Variable Capacity HVAC Compliance Software Revisions

2022-SF-HVAC3-F | Single Family HVAC| September 2020 FINAL CASE REPORT

Prepared by Frontier Energy, Inc.

Please submit comments to info@title24stakeholders.com.

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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 Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that 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 objective of this CASE Report is to present a code change proposal that is intended to improve the accuracy of compliance methods used for variable capacity split system central air conditioners and heat pumps in single family residences. This report describes the need for the code change and includes supporting information.

Measure Description

Background Information

Since the introduction of computer models for demonstrating performance-based compliance under the Title 24, Part 6 Standards, the models have calculated heating and cooling energy use using the entered equipment efficiency and fixed assumptions for duct performance. Because variable capacity systems typically have higher performance ratings, they can be used to improve compliance. However, research by the UC Davis Western Cooling Efficiency Center (WCEC) has shown that when variable capacity systems operate at lower speeds and reduce airflow in attic ducts, distribution effectiveness falls, leading to a decrease in the overall system coefficient of performance (COP). The proposed measure addresses this compliance model deficiency. This measure would apply to central ducted split system air conditioners, heat pumps, and furnaces in new single family homes and townhouses only. It would not apply to low-static variable capacity heat pumps (commonly known as mini-splits), which are dealt with separately by Title 24, Part 6 requirements (California Energy Commission 2019).

The Title 24, Part 6 Standards require testing for airflow and fan efficacy “in every zonal control mode”, for example when only the smallest zone is calling for cooling. It is nearly impossible to design a system that meets the 350 cfm per ton and 0.45 Watts per cfm (0.58 W/cfm for heat pumps) requirement under these conditions. Title 24, Part 6 Standards include an exception when zonally controlled systems include a multispeed compressor, in which case verification tests can be completed with all zones calling (all zone dampers open). The problem with this allowance is that it assumes there is a communication link that directs the compressor to run at a reduced speed when fewer than all zones are calling. Only a handful of air conditioner and heat pump models have this capability. The term “variable capacity system with integrated zonal control” is used in this report to describe systems that have the capability to vary fan and compressor speed in proportion to the number of zones calling.

This CASE measure applies to central ducted, split system HVAC systems in new homes. It does not apply to mini-splits, which are dealt with separately in the standards (California Energy Commission 2019). This measure proposes to modify current compliance simulation model calculation methods that award full credit to high performance variable capacity systems when ducts are located in unconditioned, vented attics.

This measure proposes three alternative compliance choices for variable capacity systems:

- **Specify a multispeed cooling system in the compliance model with no zonal controls**. The modified compliance model would account for the decrease in distribution effectiveness for attic ducts and would continue to provide credit for the elevated SEER (seasonal efficiency ratio) and EER (energy efficiency ratio).
- **Locate ducts in conditioned space** (as prescriptively required). The compliance model would apply the rated SEER and EER values and reduced duct losses with no change to current modeling methods.
- **Specify a variable capacity system that integrates the speed of the HVAC**

system with the number of zones calling. The compliance model would apply the rated SEER and EER values and would not change the way attic ducts are currently modeled, that is no reduction in airflow would be used in the calculation of distribution effectiveness.

Proposed Code Change

The proposed code change applies to the performance path for new construction and is limited to single family buildings and townhouses (as defined in Title 24, Part 6 Section 100.1). It does not impose new mandatory requirements, but it modifies the way that variable capacity cooling systems are modeled.

Scope of Code Change Proposal

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

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
Variable Capacity HVAC Systems	Compliance option for new residential buildings	150.0(m)13C 150.0(m)13D 150.1(b)3B	Residential Appendix 3	Yes – Section 2.4 and Appendix G will be modified	Chapter 4 would be modified

Market Analysis and Regulatory Assessment

The market structure for residential HVAC systems has not changed for decades and would not be affected by the proposed measure. Cooling systems meeting minimum federal efficiency standards are prevalent in the market, but a wide range of high-performance systems are also available through the same supply chains. Of the combined listings of small air source split system air conditioners and heat pumps in the Energy Commission's Modern Appliance Efficiency Database System (MAEDBS), 80 percent are single speed, 13 percent are dual speed, and 7 percent are multiple speed.

Except for building design features normally needed for compliance, no new building practices are required for variable capacity HVAC. A decrease in distribution effectiveness resulting from reduced duct airflow may reduce the compliance margin but this may be overcome by improving the duct insulation value, applying roof deck insulation, providing an integrated zonal control system, or other measures.

Four manufacturers of variable capacity systems that integrate zonal control with system speed were identified. These systems require more training for proper installation and commissioning of controls than single speed systems or variable capacity-zonal systems that are not integrated.

Current Title 24, Part 6 code makes verification of zonally controlled systems easier when variable capacity air conditioners and heat pumps are specified. The higher cost of certified zonal control systems may reduce the market for both zonal controls and variable capacity systems. Builders may have to more carefully weigh the options of improving duct insulation (e.g. burying ducts), adding roof deck insulation, locating ducts in conditioned space, or using certified integrated zonal systems.

Cost Effectiveness

Proposed modifications to compliance software do not represent a change to mandatory or prescriptive requirements and consequently, no cost-effectiveness evaluation is necessary for this proposal.

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

In the absence of market data on the use of variable capacity systems applied to new homes, it is not possible to assess statewide impacts. The Statewide Utility Team is pursuing this measure because it would better align cooling energy use predicted by compliance models with actual usage when variable capacity systems are installed.

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 2.5. Impacts that the proposed measure would have on market actors is described in Section 3.3 and Appendix E. The key issues related to compliance and enforcement are summarized below:

- Issue 1: Verification of variable capacity systems with integrated zonal control: HERS verification could be facilitated by adding a category for integrated variable capacity systems with integrated zonal control to listings on the Manufacturer Certification for Equipment, Products, and Devices web page[1]. With input from Energy Commission Staff it was concluded that HERS testing and verification would be sufficient to ensure that integrated zonal control is provided as specified in compliance forms.
- Issue 2: Conveying change in compliance modeling methods to energy analysts: Information on how variable capacity systems would be treated in compliance models must be conveyed to energy analysts through training and published information by the Energy Commission and Energy Code Ace. This knowledge would help them provide guidance to builders.
- Issue 3: Training of HERS Raters: HERS Raters must be trained in a new field test and verification procedure required for variable capacity zonal systems to confirm that control settings limit compressor and fan speed when fewer than all zones are calling. Familiarity with controls provided by the different manufacturers will be needed to complete the tests.

Field Verification and Diagnostic Testing

Current verification requirements that are related to the proposed measure include standard verification of duct R-value and location, roof deck insulation, airflow testing and furnace/air handler fan efficacy and verification of the cooling system manufacturer/model number. If a zonally controlled system is installed with a variable capacity system, the rater would be required to conduct a test to confirm that the compressor and fan speed are reduced when only one zone is calling for cooling. Refer to Section 2.5 for additional information.

[1] Listings can be found here https://ww2.energy.ca.gov/title24/equipment_cert/

1. Introduction

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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 Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will 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.

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The overall goal of this CASE Report is to present a code change proposal for variable capacity central split system air conditioners. 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 HVAC contractors, building officials, manufacturers, Title 24 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 October 10, 2019, and March 12, 2020. Notes from these meetings are available from title24stakeholders.com (Statewide Utility Codes and Standards Program 2019), (Statewide Utility Codes and Standards Program 2020).

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 section, this section includes a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards, such as fire, seismic, and other safety standards, and whether technical, compliance, or enforceability challenges exist.
- Section 4 – 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 typically presents a detailed cost-effectiveness analysis. This code change proposal would not modify the stringency of the existing Title 24, Part 6, so a complete cost-effectiveness analysis is not needed. For this proposed change, the Statewide CASE Team is presenting information on the cost implications in lieu of a full cost-effectiveness 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 underlined (additions) language for the Standards, Reference Appendices, Alternative Calculation Manual (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.

2. Measure Description

2.1 Measure Overview

Since the introduction of computer models for demonstrating performance-based compliance under the Title 24, Part 6 Standards, the models have calculated heating and cooling energy use using the entered equipment efficiency and fixed assumptions for duct performance. Because variable capacity systems typically have higher performance ratings, they can be used to improve compliance. However, research by the UC Davis Western Cooling Efficiency Center (WCEC) has shown that when variable capacity systems operate at lower speeds and reduce airflow in ducts, distribution effectiveness falls, leading to a decrease in the overall system coefficient of performance (COP). The proposed measure addresses this compliance model deficiency. This measure would apply to central ducted split system air conditioners, heat pumps, and furnaces in new single family homes and townhouses only. It would not apply to variable capacity heat pumps (commonly known as mini-splits), which are dealt with separately by 2019 Title 24, Part 6 requirements (California Energy Commission 2019).

For new homes using the performance path, the proposed measure would improve methods for modeling air distribution effectiveness when variable capacity heating and cooling systems are specified. The current (2019) Alternative Calculation Method provides for duct losses to be calculated at a fixed total airflow rate of 350 cfm per ton of cooling capacity and using the estimated temperature difference between the air in the ducts and the attic environment. The proposed software modification would adjust the airflow and distribution effectiveness as a function of the hourly load[2]. Energy consultants and heating, ventilating, and air conditioning (HVAC) designers for new homes would have three options for compliance when variable capacity systems are specified. These include placing ducts in the attic and allowing compliance software to calculate distribution effectiveness at reduced airflow, locating ducts in conditioned space, or installing a zone control that controls the speed of the system based on the number of zones calling. The latter two options would apply current methods for calculating distribution effectiveness used by the 2019 Title 24, Part 6 Standards.

2.2 Measure History

The proposed measure has not been considered in previous Title 24, Part 6 rulemakings and there are no known entities working on similar proposals. This code

[2] The efficiency improvement resulting from elevated air conditioner and heat pump performance at part load is also not accounted for by CBECC-Res.

change proposal is based on results of laboratory research completed by the WCEC and its graduate students and carried out under a subcontract to the Electric Power Research Institute (EPRI) who is under contract with the California Energy Commission (EPIC project number EPC-14-021: Development and Testing of the Next Generation Residential Space Conditioning System for California.) WCEC staff were invited by the Statewide Codes and Standards Team to collaborate on the proposed measure and are contributing technical information to support it.

Variable capacity split system furnaces, air conditioners, and heat pumps have seen increasing use, particularly since the development of electronically commutated motors (ECMs) in the 1980's. ECM fans and inverter-driven compressors have made it more practical to vary the speed of compressors and fans as a means of responding to varying heating and cooling loads while improving efficiency, reducing noise, and enhancing the ability of products to meet a variety of capacity needs.

Single speed systems are either "on" or "off" as they respond to thermostat calls while variable capacity systems can operate at multiple speeds. Of the variable capacity system types, two-speed systems are the most common. They may be operated by a two-stage thermostat or use internal controls that start at low speed and increase the speed if the thermostat is not satisfied within a given time. Variable speed systems either use multiple speed steps or continuously variable speed settings and require more sophisticated and often proprietary digital controls.

Variable capacity split system air conditioners and heat pumps have characteristically higher performance ratings than single speed equipment. This is important because the method described in the ACM Manual for determining hourly air conditioner energy use applies a performance curve that functionally relates the temperature of air entering the condenser (outdoor air) to watts of compressor energy per Btu of load using a curve that starts at the 82 °F SEER (seasonal energy efficiency) rating point and slopes upward to the 95°F EER (energy efficiency ratio) rating point. Thus, both EER and SEER are used to calculate compressor energy use. For heat pump heating, the method either uses the rated COPs at 17°F and 47°F, or derives those COPs from the HSPF to determine energy input and capacity. As with air conditioners, these rating points are used to calculate hour energy use based on outdoor temperature.

Figure 1 compares the average performance ratings (SEER, EER, and HSPF) of split system air conditioners and heat pumps obtained from the California Energy Commission's Modernized Appliance Efficiency Database System (MAEDBS) [3] .

[3] MAEDBS data were filtered to include split systems only and to remove duplicate model numbers. For air conditioners excluded all types except Types 3, 4, and 10. For heat pumps excluded all types except Types 23 and 24.

Variable capacity systems tend to have slightly higher EERs than single speed systems, but significantly higher SEERs. For example, the highest rated single-speed air conditioner has an EER of 13 and a SEER of 16, and the highest rated multiple-speed air conditioner has an EER of 16.5 and a SEER of 26. Rated performance tends to decline as the capacity of the equipment increases.

