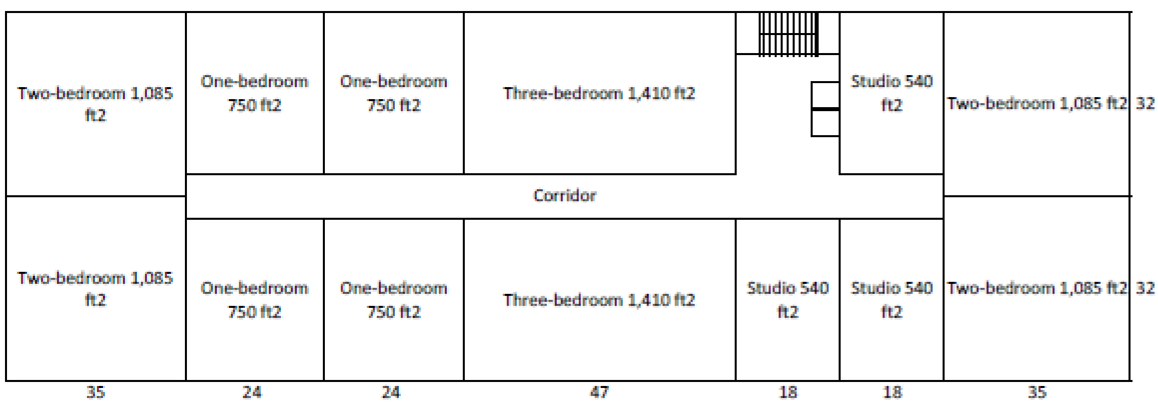

Figure 39: Low-rise loaded corridor second and third floor plan.

Figure 40: Mid-rise mixed use isometric view.

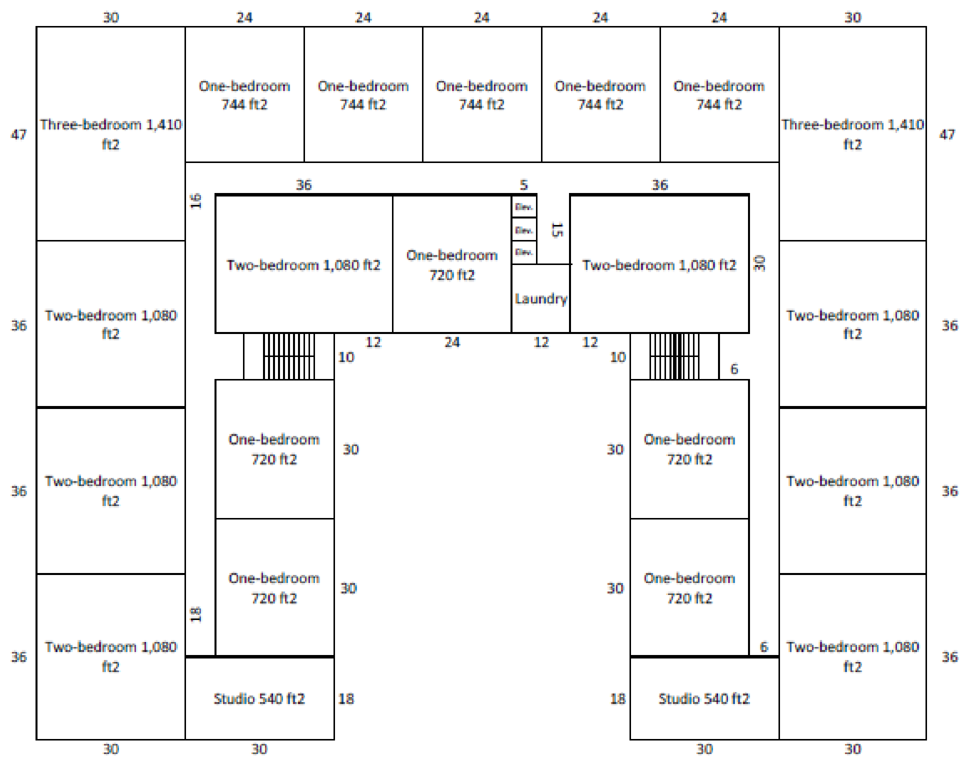

Figure 41: Mid-rise mixed use second through fifth floor plan.