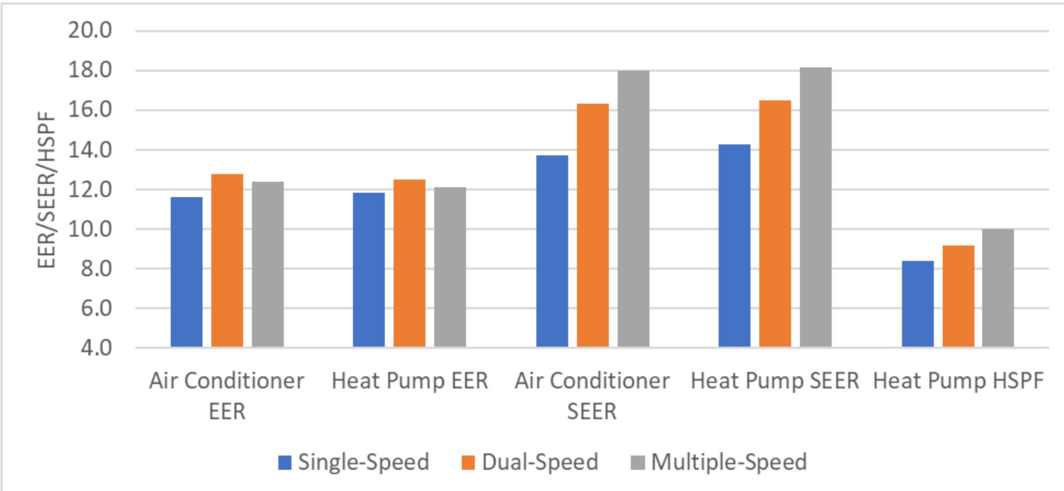

Figure 1: Average efficiencies of split-system air conditioners and heat pumps from MAEDBS listings.

Current compliance calculations allow full credit to be applied for the higher performance ratings provided by multiple and variable capacity systems. The residential compliance model (CBECC-Res) uses both seasonal energy efficiency ratio (SEER) and energy efficiency ratio (EER) to calculate an hourly efficiency (EER_t in Btu per Watt-hour) from the outdoor temperature that is then used to calculate cooling energy use (CEC Res-ACM 2019). At outdoor temperatures below 82°F, EER_t is based on SEER, and above 95°F it is based on EER. In between these temperatures CBECC interpolates. So, particularly for homes using smaller systems, modeled energy use can be significantly reduced when two-speed and variable speed systems are provided. For example, TDV energy use for the 2,100 ft^2 prototype house in Climate Zone 12 is ten percent lower for a SEER 21, EER 13.5 variable capacity system than for a SEER 14, EER 12.2 single speed system.

Research conducted by the UC Davis Western Cooling Efficiency Center (WCEC) has shown that reduced airflow velocity in ducting significantly degrades cooling performance when ducts are in hot attics and can reverse the efficiency gains provided by high efficiency equipment (Krishnamoorthy 2017). The observed reduction of distribution effectiveness as air velocity decreases is consistent with ASHRAE Standard 152 calculations (ASHRAE 2014). When the overall efficiency of the system, including condensing unit, evaporator, indoor fan, and distribution ducts are accounted for, the resulting system coefficient of performance of the overall system (including compressor-fan efficiency and duct performance) can be compared for various attic temperatures and for different air velocities.

The WCEC conducted laboratory tests by placing a typical, tightly sealed R-6 duct layout for a three-bedroom home in an environmental chamber that was used to simulate attic temperature conditions (Krishnamoorthy 2017). Ducting was connected to a two-ton variable capacity split system heat pump operated in cooling mode. The system COP was calculated by dividing the sum of the energy delivered through each of the ducts by the condensing unit and fan energy. The net effect of attic temperature on system COP is shown in Figure 2.

At an attic temperature of 84°F the highest system COP was obtained at 60 percent capacity and airflow due to improved low-speed fan and compressor efficiency, while at an attic temperature of 115°F the system COP declines at capacities/airflows lower than 100 percent due to increased heat gain resulting from longer residence times of air in the ducting.

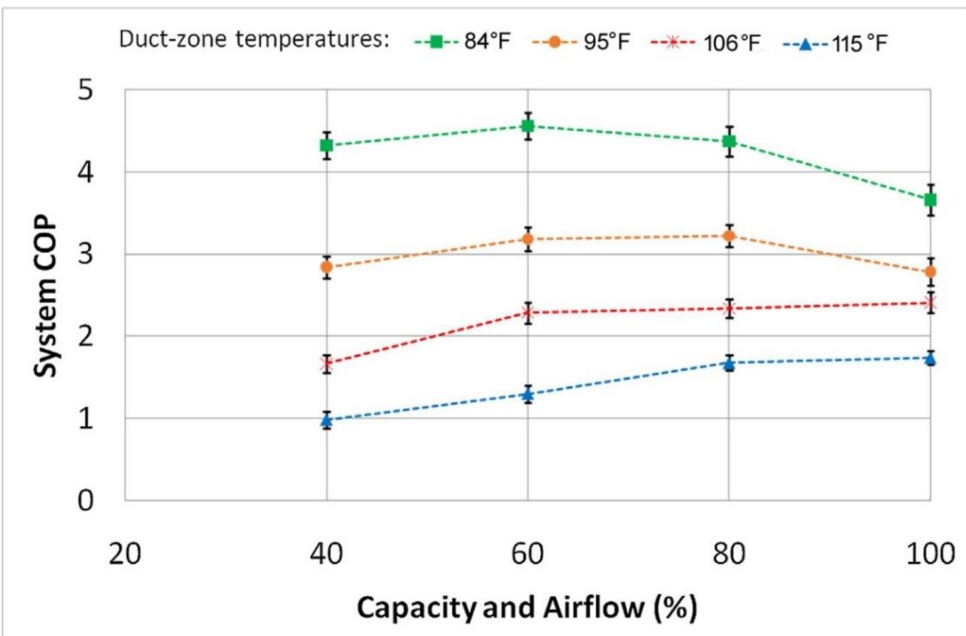

Figure 2: System COP vs. capacity/airflow percentages for different duct-zone temperatures at 75°F dry bulb and 63°F wet bulb indoor conditions.

Source: (Krishnamoorthy 2017)

As proposed, modifications to CBECC-Res would account for the impact of reduced distribution airflow on distribution effectiveness. Modifications to CBECC-Res algorithms would be based on WCEC laboratory test results and a stand-alone simulation model that was developed from those results. Systems with ducts located in conditioned space would receive full credit for reduced distribution losses as well as for improved equipment performance, and systems with ducts in a high-performance attic would have an advantage over ducts in standard vented attics due to the more moderate duct environment temperatures.

For systems using integrated zone controls, the proposed approach is for the model to ignore duct velocity effects and assign full credit for the improved equipment performance. Figure 4 shows results from WCEC laboratory tests of a three-zone system where the attic temperature was maintained at 115°F and the indoor temperature at 75°F. At 40 percent capacity the system COP was improved by 55 percent by zoning, and at 60 percent capacity zoning yielded a higher COP than at 100 percent capacity.

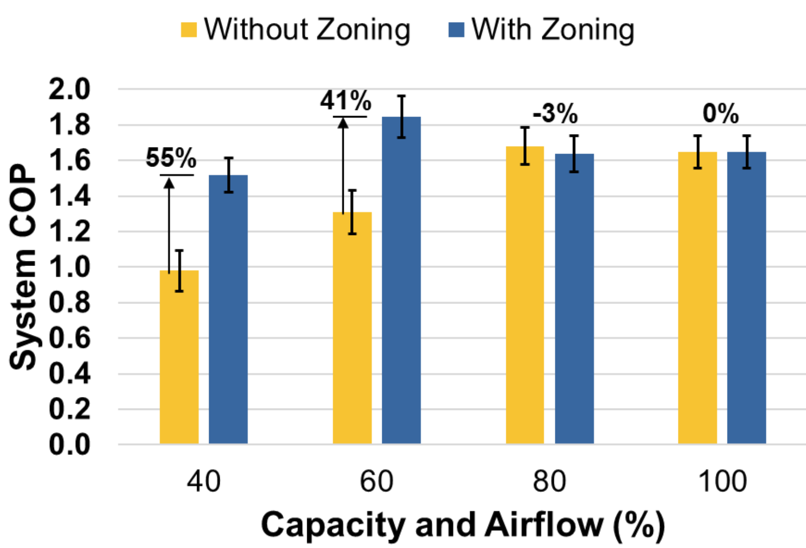

Figure 3: Impact of adding zoning (115°F attic and 75°F indoor temperature).

2.3 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.

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**

Section 100.1(b) – Definitions: Recommend new definitions for the following terms:

- "Integrated Zone Control System" is an HVAC system that combines control of compressor, fan speed, and zone dampers such that the compressor and fan speed are regulated by static pressure or other means to limit air velocity and/or over-pressurization of ducts while minimizing energy use.

— **SECTION 150.0 – MANDATORY FEATURES AND DEVICES**

- **Section 150.0(m)13C – Zonally Controlled Central Forced Air Systems:** Moving the language in Exception 1 to Section 150.0(m)13C that is under Section 150.0(m)13D to this section.
- **Section 150.0(m)13D – Small Duct High Velocity Forced Air Systems**: Deleting Exception 1 (moved as above). Deleting Exception 3 to Section 150.0(m)13B and Exception 2 to Section 150.0(m)13C as both are not relevant to the 2022 Standards.

— **SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS**

- **Section 150.1(b) – Performance Standards:** Adding Section 150.1(b)3Bx to require field verification when zone controls are to be installed with variable capacity HVAC systems.

2.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the section 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.

— **RESIDENTIAL APPENDICES**

- **RA3.4.4 – HVAC System Verification Procedures:** The proposed requirements would add sub-section 3.4.4.3 to support the updated Standards language pertaining to verification of integrated zonal control systems.

2.3.3 Summary of Changes to the Residential ACM Reference Manual

This proposal would modify sub-sections of the Residential ACM Reference Manual. Table 2 shows how checkbox entries in CBECC-Res heating or cooling system data would affect modeling assumptions and verification requirements if ducts are located in unconditioned space. For ducts in conditioned space full airflow would be applied regardless of the compressor type (as currently). Section 7.4 of this report provides detailed revisions to the text of the ACM Reference Manual.

Table 2: Effect of Checkbox Entries in CBECC-Res Heating and Cooling System Data

Box Checked	Model Assumptions for Duct Airflow	Verification Requirements
Multi-speed Compressor	Airflow based on load (proposed model)	No change
Zonal Control	Reduced airflow (300 cfm as currently)	No change
Both boxes checked	Full airflow (350 cfm/ton)	Integrated zonal control

— **SECTION 2.4 – BUILDING MECHANICAL SYSTEMS**

- **Subsection 2.4.1 – Heating Subsystems:** Inputs would be added to designate the maximum airflow (in cfm/kBtuh) and checkboxes would be added to designate whether the design includes a multi-speed compressor, zonal control, or both. If only the 'multi-speed' box is checked, the simulation would vary airflow with heating load. Checking both 'multi-speed' and 'zonal control' boxes would trigger verification of integrated zonal control systems and the simulation would use the maximum airflow in calculating distribution effectiveness. If only the 'zonal control' box is checked there would be no change to current simulation methods.
- **Subsection 2.4.5 – Cooling Subsystems:** Existing inputs for airflow (cfm/ton), and multi-speed and zonal control (checkboxes) would be used to modify duct airflow in cooling mode when attic ducts and multi-speed systems are indicated. If only multi-speed is checked, the simulation would vary airflow with cooling load. If only the zonal control box is checked, the simulation would apply a fixed reduced airflow (150 cfm default). Checking both multi-speed and zonal control boxes would trigger verification of integrated zonal control systems and the simulation would use 350 cfm (or entered value) in calculating distribution effectiveness. Changes would also be made to Subsection 2.4.5.2 – Verified System Airflow to reflect changes in Section 150.1(b)3Bx for zonally controlled systems.
- **Subsection 2.4.8.4 – Zonally Controlled Forced-Air Cooling Systems:** The language describing an exception for zonally controlled systems used with multispeed or variable-speed compressor systems would be clarified to limit the ability to measure efficacy with all zones calling to those systems using integrated zonal controls.
- **Appendix G, Section 1.10 – Duct System Model:** Proposed changes would modify duct velocities used to calculate supply and return duct heat transfers.

2.3.4 Summary of Changes to the Residential Compliance Manual

The proposed code change would modify the following sections of the Residential Compliance Manual:

- Section 2.5 – HERS Field Verification and Diagnostic Testing
- Section 4.3 – Cooling Equipment
- Section 4.5 – Controls
- Section 9.4.6 – HVAC System Alterations

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

2.3.5 Summary of Changes to Compliance Documents

The proposed code change would result in the addition of a HERS verification notification for integrated zonally controlled systems.

2.4 Regulatory Context

2.4.1 Existing Requirements in the California Energy Code

There are no relevant existing requirements for the installation of central ducted variable capacity systems in the California Energy Code. However, when zonally controlled systems are installed, they can be used to eliminate the requirement to measure fan efficacy with all zones calling instead of in every control mode. A Title 24, Part 6 compliance option for variable capacity heat pumps (including ducted and ductless mini-split and multiple-split heat pumps) has been proposed, but these systems are in a different class than central, ducted variable capacity air conditioners and heat pumps and have been treated differently for compliance (California Energy Commission 2019).

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

There are no relevant requirements in other parts of the California Building Code, nor are there relevant local, state, or federal laws governing variable capacity systems.

2.4.3 Relationship to Industry Standards

ASHRAE Standard 152 (ASHRAE 2014) describes a method of test for determining the efficacy of thermal distribution systems, including duct systems, that is based on duct environment, surface area, insulation, air velocity, and other factors. The proposed measure does not rely on this test procedure, though elements of Standard 152 calculation methods have been used in developing compliance software.

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:** For new homes, the builder or energy consultant identifies whether prescriptive or performance compliance path should be used. If the performance path is used and the initial design does not comply, the energy consultant may identify options for improving the compliance margin that can include using above minimum standard efficiency HVAC equipment. With direction from the builder, the energy consultant generates the compliance documents. The equipment performance specifications are conveyed to the architect or builder, who will coordinate with an HVAC designer or design-build mechanical contractor to select a manufacturer and model number that meets or exceeds the performance specifications.

  Typically, HVAC contractors are allied with specific manufacturers, and the performance values for the equipment they select will vary somewhat from what is specified. If either the EER or SEER values are less than specified, then HVAC contractor should notify the builder who calls on the energy consultant to revise compliance calculations so that the information on compliance forms aligns with the installed equipment and systems. The proposed measure imposes no significant changes to this process, except that if the design includes zonal control, the energy consultant should confirm that the zonal control system integrates with the variable capacity equipment by checking with the HVAC contractor, manufacturer, or supplier.

- **Permit Application Phase:** For new homes, the general building contractor or contractor's representative applies for the building permit and submits the necessary compliance documents that are provided by the energy consultant. Either the general contractor who has responsibility for the entire design signs all compliance documents, or the mechanical contractor signs the documents related to HVAC systems. Construction documents are registered prior to submittal to the enforcement agency. The plans examiner reviews the Certificate of Compliance (CF1R) which lists the efficiency of the equipment being installed[4]. The CF1R also indicates whether the design includes a multi-speed compressor and/or zonal control.

- **Construction Phase:** During the new home construction phase the HVAC contractor installs the specified equipment as described in plans and specifications and compliance forms as is routinely done.
- **Inspection Phase:** The HERS Rater will use CF2R and CF3R forms to verify that the installed equipment has the efficiency ratings used for compliance**.** The CF2R-MCH-01 lists equipment efficiencies as well as the cooling system compressor speed type and zoning type. When credit is taken for rated system performance, the CF3R-MCH-H is used to list the manufacturer and model and the AHRI certification number as well as the SEER and EER ratings. The HERS Rater will also verify duct location, insulation level, and leakage, and whether the roof deck is insulated. If a zonal control system is installed with a variable capacity (multi-speed compressor) system, the HERS Rater will be required to complete additional diagnostic tests as described in RA3.4.4.3. The HERS Rater may need to communicate with the HVAC contractor to determine how to set the system speed for test purposes.

In the design and permitting phases there would be no changes to current practice, except that there must be an awareness of the method of compliance used with variable capacity systems. As always, communications and collaboration between the energy consultant and the builder are important at this stage. In the construction stage the builder must clearly communicate the equipment requirements to the mechanical contractor. In the inspection phase, the only procedural change required would be for variable capacity systems with integrated zonal control.

Compliance documents would include sufficient information to alert HERS Raters of the need to verify systems that use variable capacity systems with zonal control. Because this measure only applies to ducted split systems, it would be useful to add a category for central split system heat pumps to distinguish them from central packaged heat pumps.

Currently the Multi-Speed Compressor checkbox in CBECC-Res is only for informational purposes and is used to provide guidance on the proper method for testing fan efficacy for zonally controlled systems. As proposed, this checkbox would trigger the calculation of distribution effectiveness based on lower variable speed fan airflow only if ducts are located in a non-conditioned space. CBECC-Res inputs currently provide for defining duct location, R-value, duct temperature environment, and

[4] Air conditioners or heat pumps with a SEER rating exceeding 15 are most likely not single speed but there are some exceptions.

“Cooling Zoning Type”. Ducts located in a high-performance attic (Option B in Table 150.1-A) or buried in ceiling insulation would be less subject to losses resulting from decreased velocity. If both the multi-speed and zonal control boxes are checked then verification of a variable capacity system with integrated zonal control would be triggered (see Table 2). The notification to verify such systems would be added to the CF3R.

If no zonal control, or only zonal control, is used, no changes to inspection phase practices would be needed. If a variable capacity system with zonal control is indicated, then the compliance forms should include a note that a diagnostic test must be performed in accordance with the proposed new section of the Residential Appendices (RA 3.4.4.3). This test would involve activating one zone and verifying that airflow is reduced in that zone. No additional diagnostic testing is proposed.

In summary, there are no changes to current practices when using the performance method of compliance unless a zonally controlled system is used for compliance. Changes to the performance compliance method would automatically improve or depreciate performance depending on the system options applied and other building design features. The primary challenge would be to educate energy consultants on the impact of those options, which can be accomplished through additions to the Compliance Manual, the Blueprint newsletter, and Energy Code Ace.

A Compliance Improvement Subject Matter Expert suggested the proposed measure should be extended to include alterations through changes to Title 24, Part 6 Section 150.2(b). When HVAC equipment is replaced with variable capacity equipment in existing homes, ducts should be upgraded (sealed and insulated to current standards) to avoid excessive duct thermal losses, but these measures could worsen the already notoriously low compliance levels and could be a further impediment to improving energy efficiency in the replacement market. CBECC-Res analysis using WCEC’s duct model was completed for the 2100 ft^2 Energy Commission prototype house built to 1982 Title 24, Part 6 Standards with R4.2 attic ducts. Results showed slightly lower energy use for a two-speed 18 SEER, 13 EER, 9 HSPF heat pump compared to a 14 SEER, 8 EER, 8.2 HSPF single speed heat pump. Thus, no changes to Section 150.2 are proposed.

3. Market Analysis

3.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. It then considered how the proposed standard may impact the market in general as well as individual market actors. Information was gathered about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during a public stakeholder meeting that the Statewide CASE Team held on September 5, 2019 (Statewide Utility Codes and Standards Program 2019), and March 12, 2020 (Statewide Utility Codes and Standards Program 2020).

Currently, market actors that play a role in designing, installing, and commissioning HVAC systems include equipment manufacturers and suppliers, builders, HVAC designers and contractors, energy consultants, building officials, and HERS Raters. For alterations to existing homes, HVAC contractors, and in some cases performance contractors, assume the role of designers and installers and provide commissioning with the homeowner involved in decision-making. For example:

- **Manufacturers:** Produce and deliver products to dealers or supply houses and in some cases directly to contractors.
- **Builders**: Work with energy consultants, HVAC designers, and contractors to decide on which products to install based on cost, the need for compliance credits, suitability for use in their building designs, and customer satisfaction.
- **Energy Consultants**: Coordinate with builders to define what is needed to comply with Title 24, Part 6. Complete modeling for compliance, generate compliance forms, and submit them to the registry.
- **HVAC Designers**: Complete heating and cooling load calculations, select equipment that has performance specifications similar to what is provided in compliance documents, and design ductwork.
- **HVAC Contractors:** Supply, install, and commission the equipment that is specified by the builder or HVAC designer and provided by manufacturers and/or supply houses. They may also serve as the HVAC designer.
- **HERS Raters**: Complete inspections during construction (CF2R) and at the completion of construction (CF3R) and complete final submissions to the registry.

- **Building Officials**: Approve construction documents including Title 24, Part 6 documents. Complete inspections related to compliance with building, plumbing, electrical, and mechanical codes and ensure conformity to construction documents to ensure structural integrity, health, and safety.

3.2 Technical Feasibility, Market Availability, and Current Practices

3.2.1 Prevalence of Variable Capacity Systems in the Market

Information on the prevalence of use of variable capacity systems in the California market is limited. Information sources relied upon include MAEDBS listings, HERS registry data provided by CalCERTS, a contractor survey, and a general web search. Results of a review of MAEDBS data are presented in .

Table 3, and show that variable capacity systems are widely available and that manufacturers have been diligent about listing them with the Energy Commission's Appliance Efficiency Division[5]. (The MAEDBS data referenced in the Executive Summary is a subset of this data).

Table 3: Residential Cooling Equipment MAEDBS Listings by Compressor/Fan Type

Product Category	Total Listings	Single	Dual	Multiple
Air Conditioners	4,482	80%	14%	6%
Heat Pumps	3,903	79%	12%	8%
Furnaces	1,478			16%

The percentage of variable capacity systems installed may be much lower than the approximate 20 percent of all air conditioners and heat pumps listed by MAEDBS. CalCERTS data gathered under the 2016 standards indicated that in only 2 percent of the compliance forms was the "Multi-Speed Compressor" box checked. The purpose of this box is to notify HERS Raters that fan efficacy can be verified with all zones calling when zonal control is used, as opposed to testing in every control mode. It is possible that many more multi-speed systems were installed where the box was not checked. For single zone systems there is currently no HERS requirement to verify the type of compressor.

[5] MAEDBS data were filtered to include split systems only and to remove duplicate model numbers. For air conditioners excluded all types except Types 3, 4, and 10. For heat pumps excluded all types except Types 23 and 24. The statistics for furnaces are limited to gas fired indoor types. Those designated in the database as having variable-speed or premium fan motors are listed here as "Multiple" though standard permanent split capacitor fan motors typically have two or more speed taps. The database does not distinguish furnaces with multiple stage or modulating gas burners.

Results from a statewide contractor survey (Table 4) completed by the Statewide CASE Team suggest that about 5 percent of systems used in new home installations, and 20 to 90 percent of replacement systems are multispeed. Since this measure only addresses new construction only the results for Contractors A and B are relevant, though it is of interest to see what is occurring in the replacement market. One contractor noted that he used two-speed systems for replacements to avoid oversizing because some customers demand larger systems than are needed. The reason given by contractor "A" for their use was to facilitate compliance. Only one contractor (D) indicated that integration with zoning was the prime reason for installing multispeed systems. The contractors had a mixed response to the proposed measure. All those polled were invited to participate in stakeholder workshops and provided with a link to Title24Stakeholders.com to learn more about the code change proposal and reasons behind it. A 2017 article in The Air Conditioning, Heating, and Refrigeration News announced that variable-speed options have become the industry standard and are now abundant in the marketplace (The News 2017). The article quoted one contractor as saying that one-fifth of all outdoor unitary products sold were variable speed, so the article may have been misleading. However, after the 2019 Title 24, Part 6 Standards take effect California builders may increasingly lean on high performance HVAC systems to demonstrate compliance.

Table 4: HVAC Contractor Survey Results

Contractor	Business Focus	Multispeed	Multizone	Integrated Multispeed/Zoning
A	New home construction	5%	60%	Almost never
B	New home construction	5%	40%	Sometimes
C	Replacements & Service	20%	0%	Almost never
D	Replacements & Service	90%	30%	Almost always
E	Replacements & Service	40%	0%	Almost never
F	Replacements & Service	5%	2%	Almost always

3.2.2 Technical Considerations and Changes to Current Practice

Variable capacity systems are currently in use and do not impose significant technical challenges. They may consist of a two-speed condensing unit coupled with a two-speed furnace, a two-speed heat pump, or use more efficient multi-speed or variable-speed components. WCEC research results indicate that rooms served by long duct runs from these systems will not receive sufficient heating or cooling capacity unless measures are taken to minimize duct heat gains or losses.