Figure 42: High-rise mixed use isometric view.

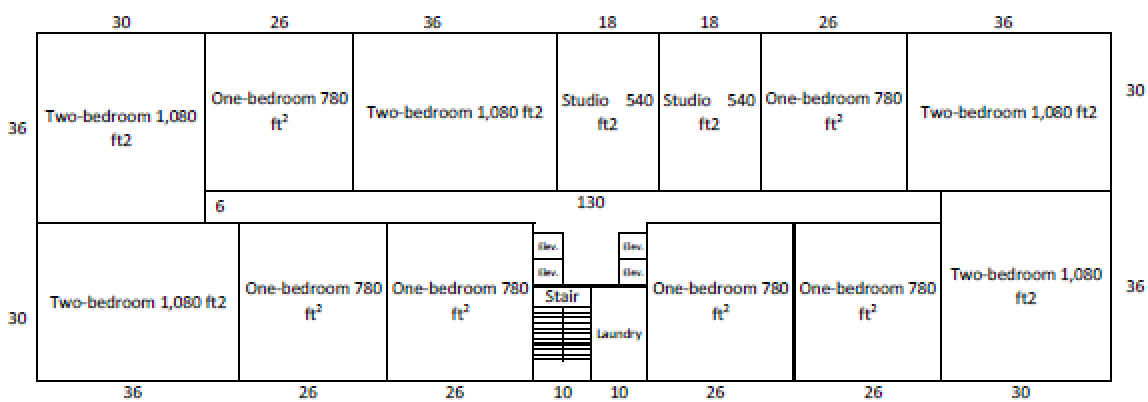

Figure 43: High-rise mixed use second through tenth floor plan.

Appendix I: Methodology for Testing Capture Efficiency for Sample of Range Hoods

SUBJECT: MEMO DESCRIBING LABORATORY TESTING OF KITCHEN EXHAUST HOODS

Statewide Utility MF IAQ Codes and Standards Enhancement Team
March 10, 2020

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[24]. 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 the development of ASTM Standard E3087-2018, 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 Engineering Experiment Station (TEES), 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, TEES 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 this publication.

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

---

[24] 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.

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.

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 requirement (>=70%)
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. Also, LBNL's correlations between capture efficiency and pollutant exposure were developed using a different test method than used by the ASTM standard.

Supporting #2: Given the current lack of capture efficiency data, the Statewide CASE Team proposed an alternate means of compliance, which is to require that hoods be rated to exhaust at least 250 cfm at a static pressure of 0.1 inches water column (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 TEES 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 81: 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 82: 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 at Texas A&M University.

TRC Capture Efficiency Test Summary

Contract number: 20-1159

1. Project Overview

The Relles 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 44 and Figure 45 present a side and front view of the chamber setup.

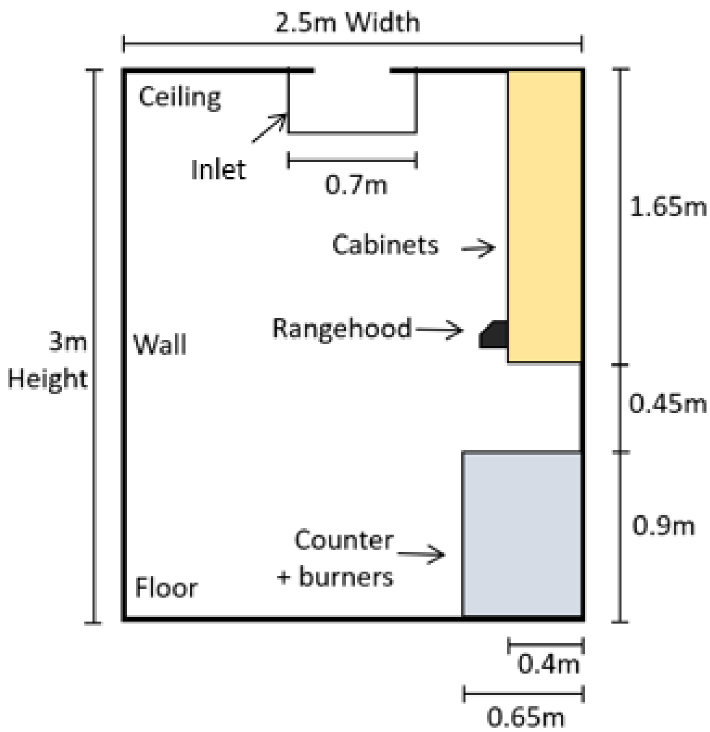

Figure 44: Test chamber side view with dimensions

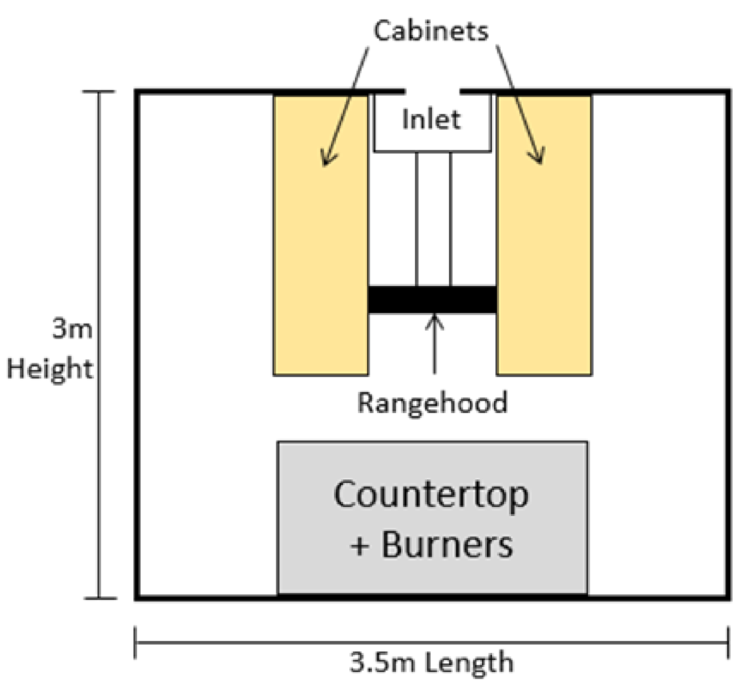

Figure 45: Test chamber front view with dimensions

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 44 through Figure 45 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 83 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 83: 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	CO_2 Mass Flow Controller	Cole-Parmer/32907-75	Integrated Service Solution	161904_899_152_0221	Feb. 11 2020	Feb. 11 2021
4	5297	CO_2 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 83 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 84: Capture efficiency results recorded at 2 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	49.4
	Vertical rectangular	20-1159H	18	0.25	214	TBD
OTR 2	Vertical rectangular	20-1159I	18	0.1	218	57.9
	Vertical rectangular	20-1159J	18	0.25	201	54.2

The measured capture efficiency ranged from 57.9 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 capture efficiency correlates fairly closely to airflow rate and decreases with airflow.

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.

5. Pictures of Test Set-up

Figure 46: WRH1

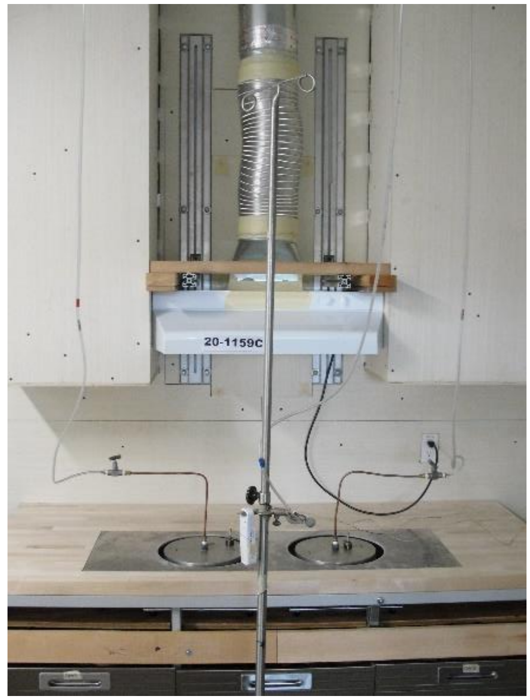

Figure 47: WRH2

Figure 48: WRH3

Figure 49: OTR2