The HVAC News article cited above pointed out that variable-speed systems are complex and require a greater level of training for installing technicians. If equipment availability is not a constraint, then proper training on installation and commissioning may be. The burden for this training should fall on manufacturers and their distributors who can provide training materials, and contractors who should set aside training time for their technicians. Whether the proposed measure is implemented or not, training would be important for the more sophisticated variable capacity systems, particularly those that integrate zonal control.

Software changes to improve modeling accuracy would not affect technical feasibility because methods to improve distribution system efficiency, such as insulating the roof deck, enhancing duct insulation, and locating ducts in conditioned space are already embedded in the standards. All market actors should be made aware that installing high efficiency variable capacity HVAC systems may require increased attention to duct location if the performance potential of these systems is to be fully realized. Improvements to the compliance model would help convey this message, and improved design practices would aid the compliance process and result in more efficient homes with lower energy bills.

Only where zonal control is selected as the means to reduce attic duct losses from variable capacity systems would there be any impact on market actors, particularly HERS Raters. If zonal control is used to comply, equipment suppliers, designers, and HVAC contractors must play a larger role, and HERS Raters must apply a new verification method added to the Reference Appendices. HVAC contractors would need to be trained on design, installation, and commissioning, and HERS Raters must obtain sufficient knowledge of the technology to enable them to complete required tests and field verification.

The Statewide CASE Team surveyed product literature to identify how many manufacturers offer systems that integrate zonal control with variable speed capability. Though there may be more under different labelling, four systems were identified that have that capability. These include Carrier's Infinity SYSTXCCUIZ01-V, Trane's ComfortLink II, Rheem's EcoNet, and Lennox's Harmony III and LZP-4 zone systems. The Carrier Infinity system must be used with compatible Carrier furnaces and air handlers and employs digital controls. Trane's system also uses digital control and can be used with either single or multiple speed indoor and outdoor units Both of these can control modulating dampers and can avoid the need for a bypass damper. Rheem's EcoNet zone controls include two options for outdoor units, one using a fully variable speed compressor and another using a two-speed compressor. The Lennox system can use typical, non-proprietary thermostats to control single and two-stage indoor and outdoor units, and in some applications it requires a bypass damper. All four of these integrated zoning systems have unique user interfaces and control settings and would require product-specific training to ensure they are properly commissioned.

For each of the applications of variable capacity systems, as for all conventional HVAC systems, energy savings will be persistent if systems are properly maintained. Some systems, such as Trane's ComfortLink, include built-in diagnostics that automatically alert dealers if a defect is detected, ensuring improved persistence of performance.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

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

California's construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 5).[6] In 2018, total payroll was $80 billion. Nearly 60,000 of these business establishments and 420,000 employees are engaged in the residential building sector. The remainder of establishments and employees work in industrial, utilities, infrastructure, and other heavy construction (industrial sector).

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

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

Construction Sectors	Establishments	Employment	Annual Payroll (billions $)
Residential	**59,287**	**420,216**	**$23.3**
Residential Building Construction Contractors	22,676	115,777	$7.4
Foundation, Structure, & Building Exterior	6,623	75,220	$3.6
Building Equipment Contractors	14,444	105,441	$6.0
Building Finishing Contractors	15,544	123,778	$6.2
Commercial	**17,273**	**343,513**	**$27.8**
Commercial Building Construction	4,508	75,558	$6.9
Foundation, Structure, & Building Exterior	2,153	53,531	$3.7
Building Equipment Contractors	6,015	128,812	$10.9
Building Finishing Contractors	4,597	85,612	$6.2
Industrial, Utilities, Infrastructure, & Other	**4,103**	**96,550**	**$9.2**
Industrial Building Construction	299	5,864	$0.5
Utility System Construction	1,643	47,619	$4.3
Land Subdivision	952	7,584	$0.9
Highway, Street, and Bridge Construction	770	25,477	$2.4
Other Heavy Construction	439	10,006	$1.0

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

The proposed change to the Variable Capacity HVAC Compliance Software measure would likely affect residential builders but would not impact firms that focus on construction and retrofit of industrial buildings, utility systems, public infrastructure, or other heavy construction. The effects on the residential building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors.

Table 6 shows the residential building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report. Where builders are attempting to avoid certain prescriptive requirements by installing efficient variable capacity air conditioners or heat pumps, the proposed measure would impose additional requirements that would ensure against sub-par performance. As a result, there may be a cost impact associated with this measure that the builder would have to assess against the cost of meeting standard prescriptive requirements or selecting high performance single speed equipment. The impact on custom builders that install advanced zoning systems would be less significant or neutral. The Statewide CASE Team's estimates of the magnitude of these impacts are shown in Section 3.4, Economic Impacts.

Table 6: Size of the California Residential Building Industry by Subsector

Residential Building Subsector	Establishments	Employment	Annual Payroll (billions $)
New single family general contractors	10,968	55,592	$3.7
New multifamily general contractors	406	5,333	$0.5
New housing for-sale builders	180	2,719	$0.3
Residential Remodelers	11,122	52,133	$3.0
Residential poured foundation contractors	1,185	14,296	$0.7
Residential Structural Steel Contractors	215	3,216	$0.2
Residential Framing Contractors	657	23,690	$1.0
Residential Masonry Contractors	1,108	8,984	$0.4
Residential glass and glazing contractors	577	3,660	$0.2
Residential Roofing Contractors	2,208	16,814	$0.8
Residential Siding Contractors	208	1,894	$0.1
Other Residential Exterior Contractors	465	2,666	$0.2
Residential Electrical Contractors	6,095	37,933	$2.2
Residential plumbing and HVAC contractors	8,086	66,177	$3.8
Other Residential Equipment Contractors	263	1,331	$0.1
Residential Drywall Contractors	1,694	28,250	$1.4
Residential Painting Contractors	4,220	24,833	$1.0
Residential Flooring Contractors	1,734	9,198	$0.5
Residential tile and terrazzo contractors	1,569	10,771	$0.5
Residential Finish Carpentry Contractors	2,173	14,461	$0.7
Other Residential Finishing Contractors	533	3,855	$0.2
Residential Site Preparation Contractors	1,265	11,130	$0.7
All other residential trade contractors	2,356	21,280	$1.2

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

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Energy Code) are typically updated on a three-year revision cycle and building designers and energy consultants engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310).

Table 7 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code change proposals would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for the Variable Capacity HVAC Compliance Software measure to affect firms that focus on single family construction (including townhouses).

There is not a North American Industry Classification System (NAICS)[7] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[8] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in

Table 7 provides an upper bound indication of the size of this sector in California.

[7] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was development jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

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

Table 7: California Building Designer and Energy Consultant Sectors

Sector	Establishments	Employment	Annual Payroll (billions $)
Architectural Services [a]	3,704	29,611	$2.91
Building Inspection Services [b]	824	3,145	$0.22

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

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

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

Energy consultants would need to become aware of how the revised compliance tools would treat attic ducts when variable capacity systems are modeled and anticipate that measures must be taken to mitigate the diminished compliance margin, particularly when ducts are located in standard (non-high performance) vented attics. Communications with building designers and builders may need to be raised to a higher level than is typical, to address duct location and insulation, cooling equipment type and specifications, and zoning options.

Building designers would also need to be more attentive to the selection of equipment, duct location and insulation methods, and cost implications of HVAC design decisions where the efficiency of variable capacity systems is needed to improve the compliance margin. Designers should coordinate closely with energy consultants and HVAC contractors and ensure that compliance forms include the correct equipment model numbers and performance specifications.

3.3.3 Impact on Occupational Safety and Health

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

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

Commercial Buildings

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

Residential Buildings

According to data from the U.S. Census, American Community Survey (ACS), there were nearly 14.3 million housing units in California in 2018 and nearly 13.1 million were occupied (see Table 8). Most housing units (nearly 9.2 million were single-family homes (either detached or attached), while about 2 million homes were in building containing two to nine units and 2.5 million were in multi-family building containing 10 or more units. The U.S. Census reported that 59,200 single-family and 50,700 multi-family homes were constructed in 2019.

Table 8: California Housing Characteristics

Housing Measure	**Estimate**
Total housing units	14,277,867
Occupied housing units	13,072,122
Vacant housing units	1,205,745
Homeowner vacancy rate	1.2%
Rental vacancy rate	4.0%
Units in Structure	**Estimate**
1-unit, detached	8,177,141
1-unit, attached	1,014,941
2 units	358,619
3 or 4 units	783,963
5 to 9 units	874,649
10 to 19 units	742,139

20 or more units	1,787,812
Mobile home, RV, etc.	538,603

Source: (2018 American Community Survey n.d.)

Table 9 shows the distribution of California homes by vintage. About 15 percent of California homes were built in 2000 or later and another 11 percent built between 1990 and 1999. The majority of California's existing housing stock (8.5 million homes – 59 percent of the total) were built between 1950 and 1989, a period of rapid population and economic growth in California. Finally, about 2.1 million homes in California were built before 1950. According to Kenney et al, 2019, more than half of California's existing multifamily buildings (those with five or more units) were constructed before 1978 when there no building energy efficiency standards (Kenney 2019).

Table 9: Distribution of California Housing by Vintage

Home Vintage	Units	Percent	Cumulative Percent
Built 2014 or later	343,448	2.4%	2.4%
Built 2010 to 2013	248,659	1.7%	4.1%
Built 2000 to 2009	1,553,769	10.9%	15.0%
Built 1990 to 1999	1,561,579	10.9%	26.0%
Built 1980 to 1989	2,118,545	14.8%	40.8%
Built 1970 to 1979	2,512,178	17.6%	58.4%
Built 1960 to 1969	1,925,945	13.5%	71.9%
Built 1950 to 1959	1,896,629	13.3%	85.2%
Built 1940 to 1949	817,270	5.7%	90.9%
Built 1939 or earlier	1,299,845	9.1%	100.0%
Total housing units	**14,277,867**	**100%**	

Source: (2018 American Community Survey n.d.)

Table 10 shows the distribution of owner- and renter-occupied housing by household income. Overall, about 55 percent of California housing is owner-occupied and the rate of owner-occupancy generally increases with household income. The owner-occupancy rate for households with income below $50,000 is only 37 percent, whereas the owner occupancy rate is 72 percent for households earning $100,000 or more.

Table 10: Owner- and Renter-Occupied Housing Units in California by Income

Household Income	Total	Owner Occupied	Renter Occupied
Less than $5,000	391,235	129,078	262,157

$5,000 to $9,999	279,442	86,334	193,108
$10,000 to $14,999	515,804	143,001	372,803
$15,000 to $19,999	456,076	156,790	299,286
$20,000 to $24,999	520,133	187,578	332,555
$25,000 to $34,999	943,783	370,939	572,844
$35,000 to $49,999	1,362,459	590,325	772,134
$50,000 to $74,999	2,044,663	1,018,107	1,026,556
$75,000 to $99,999	1,601,641	922,609	679,032
$100,000 to $149,999	2,176,125	1,429,227	746,898
$150,000 or more	2,780,761	2,131,676	649,085
Total Housing Units	**13,072,122**	**7,165,664**	**5,906,458**
Median household income	**$75,277**	**$99,245**	**$52,348**

Source: (2018 American Community Survey n.d.)

Understanding the distribution of California residents by home type, home vintage, and household income is critical for developing meaningful estimates of the economic impacts associated with proposed code changes affecting residents. Many proposed code changes specifically target single-family or multi-family residences and so the counts of housing units by building type shown in Table 10 provides the information necessary to quantify the magnitude of potential impacts. Likewise, impacts may differ for owners and renters, by home vintage, and by household income, information provided in Table 9 and

Table 10.

Estimating Impacts

For California residents, the proposed code changes would result in lower energy bills for about 5 percent of owners of new homes. The Statewide CASE Team estimates that on average the proposed change to Title 24, Part 6 would only marginally increase construction cost, but the measure is estimated to result in savings of about $3100 in energy and maintenance cost per house over 30 years. In total, the Statewide CASE Team expects this proposed change to 2022 Title 24, Part 6 Standards to save homeowners about $610,000 per year statewide relative to homeowners whose single-family homes are minimally compliant with the 2019 Title 24, Part 6 requirements. As discussed in Section 3.4.1, when homeowners or building occupants save on energy bills, they tend to spend it elsewhere thereby creating jobs and economic growth for the California economy. Energy cost savings can be particularly beneficial to low income homeowners who typically spend a higher portion of their income on energy bills, often have trouble paying energy bills, and sometimes go without other necessities to save money for energy bills (Association, National Energy Assistance Directors 2011).

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

This measure may require manufacturers of variable capacity systems with integrated zonal control to list their products with the California Energy Commission Manufacturer Certification for Building Equipment to be used for compliance. Currently, four manufacturers have been identified that advertise this capability: Trane, Carrier, Lennox, and Rheem. Dealers and distributors may see a small increase in sales of these systems. Manufacturers and dealers would need to provide training for installation and commissioning.

3.3.6 Impact on Building Inspectors

Table 11 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 11: Employment in California State and Government Agencies with Building Inspectors

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

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

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

3.3.7 Impact on Statewide Employment

As described in Sections 3.3.1 through 3.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 3.4, the Statewide CASE Team estimated the proposed change in the implementation of changes proposed by the Variable Capacity HVAC Compliance Software measure would affect statewide employment and economic output directly and indirectly through its impact on builders, designers and energy consultants, and building inspectors. In addition, the Statewide CASE Team estimated how energy savings associated with the proposed change in the implementation of changes proposed by the Variable Capacity HVAC Compliance Software measure would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities.

Contractors and manufacturers would need to provide access to information to support occupants so that they can achieve the best balance of comfort and energy efficiency. Manufacturer websites can provide readily accessible use information with videos that help answer questions.

3.4 Economic Impacts

For the 2022 code cycle, the Statewide CASE Team used the IMPLAN model software, along with economic information from published sources, and professional judgement to developed estimates of the economic impacts associated with each proposed code changes.[9] The IMPLAN model provides a relatively simple representation of the California economy and, though the Statewide CASE Team is confident that direction and approximate magnitude of the estimated economic impacts are reasonable, it is important to understand that the IMPLAN model is a simplification of extremely complex actions and interactions of individual, businesses, and other organizations as they respond to changes in energy efficiency codes. In all aspect of this economic analysis, the CASE authors rely on conservative assumptions regarding the likely economic benefits associated with the proposed code change. By following this approach, the Statewide CASE Team believes the economic impacts presented below represent lower bound estimates of the actual impacts associated with this proposed code change.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the residential building industry, including designers, energy consultants, and HERS Raters, as well as indirectly as residents spend all or some of the money saved through lower utility bills on other economic activities. There may also be some non-residential customers that are impacted by this proposed code change, however the Statewide CASE Team does

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

not anticipate such impacts to be materially important to the building owner and would have measurable economic impacts.

3.4.1 Creation or Elimination of Jobs

The Statewide CASE Team does not anticipate that the measures proposed for the 2022 code cycle regulation would lead to the creation of new *types* of jobs or the elimination of *existing* types of jobs. In other words, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. Rather, the estimates of economic impacts discussed in Section 3.4 would lead to modest changes in employment of existing jobs.

3.4.2 Creation or Elimination of Businesses in California

As stated in Section 3.4.1, the Statewide CASE Team's proposed change would not result in economic disruption to any sector of the California economy. The proposed change represents a modest change to home design and installation of HVAC systems which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes to the California Energy Code.

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses operating in California, regardless of whether the business is located inside or outside of the state.[10] Therefore, the Statewide CASE Team does not anticipate that these proposed measures would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

3.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private

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

domestic investment, or NPDI).[11] As Table 12 shows, between 2015 and 2019, NPDI as a percentage of corporate profits ranged from 26 to 35 percent, and the average was 31 percent. While only an approximation of the proportion of business income used for net capital investment, the Statewide CASE Team believes it provides a reasonable estimate of the proportion of proprietor income that would be reinvested by business owners into expanding their capital stock.

Table 12: Net Domestic Private Investment and Corporate Profits, U.S.

Year	Net Domestic Private Investment by Businesses, Billions of Dollars	Corporate Profits After Taxes, Billions of Dollars	Ratio of Net Private Investment to Corporate Profits
2015	609.3	1,740.4	35%
2016	456.0	1,739.8	26%
2017	509.3	1,813.6	28%
2018	618.3	1,843.7	34%
2019	580.9	1,827.0	32%
		5-Year Average	**31%**

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

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

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

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

3.4.5.1 Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are

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

already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals. Residential changes will not impact state buildings.

Cost to the Local Governments

All revisions to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2022 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining, including tools, training and resources provided by the IOU codes and standards program (such as Energy Code Ace). As noted in Section 2.5 and Appendix C, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

3.4.6 Impacts on Specific Groups of Californians

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed update to the 2022 code cycle may result in unintended consequences. To this end, the Statewide CASE Team considers the potential impacts that the proposed updates to the 2022 code cycle regulation described in this report would have on the following groups:

- Low-income households and communities
- First-time home buyers
- Renters
- Seniors
- Families
- Rural communities

4. Energy Savings

The code change proposal would not modify the stringency of the existing Title 24, part 6 for new homes. Changes to the compliance software would employ the same methods for determining distribution loss for the standard as for the proposed design, but the more accurate method of accounting for duct heat transfers would guide better design decisions when variable capacity HVAC systems are selected. As a result, the improvement in the accuracy of the compliance model is expected to yield energy savings as detailed in this section.

4.1 Key Assumptions for Energy Savings Analysis

Ultimately, proposed changes to the compliance model would alter methods of calculating distribution effectiveness when ducts are located in a vented attic to account for the effect of reduced airflow and system capacity on overall system efficiency, as illustrated in Table 4. Changes to Residential California Building Energy Code Compliance software (CBECC-Res) could not be made in advance of the need to estimate energy savings for this report. However, WCEC compared distribution effectiveness predicted by their model, which was developed from laboratory testing, to results obtained using the California Simulation Engine (CSE). WCEC's research to develop the model is documented int an ASHRAE paper (Krishnamoorthy 2017).

The CSE contains the code that is used by CBECC-Res to calculate building heating and cooling loads and HVAC energy use. As shown in Figure 4, duct delivery effectiveness calculated using the WCEC model compared favorably to CSE results. To correct duct heat gain calculations in the CSE, the Statewide CASE Team applied hourly attic temperatures to estimate the energy impacts resulting from reduced delivery effectiveness and capacity using the data shown in Figure 4.

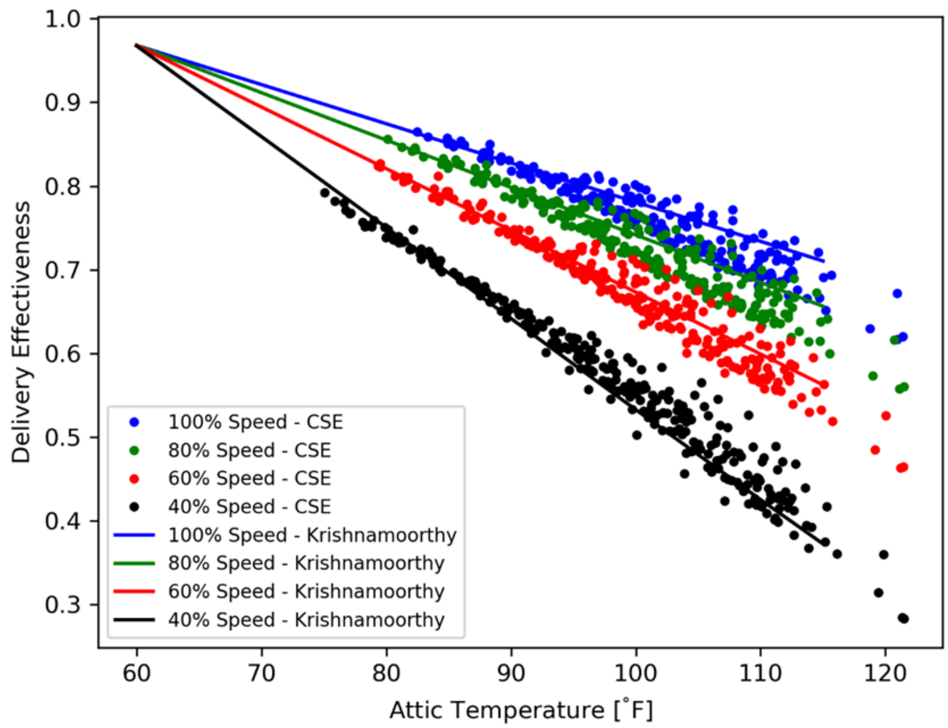

Figure 4: Comparison of the model developed from laboratory tests to CSE results

Source: (Krishnamoorthy 2017)

For the purposes of the savings analysis, hourly system capacity and airflow was determined from the fraction of maximum heating or cooling capacity that is needed each hour based on hourly loads. The various dual-speed and multiple-speed systems available have different limits to how much their capacity can be reduced, or "turn-down ratios". The savings analysis used a turn-down ratio limit of 25 percent of full capacity. To avoid the need to define another system type in CBECC-Res inputs, permanent changes to the software should apply the same ratio for systems defined as "dual-speed" and "multiple-speed" in the MAEDBS directory.

4.2 Energy Savings Methodology

4.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 13. Additional information about the prototypes is available in Appendix A of the 2019 ACM Approval Manual (CEC Res-ACM 2019). Although energy savings are expected when variable capacity systems are used to replace systems in existing homes with attic ducts, the proposed measure and energy savings analysis is limited to new homes.

Table 13: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
SF2100	1	2100	single story house with attached garage, pitched roof, attic. 9-ft ceilings, 1 ft overhang, front door, garage door.
SF2700	2	2700	2-story home with attached 2-car garage. 9-ft ceilings, 1-ft between floors, 1-ft overhang.

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of CBECC-Res software for residential buildings (CBECC-Res) as well as a stand-alone external duct model (CalCERTS, Inc. 2019).

CBECC-Res generates two models based on user inputs: the Standard Design and the Proposed Design.[12] The Standard Design represents the geometry of the design that the builder would like to build and inserts a defined set of features that result in an energy budget that is minimally compliant with 2019 Title 24, Part 6 code requirements. Features used in the Standard Design are described in the 2019 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.

There is an existing Title 24, Part 6 requirement that covers the building system in question and applies to both new construction and alterations, so the Standard Design is minimally compliant with the 2019 Title 24 requirements. For example, Section 150.1(c)9 includes a prescriptive requirement that ducts either be located in conditioned space or in a high performance attic that has an uninsulated roof deck insulation (Option B in Table 150.1-A). The proposed design can include ducts in a vented attic without roof deck insulation, but compliance software would account for the decreased distribution efficiency.

Rather than develop savings estimates for the proposed code changes using standard and prototypical designs for each building, the Statewide CASE Team evaluated the

[12] 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.

energy impact resulting from the proposed software change for two cases, one that follows current modeling protocol of fixed airflow using the prototypes with prescriptive design features, and the other that accounts for airflow that is in proportion to building loads. Table 14 presents precisely which parameters were modified and which values were used to estimate energy impacts.

Currently, CBECC-Res only varies cooling and heating efficiency as a function of outdoor temperature based on entered values for EER, SEER, AFUE, and HSPF. Permanent changes to the simulation code were not available to calculate energy savings for this CASE report. Instead, an external model was developed that varies distribution effectiveness with airflow rate. Distribution effectiveness results from this model were verified by comparing to results from the CSE as shown in Figure 4.

The external model uses hourly loads from CBECC-Res to determine the required fan and compressor operating speed for each hour. The distribution effectiveness is then calculated for the fan speed and airflow rate. The efficiency and capacity of the cooling system is also modified given the reduced speed and the outdoor temperature for the hour. Normally, as speed is reduced air conditioner and heat pump efficiency improves as a result of an effective increase in condenser and evaporator coil size relative to the load, and due to fan cube law energy use reduction at the reduced airflow rate. Under these conditions the reduced low-speed capacity matches the load. The resulting overall efficiency is then used to calculate energy use and to modify CBECC-Res results.

CBECC-Res was used to develop baseline energy use in all sixteen climate zones and for the 2100 ft^2 single story and 2700 ft^2 two-story single family new construction prototype houses[13] using assumed equipment efficiencies of 20 SEER, 14 EER, 10 HSPF, and 0.95 AFUE. The external duct model, combined with CBECC-Res output, was used to evaluate energy impacts for the same prototypes and climate zones.

In developing energy impacts the Statewide CASE Team utilized all features of the Standard Design except for system efficiency, substituting typical performance ratings for variable capacity systems. The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes that account for distribution effectiveness.

[13] Detailed descriptions of the prototypes are provided in Section F of the California Energy Commission ACM Approval Manual (CEC 2018)

Table 14: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
SF2100	All	Heat pump	SEER 20, HSPF 10, current duct model, R-6/R-8 ducts	Same as Standard, modified duct model
SF2700	All	Heat pump	SEER 20, HSPF 10, current duct model, R-6/R-8 ducts	Same as Standard, modified duct model
SF2100	All	Gas heat / electric cooling	SEER 20, AFUE 95, current duct model, R-6/R-8 ducts	Same as Standard, modified duct model
SF2700	All	Gas heat / electric cooling	SEER 20, AFUE 95, current duct model, R-6/R-8 ducts	Same as Standard, modified duct model

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

For new homes, energy impacts are reported as site kWh for new construction and were based on duct insulation as required by Table 150.1-A (R-6 or R-8). Since variable capacity equipment is a compliance option, TDV savings were not calculated.

The energy impacts of the proposed code change vary by climate zone. The Statewide CASE Team simulated the energy impacts in every climate zone. TDV factors were not applied.

Per-unit energy impacts for single family buildings are presented in savings per prototype building. Savings are presented for both single family prototypes. Statewide savings were not calculated because of uncertainties about market penetration of variable capacity systems in new construction, and for system replacements in existing homes.

4.2.2 Statewide Energy Savings Methodology

As applied to new homes the proposed measure modifies how compliance options for above-minimum efficiency variable capacity HVAC systems are modeled. The measure does not increase the stringency of the standards. Also, there are no reliable sources of data on market penetration of variable capacity systems. For these reasons, estimates of statewide impacts were not developed for this measure.

4.3 Per-Unit Energy Impacts Results

Energy impacts per unit are presented in Table 15, Table 16, Table 17, and Table 18 for the 2100 ft^2 and 2700 ft^2 new home prototypes equipped with heat pumps and gas furnace-air conditioning systems. Results also show how roof deck insulation affects energy impacts in those climate zones where it is prescriptively required (not required in Climate Zones 1-3 and 5-7). Peak load impacts were not determined nor are they expected. Under high load conditions variable capacity systems operate at full capacity (and airflow), so there are no distribution effectiveness penalties and therefore no changes in peak load.

The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates. Per-unit energy impacts for the first year are expected to range from 0 to 1167 kWh/yr and 0 to 125 therms/yr depending upon climate zone, house type, and system type (heat pump or gas-electric). No demand savings are expected for this measure because systems would be operating at full speed during peak periods.

To keep results in perspective, they compare differences between energy use predictions made by the 2019 version of CBECC-Res to the proposed 2022 model that includes improvements to the distribution effectiveness calculations, where the proposed 2022 modeling results are based on the WCEC duct model. Results are based on a cooling SEER of 20, heat pump HSPF of 10, and furnace AFUE of 95. As expected, impacts are lower in mild climate zones (with one exception), and typically lower where roof deck insulation is modeled due to more moderate attic temperatures. Climate Zone 15 is an anomaly in that it shows a benefit to reducing duct velocity, particularly for heating. This may be due to increased attic duct heat gains which help offset winter heating load.

Table 15: First-year Energy Impacts – 2100 ft^2 Single Story Prototype, Heat Pump

Climate Zone	Electricity Impact (kWh/yr) - No Roof Deck Insulation	Electricity Impact (kWh/yr) - With Roof Deck Insulation
1	958	n/a
2	785	n/a
3	469	n/a
4	562	405
5	568	n/a
6	251	n/a
7	93	n/a
8	175	129
9	255	209
10	295	266
11	624	574
12	728	604
13	526	460
14	660	615
15	(214)	(83)
16	1,167	1,063

Table 16: First-Year Energy Impacts – 2700 ft^2 Two Story Prototype, Heat Pump

Climate Zone	Electricity Impact (kWh/yr) - No Roof Deck Insulation	Electricity Impact (kWh/yr) - With Roof Deck Insulation
1	849	n/a
2	607	n/a
3	396	n/a
4	449	325
5	421	n/a
6	228	n/a
7	98	n/a
8	171	132
9	256	218
10	260	224
11	525	461
12	536	423
13	403	359
14	511	428
15	(327)	(226)
16	1,134	805

Table 17: First-Year Energy Impacts – 2100 ft^2 Single Story Prototype, Air Conditioner and Furnace

Climate Zone	Electricity Impact (kWh/yr) - No Roof Deck Insulation	Electricity Impact (kWh/yr) - With Roof Deck Insulation	Gas Impact (therms/yr) - No Roof Deck Insulation	Gas Impact (therms/yr) - With Roof Deck Insulation
1	0	n/a	119	n/a
2	1	n/a	70	n/a
3	0	n/a	64	n/a
4	1	0	59	56
5	0	n/a	53	n/a
6	3	n/a	29	n/a
7	0	n/a	14	n/a
8	22	6	19	17
9	26	1	26	24
10	36	18	31	28
11	43	35	65	60
12	30	13	75	69
13	48	40	62	58
14	46	37	64	61
15	7	25	4	2
16	10	5	125	112

Table 18: First-Year Energy Impacts – 2700 ft^2 Single Story Prototype, Air Conditioner and Furnace

Climate Zone	Electricity Impact (kWh/yr) - No Roof Deck Insulation	Electricity Impact (kWh/yr) - With Roof Deck Insulation	Gas Impact (therms/yr) - No Roof Deck Insulation	Gas Impact (therms/yr) - With Roof Deck Insulation
1	0	n/a	88	n/a
2	4	n/a	56	n/a
3	0	n/a	48	n/a
4	4	2	47	42
5	0	n/a	37	n/a
6	1	n/a	23	n/a
7	0	n/a	11	n/a
8	18	6	15	14
9	19	6	22	20
10	27	14	25	22
11	19	11	54	48
12	22	11	63	55
13	24	16	53	47
14	27	15	54	49
15	(34)	(26)	6	5
16	9	4	107	91

5. Cost and Cost Effectiveness

This code change proposal would not modify the stringency of the existing Title 24, Part 6, so a complete cost-effectiveness analysis is not needed. Section 5 of the CASE Reports typically presents a detailed cost-effectiveness analysis. For this proposed change, the Statewide CASE Team is presenting information on the cost implications in lieu of a full cost-effectiveness analysis.

6. First-Year Statewide Impacts

The code change proposal would not modify the stringency of the existing Title 24, Part 6, so the savings associated with this proposed change are minimal. Typically, the Statewide CASE Team presents a detailed analysis of statewide energy and cost savings associated with the proposed change in Section 6 of the CASE Report. As discussed in Section 4, although the energy impacts are limited, the measure would improve guidance on the selection of equipment and duct location/insulation through energy modeling results, and would promote improved comfort by minimizing distribution losses.

There is no reliable data on the statewide market penetration of variable capacity HVAC systems. The contractor survey completed (Table 4) was too limited to use for this purpose, and information on this question was not volunteered at stakeholder meetings.

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).

7.2 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

Section 100.1(b) – Definitions: Recommend new definitions for the following terms:

"Integrated Zonal Control System" is a variable capacity HVAC system that combines control of compressor, fan speed, and zone dampers such that the compressor and fan speed are regulated by static pressure or other means to prevent low air velocity and/or over-pressurization of ducts.

"Variable Capacity HVAC System" is a ducted HVAC system (not including low-static systems) utilizing split indoor-outdoor units that include either a dual-speed, multiple-speed, or variable-speed compressor as referred to in the Energy Commission's Modern Appliance Database (MAEDBS) and an indoor air handler having more than one speed.

SECTION 150.0 – MANDATORY FEATURES AND DEVICES

150.0(m)13. Space Conditioning System Airflow Rate and Fan Efficacy. Space conditioning systems that utilize forced air ducts to supply cooling to an occupiable space shall:

C. **Zonally Controlled Central Forced Air Systems.** Zonally controlled central forced air cooling systems shall be capable of simultaneously delivering, in every zonal control mode, an airflow from the dwelling, through the air handler fan and delivered to the dwelling, of greater than or equal to 350 CFM per ton of nominal cooling capacity, and operating at an air-handling unit fan efficacy of less than or equal to the maximum W/CFM specified in subsections i or ii below. The airflow rate and fan efficacy requirements in this section shall be confirmed by field verification and diagnostic testing in accordance with the applicable procedures specified in Reference Residential Appendix RA3.3.

i. 0.45 W/CFM for gas furnace air-handling units.

ii. 0.58 W/CFM for air-handling units that are not gas furnaces.

EXCEPTION ~~1~~ to Section 150.0(m)13C: ~~Multispeed or variable speed compressor systems, or single speed compressors~~ Integrated zonal control systems as defined in Section 110.1(b) that utilize the performance approach, shall demonstrate compliance with the airflow (cfm/ton) and fan efficacy (Watt/cfm) requirements of Section 150.0(m)13C by operating the system at maximum compressor capacity and system fan speed with all zones calling for conditioning, rather than in every zonal control mode.

D. **Small Duct High Velocity Forced Air Systems.** Demonstrate, in every control mode, airflow greater than or equal to 250 CFM per ton of nominal cooling capacity through the return grilles, and an air-handling unit fan efficacy less than or equal to 0.62 W/CFM as confirmed by field verification and diagnostic testing in accordance with the procedures given in Reference Residential Appendix RA3.3

EXCEPTION 1 to Section 150.0(m)13B and D: Standard ducted systems without zoning dampers may comply by meeting the applicable requirements in TABLE 150.0-B or 150.0-C as confirmed by field verification and diagnostic testing in accordance with the procedures in Reference Residential Appendix Sections RA3.1.4.4 and RA3.1.4.5. The design clean-filter pressure drop requirements specified by Section 150.0(m)12Div for the system air filter(s) shall conform to the requirements given in TABLES 150.0-B and 150.0-C.

EXCEPTION 2 to Section 150.0(m)13B and D: Multispeed compressor systems or variable speed compressor systems shall verify airflow (cfm/ton) and fan efficacy (Watt/cfm) for system operation at the maximum compressor speed and the maximum air handler fan speed.

~~**EXCEPTION 3 to Section 150.0(m)13B: Gas furnace air-handling units manufactured prior to July 3, 2019 shall** comply with **a fan efficacy value less than or equal to 0.58 w/cfm** as **confirmed by field verification and diagnostic testing in accordance with the procedures given in Reference Residential Appendix RA3.3.**~~

~~**EXCEPTION 1 to Section 150.0(m)13C:** Multispeed or variable speed compressor systems, or single speed compressor systems that utilize the performance compliance approach, shall demonstrate compliance with the airflow (cfm/ton) and fan efficacy (Watt/cfm) requirements of Section 150.0(m)13C by operating the system at maximum compressor capacity and system fan speed with all zones calling for conditioning, rather than in every zonal control mode.~~

~~**EXCEPTION 2 to Section 150.0(m)13C: Gas furnace air-handling units manufactured prior to July 3, 2019 shall comply with a fan efficacy value less than or equal to 0.58 w/cfm as confirmed by field verification and diagnostic testing in accordance with the procedures given in Reference Residential Appendix RA3.3.**~~

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

150.1(b)3. Compliance Demonstration Requirements for Performance Standards.

B. **Field Verification**. When performance of installed features, materials, components, manufactured devices or systems above the minimum specified in Section 150.1(c) is necessary for the building to comply with Section 150.1(b), or is necessary to achieve a more stringent local ordinance, field verification shall be performed in accordance with the applicable requirements in the following subsections, and the results of the verification(s) shall be documented on applicable Certificates of Installation pursuant to Section 10-103(a)3 and applicable Certificates of Verification pursuant to Section 10-103(a)5.

x. **Variable Capacity Systems**. When performance compliance includes zonally controlled variable capacity systems with ducts in non-conditioned space, zone controls shall be field verified to operate in concert with the compressor and furnace or heat pump air handler fan in accordance with the procedures specified in Residential Appendix RA3.4.4.3.

7.3 Reference Appendices

Appendix RA3 – Residential Field Verification and Diagnostic Test Protocols

RA3.4.4 HVAC System Verification Procedures

RA3.4.4.3. ***Verification Procedure for Variable Capacity Systems with Zonal Controls***

When performance compliance includes a multiple speed or variable speed (variable capacity) split system with zonal controls, the controls for the system shall be verified according to the procedure specified in this section. The verification procedure shall consist of visual inspection to confirm that the furnace or heat pump air handler, outdoor unit, and zone controls are as listed in the compliance forms, and the following tests shall be performed and documented in compliance documents:

(a) Verify that no bypass damper is installed (per RA3.1.4.6).

(b) Set thermostats so that all zones are calling for cooling.

(c) After the system has been operating for at least five minutes, measure and record the airflow using methods described in RA3.3.

(d) Set all thermostats but the one zone with the lowest cooling load to the off position.

(e) Measure and record airflow again.

(f) For the HERS Rater inspecting the system, if the second airflow measurement is not greater than 60 percent of the first airflow measurement with all zones calling for cooling, then there is sufficient evidence that controls link zonal operation to equipment capacity and the system passes.

(g) For the Installer, if the system fails to meet the maximum airflow criteria with one zone calling, then necessary control adjustments or equipment substitutions must be made and the measurement procedure repeated.

7.4 ACM Reference Manual

Proposed changes to calculation methods used by the CSE are described in Appendix D. Modifications to ACM language are provided below.

2.4.5.2 Verified System Airflow

Adequate airflow from the conditioned space is required to allow ducted air-conditioning systems to operate at full efficiency and capacity. Efficiency is achieved by the air distribution system design by improving the efficiency of motors or by designing and installing air distribution systems that have less resistance to airflow. Software calculations account for the effect of airflow on sensible heat ratio and compressor efficiency.

For systems other than small-duct, high-velocity types, a value less than 350 CFM/ton (minimum 150 CFM/ton) is a valid input only if zonally controlled equipment is selected and multispeed compressor is not selected. Inputs less than 350 cfm/ton for zonally controlled systems require verification using procedures in *Reference Residential Appendix* RA3.3.

Section 150.0(m)13 requires verification that the central air-handling unit airflow rate is greater than or equal to 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems. Values greater than the required CFM/ton may be input for compliance credit, which requires diagnostic testing using procedures in *Reference Residential Appendix RA3.3*.

For Single-Zone Systems:

- As an alternative to verification of 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems, HERS verification of a return duct design that conforms to the specification given in Table 150.0-B or C may be used to demonstrate compliance.
- The return duct design alternative is not an input to the compliance software, but must be documented on the certificate of installation.
- If a value greater than 350 CFM/ton for systems other than small-duct, high-velocity types or greater than 250 CFM/ton for small-duct, high-velocity systems is modeled for compliance credit, the alternative return duct design method using Table 150.0-B or C is not allowed for demonstrating compliance.
- Variable capacity systems (including ~~M~~multi-speed, and ~~or~~ variable-speed compressor systems) must verify airflow rate (CFM/ton) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For Zonally Controlled Systems:

- The Table 150.0-B or C return duct design alternative is not allowed for zonally controlled systems.

- Variable capacity~~, multi-speed, variable-speed, and single-speed~~ compressor systems (including multi-speed) must ~~all~~ verify airflow rate (CFM/ton) by operating the system at maximum compressor capacity and maximum system fan speed in every zonal control mode,~~with all zones calling for conditioning.~~ except that systems that integrate zonal control with compressor and fan speed may verify airflow with all zones calling for conditioning.
- ~~Single-speed compressor systems must also verify airflow rate (CFM/ton) in every zonal control mode.~~
- For systems that input less than 350 CFM/ton, HERS verification compliance cannot use group sampling.

PROPOSED DESIGN

The default cooling airflow is 150 CFM/ton for a system with “zonally controlled” selected and “multispeed compressor” not selected (single-speed). Users may model airflow for these systems greater than or equal to 150 CFM/ton, which must be verified using the procedures in *Reference Residential Appendix RA3.3.* Inputs less than the rates required by Section 150.0(m)13 would be penalized in the compliance calculation.

The default cooling airflow is 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems. Users may model a higher-than-default airflow for these systems and receive credit in the compliance calculation if greater-than-default system airflow is diagnostically tested using the procedures of *Reference Residential Appendix RA3.3*.

2.4.5.3 *Verified Air-Handling Unit Fan Efficacy*

The mandatory requirement in Section 150.0(m)13 is for an air-handling unit fan efficacy less than or equal to 0.45 watts/CFM for gas furnace air-handling units, 0.58 watts/CFM for air-handling units that are not gas furnaces, and 0.62 W/CFM for small-duct, high-velocity systems as verified by a HERS Rater. Users may model a lower fan efficacy (W/CFM) and receive credit in the compliance calculation if the proposed fan efficacy value is diagnostically tested using the procedures in *Reference Residential Appendix RA3.3*.

For Single-Zone Systems:

- Installers may elect to use an alternative to HERS verification of the watts/CFM required by Section 150.0(m)13: HERS verification of a return duct design that conforms to the specification given in Table 150.0-B or C.
- The return duct design alternative is not an input to the compliance software, but must be documented on the certificate of installation.
- If a value less than the watts/CFM required by 150.0(m)13 is modeled by the software user for compliance credit, the alternative return duct design method using Table 150.0-B or C is not allowed for use in demonstrating compliance.

- Multispeed or variable-speed compressor systems must verify fan efficacy (watt/CFM) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For Zonally Controlled Systems:

- The Table 150.0-B or C return duct design alternative is not allowed for zonally controlled systems.
- Variable capacity systems with integrated zonal control ~~Multispeed, variable-speed and single-speed compressor systems~~ must all verify fan efficacy (watt/CFM) by operating the system at maximum compressor capacity and maximum system fan speed with all zones calling for conditioning.
- Single-speed compressor systems and variable capacity systems without integrated zonal control must verify fan efficacy in every zonal control mode.

7.5 Compliance Manuals

Chapter 4, Building HVAC Requirements, of the Residential Compliance Manual would need to be revised. In Section 4.1.2 (What's New) changes to CBECC-Res that account for duct performance with variable capacity systems would be described.

Section 4.4.1.18 would be edited to make it clear that specialized controls are needed to ensure that multispeed compressors "allow the system capacity to vary to more closely match reduced cooling loads when fewer than all zones call for cooling" and that simply installing a multispeed compressor system with zoning does not mean that the controls of the two systems communicate to meet this objective.

Section 4.5.2 would provide more information on zoning systems and would distinguish between living-sleeping zoning and zonally controlled cooling equipment, which CBECC models differently than the living-sleeping zoning option. Treatment of bypass dampers, which are not needed when zoning systems communicate with multispeed compressors, would also be addressed.

7.6 Compliance Documents

Compliance documents CF1R-PRF-01-E and CF2R-MCH-01-E (for use with performance compliance) must have a check box added to indicate that a variable capacity system with integrated zoning is being used for performance compliance.

The compliance document CF3R-MCH-22-H must be modified to indicate use of a zonal controls and multispeed compressor type and verification requirements.

It is probable that these changes would not require new forms. Entries on the CF1R forms made by the energy consultant would alert HERS Raters of the requirement for acceptance testing as described in RA3.4.4.3.

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Appendix A: Statewide Savings Methodology

The Statewide CASE Team did not estimate statewide impacts because this measure is not a change to mandatory requirements and only affects how a compliance option is applied, and because data on statewide use of variable capacity systems in new and existing homes is not available.

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

The Statewide CASE Team did not estimate statewide impacts related to greenhouse gas emissions because this measure is not a change to mandatory requirements and only affects how a compliance option is applied, and because data on statewide use of variable capacity systems in new and existing homes is not available.

Water Use and Water Quality Impacts Methodology

There are no impacts to water quality or water use related to the proposed measure.

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

Introduction

The purpose of this appendix is to present proposed revisions to CBECC for residential buildings (CBECC- Res) along with the supporting documentation that the Energy Commission staff and the technical support contractors would need to approve and implement the software revisions.

Technical Basis for Software Change

Through laboratory testing and simulation work, the UC Davis Western Cooling Efficiency Center has demonstrated that when variable capacity HVAC systems operate at reduced speed, duct distribution effectiveness can be severely reduced (Krishnamoorthy 2017). The reduced air volume increases duct heat transfers to attic air and results in a reduction of the overall system COP (see Figure 2). This effect is also seen when ducts are modeled using the methods described in ASHRAE Standard 152 (ASHRAE 2014).

As Title 24, Part 6 Standards become more stringent builders will be looking to the higher equipment efficiency provided by variable capacity systems as a cost-effective means to improving compliance margins. It is important that CBECC reflect not just the increase in equipment efficiency based on performance ratings, but also the effect of reduced distribution effectiveness. The approach described in this appendix provides a basis by which variable capacity systems should be evaluated, and outlines the key variables needed to simulate the performance of these systems in energy modeling software.

Description of Software Change

Background Information for Software Change

For new homes using performance compliance, the proposed software change would improve the calculation of duct heat loss and gain for variable capacity systems that vary airflow in attic ducts. It would apply only to ducted split system HVAC systems in new single family units and townhouses. The same duct modeling change would apply to the Standard Design model as to the Proposed model. Relevant test results and research findings are identified in the above section.

The Statewide CASE Team recommends that CBECC-Res be modified to account for changes in distribution effectiveness for all cases where the design calls for variable capacity systems with attic ducts (Krishnamoorthy 2017), except where a certified zonal control system that integrates with the variable capacity system is to be provided. In the latter case, airflow would not be modified with respect to the load because it is assumed that duct velocity would be maintained as zone dampers close when loads are reduced. For non-zoned systems, the proposed change would reduce the velocity of the air used in the duct model in proportion to the load. A lower limit of 25 percent of maximum airflow and capacity is subject to review by the software development team. The same value was used to develop energy impacts (see Section 4).

Existing CBECC- Res Modeling Capabilities

The 2019 version of CBECC-Res uses entered values for SEER and EER to calculate cooling efficiency (EERt) and uses entered values of AFUE and HSPF to calculate heating efficiency for furnaces and heat pumps respectively. The calculation of distribution effectiveness and duct loss is based on a fixed airflow rate for variable capacity as well as single speed systems. The substantial reduction in duct efficiency at the lower airflow rates delivered by variable capacity systems, and the impact on system COP as shown in Figure 2 is not accounted for by the model.

Duct modeling methods currently in use are defined in the 2019 Residential ACM Reference Manual in Sections 2.4.6 and Appendices A and G. Appendix A provides the derivation of duct loss equations, including Equations A-1 through A-20, which conduct an energy balance between the rate of change of heat flow through the duct and heat flow through the duct wall as a function of the mass flow rate and other parameters, and determine conduction losses to the duct zone. Appendix G includes algorithms for the duct thermal model and uses a steady state heat exchanger effectiveness approach to get analytical expressions for instantaneous duct loss and system efficiencies.

The mass flow used in CBECC is based on a fixed 350 cfm per ton unless a zonally controlled system is installed. For single-speed zonally controlled systems the user may specify an airflow as low as 150 cfm per ton to account for bypass dampers that allow air to shunt around the air handler to maintain airflow through the coil or furnace when fewer than all zone dampers are open. When zonal control is combined with multi-speed systems, the default 350 cfm/ton can be used. The lower airflows have the effect of reducing compliance. For a given system, airflow is assumed to be constant regardless of the type of fan installed (constant or multi-speed).

Duct location (attic or other) and duct insulation level are user inputs. Duct surface area is a function of the duct type (supply or return), floor area and number of stories. The modeler may enter reduced surface area subject to HERS verification.

Building loads are calculated by the CSE. Buildings can be modeled with multiple conditioned and unconditioned zones. Each conditioned zone includes a dedicated thermostat, air handler, and duct system. When the conditioned zone energy balance is performed, duct heat gains and losses are subtracted from system heating or cooling capacity. To avoid iteration the duct efficiency for the current time step is calculated from the previous time step. The model also accounts for the effect that duct heat transfers have on the temperature of the unconditioned space in which they are located and the resulting reduction of duct losses (known as regain).

The ACM Reference Manual has little information on modeling of furnaces. Presumably, gas energy use is directly calculated from AFUE and heating load.

Summary of Proposed Revisions to CBECC-Res

CBECC-Res provides two check boxes under Mechanical / Cooling Systems and Heat Pump Systems: "Multi-Speed Compressor" and "Zonally Controlled". Currently, the check boxes do not affect the way that the system is modeled but only serve as points of reference for the HERS Rater, but they may be used to alter the way that ducts are modeled. Only one input needs to be added, which is cfm per kBtuh of furnace capacity in Heating System Data.

Using CBECC-Res 2019, if the Zonally Controlled box is checked, then the HERS Rater must test the system to ensure it delivers the airflow that is specified under Cooling System Data or Heat Pump Data tabs, which is allowed to be as low as 150 cfm per ton but may be greater. The HERS Rater must also verify that the fan efficacy (watts per cfm) is not more than 0.45 W/cfm for furnaces and 0.58 W/cfm for heat pumps. For single-speed systems (Multi-Speed Compressor box not checked), airflow must be verified in "every control mode", meaning that all but the smallest zone must be closed during the test. If both the Multi-Speed Compressor and Zonally Controlled boxes are checked the HERS Rater can measure airflow and verify efficacy with all zone dampers open. Thus, the check boxes only serve to direct the HERS Rater on how to conduct inspections and they do not affect the simulation.

Standards language and compliance software assume that there is communication between zone controls and the multi-speed compressor (and indoor unit fan), which is not usually the case. Except for a handful of multi-speed systems, airflow is not reduced when fewer than all zones are calling and bypass dampers must be used to relieve excess pressure. Bypass dampers reduce airflow to the zones, which lowers the temperature of the cooling coil, and decreases sensible capacity and lowers efficiency.

It is proposed that the checkboxes be used to alter compliance calculations in the following way. If the Multi-Speed box is checked, the software would base the airflow used to calculate duct efficiency on instantaneous building load. If both boxes are checked, the airflow would not be altered, but this would trigger a verification that a certified variable capacity system with integrated zonal control is provided.   Specific modeling changes are proposed in the following section.

User Inputs to CBECC-Res

Existing user inputs can be used to improve CBECC-Res modeling accuracy by changing how they are used. Additional user inputs are needed to improve modeling of heating systems. These recommendations include:

- Add a Multi-Speed checkbox and a cfm/kWh input to the Heating System Data tab that defaults to 20 cfm per kBtuh of furnace heating capacity.
- When the Multi-Speed check box is selected in Cooling Systems or and Heat Pump Systems, apply the rated capacity and default (or entered) airflows for maximum building load, and reduce the system heating or cooling capacity to match the building load when the instantaneous part load is less than the equipment capacity, and correspondingly reduce the airflow rate.
- When the Multi-Speed checkbox is selected in Heating Systems (furnaces), calculate airflow based on the default or entered airflow (in cfm per kBtuh of furnace capacity). If the heating load falls below 60 percent of maximum heating capacity, the airflow is correspondingly reduced to 60 percent of the default/entered value (these percentages are believed to be representative).
- Apply the airflow rate from the part load calculation to derive the hourly duct loss (Equations A-1 through A-20).
- If both the Multi-Speed and Zonal Control boxes are checked, set the airflow to a constant 350 cfm per ton (or other input value) for cooling, and 20 cfm per kBtuh for heating.

Relevant inputs to the CBECC-Res user interface that are passed in some form to the California Simulation Engine (CSE) are listed in Table 19.

Table 19: User Inputs Relevant to Variable Capacity Systems

HVAC System Type / Tab	Input Description	Current Use	Proposed CSE Use
HeatingComponent (CntrlFurnace)			
Heating System Data	cfm/kBtuh	n/a	Maximum heating airflow
Heating System Data	Multi-Speed*	n/a	Vary airflow with load
Heating System Data	Zonal Control*	n/a	HERS verification/set constant airflow
CoolingComponent (SplitAirCond)			
Cooling System Data	Multi-Speed**	HERS verification	Vary airflow with load

HVAC System Type / Tab	Input Description	Current Use	Proposed CSE Use
Cooling System Data	Zonal Control**	HERS verification	HERS verification/set constant airflow
HeatPumpSystem			
Heat Pump Data	Multi-Speed**	HERS verification	Vary airflow with load
Heat Pump Data	Zonal Control**	HERS verification	HERS verification/set constant airflow

*New checkbox

**Existing checkbox

Simulation Engine Inputs

Inputs passed to the CSE would be used to determine how duct performance would be simulated, either using the current fixed airflow method (for single-speed systems, buildings with ducts in conditioned space, or variable capacity systems with certified zonal controls), or using a new algorithm that relates system capacity and airflow to building load. The Statewide CASE team will share the algorithms used in the WCEC model, but details on the development of the CSE algorithm should be handled by the compliance software team. The Statewide CASE team is recommending a lower limit to the capacity and airflow reduction of 25 percent.

Simulation Engine Output Variables

Simulation output variables that would be affected by inputs include compressor energy, and for gas/electric systems, gas therms. Reporting of hourly loads and airflows would be useful for verifying that the simulation is completing the calculations correctly. Where variable capacity systems with attic ducts and without zonal control are modeled, energy use for heating and cooling is expected to be higher than for CBEC-Res 2019 and compliance margins would be lower.

Compliance Report

No changes to the compliance report are needed except that reports would need to indicate the need for verification of variable capacity systems with integrated zonal control.

Compliance Verification

Verification is needed only for variable capacity systems utilizing integrated zonal control, as identified in compliance reports. Verification may involve only the methods described in Reference Appendices, or in addition verification that the system is listed in the Energy Commission's Certified Equipment directory.

Testing and Confirming CBECC-Res Modeling

Tests to verify that the proposed changes have the desired impact on energy use are listed in

Table 20. All cases use the 2100 ft2 single story prototype with prescriptive design features and Roof/Ceiling Option B except as noted in the table. The efficiencies of air conditioners and heat pumps were selected to make the results agnostic to system efficiency - the MAEDBS lists both single-speed and dual-speed systems that are close to these efficiencies.

Runs 1a – 1d use an extreme case to verify that airflow reduction is functioning in the model, and to show the magnitude of the change in duct modeling in selected climate zones. The CASE authors or the software development team can cross-check results against the results from the WCEC model.

Runs 2a – 2c also use the extreme case to verify that when zonal control is selected in concert with variable capacity that duct airflow is restored to 350 cfm/ton, and that airflow is appropriately reduced when only zonal control is selected (as in the 2019 version of CBECC-Res).

Runs 3a – 3d measure the impact of duct airflow change across all climate zones. Any bugs in the model that are identified in the prior to run sets will be repaired before this analysis is completed.

Table 20: Table of Inputs and Assumptions for Software Testing and Verification

Run Set	Exceptions to Prescriptive Design	HVAC System	HVAC Check Boxes	Climate Zones
1a	No roof deck insulation, no radiant barrier, roof reflectance 0.10 & emittance 0.85, R-6 attic ducts	Heat Pump: 16 SEER, 12.5 EER, 9.5 HSPF	None	2, 5, 12, 14, 16
1b	Same as 1a	Cntrl Furnace & SplitAirCond: 16 SEER, 12.5 EER, 80 AFUE	None	2, 5, 12, 14, 16
1c	Same as 1a	Same as 1a	Multi-Speed Compressor	2, 5, 12, 14, 16
1d	Same as 1a	Same as 1b	Multi-Speed Compressor and Multilspeed Furnace	2, 5, 12, 14, 16
2a	Same as 1a	Same as 1a	Multi-Speed Compressor plus Zonal Control	12
2b	Same as 1a	Same as 1b	Multi-Speed Compressor and Multilspeed Furnace plus Zonal Control	12
2c	Same as 1a	Same as 1a	Zonal Control only	12
3a	Consistent with Table 150.1-A, Roof/Ceiling Option B	Same as 1a	None	All
3b	Same as 3a	Same as 1b	None	All
3c	Same as 3a	Same as 1a	Multi-Speed Compressor	All
3d	Same as 3a	Same as 1b	Multi-Speed Compressor and Multilspeed Furnace	All

Description of Changes to ACM Reference Manual

Proposed changes to the ACM Reference Manual language are provided in Section 7.5. Changes to algorithms listed in Appendix G of the Reference Manual would also be required and are subject to the determination of the Software Development Team.

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. Table 21 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. The information contained in Table 21: Roles of Market Actors in the Proposed Compliance Process 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.

The proposed compliance process will fit within the current work flow of market actors. No additional HERS inspections are required. Where verification of certified zonal control systems is required HERS Raters would need to be trained on their operation so that they can complete the verification described in Reference Residential Appendix Section RA3.3.4.4.

No need for additional coordination of market actors or need for resources has been identified. If the Energy Commission determines that a certification process is needed for integrated zonal control systems, this would require the Energy Commission to establish new documentation and revisions to existing documentation as described in Table 21.

Table 21: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
HVAC Contractor / Installer	Only install equipment that is listed in the CF2R. Installing variable capacity systems that do not meet code requirements will result in poor performance.	Avoiding installation of variable capacity systems with attic ducts that will compromise performance unless zoning is integrated with system capacity or installing ducts in conditioned space (or fully buried).	• Will eliminate contractor's ability to install equipment, ducting, and zoning other than what is specified in compliance forms. • When complying prescriptively must install system that integrates zoning with system capacity.	• Educate contractors on what to look for on compliance forms and consequences of installing the wrong equipment. • Encourage communications with Energy Consultant on equipment and systems modeled.
Energy Consultant	• Coordinate with builder and/or mechanical contractor on equipment/system choices and obtain model numbers • Identify type of equipment in product literature or MAEDBS database and model appropriately	• Convey in compliance forms what equipment and installation method is being used (ducts in conditioned space, integrated zoning, or neither) • Easily identify if the proposed equipment is variable capacity	• Requires more diligence to obtain model numbers and verify equipment type. • Often equipment specifications are unknown when compliance models are run • May need to revise the CF1R based on what HERS Rater discovers and re-run the compliance model.	• Educate on importance of Multi-Speed Compressor checkbox in CBECC-res (Cooling System Data) and compliance forms process • Educate on design alternatives for variable speed equipment and where to find equipment information • Encourage communications with HVAC contractor

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
CEC				• Develop list of approved variable capacity systems that integrate zone control • Add central air variable capacity split system as cooling system type in CF1R-NCB, J5 and CF2R-MCH, B12; add line in CF3R-MCH A09 for variable capacity. • Coordinate with software team on ACM changes
HERS Rater	Cross-check condensing unit manufacturer against installed equipment	Easily identify when variable capacity equipment is installed from compliance forms	• Verify zone controls used with variable capacity • Identify make and model number and suggest ways to comply based on CF1R	Update HERS Registry – when prescriptive accommodate the requirement for zonal control

Appendix F: Summary of Stakeholder Engagement

Collaborating with stakeholders that might be impacted by proposed changes is a critical aspect of the Statewide CASE Team's efforts. The Statewide CASE Team aims to work with interested parties to identify and address issues associated with the proposed code changes so that the proposals presented to the Energy Commission in this Final CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including: cost effectiveness; market barriers; technical barriers; compliance and enforcement challenges; or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

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

Utility-Sponsored Stakeholder Meetings

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

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

The Statewide CASE Team hosted two stakeholder meetings for Variable Capacity HVAC via webinar. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting, such as slide presentations, proposal summaries with code language, and meeting notes, are referenced in the bibliography section of this report.

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
First Round of Single Family HVAC Utility-Sponsored Stakeholder Meeting	Thursday, October 10, 2019	https://title24stakeholders.com/measures/cycle-2022/variable-capacity-hvac-compliance-software-revisions/
Second Round of Nonresidential and Single Family HVAC Utility-Sponsored Stakeholder Meeting	Thursday, March 12, 2020	https://title24stakeholders.com/measures/cycle-2022/variable-capacity-hvac-compliance-software-revisions/

The first round of utility-sponsored stakeholder meetings occurred from September to November 2019 and were important for providing transparency and an early forum for stakeholders to offer feedback on measures being pursued by the Statewide CASE Team. The objectives of the first round of stakeholder meetings were to solicit input on the scope of the 2022 code cycle proposals; request data and feedback on the specific approaches, assumptions, and methodologies for the energy impacts and cost-effectiveness analyses; and understand potential technical and market barriers. The Statewide CASE Team also presented initial draft code language for stakeholders to review.

The second round of utility-sponsored stakeholder meetings occurred from March to May 2020 and provided updated details on proposed code changes. The second round of meetings introduced early results of energy, cost-effectiveness, and incremental cost analyses, and solicited feedback on refined draft code language.

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[14] (and cross-promoted on the Energy Commission LinkedIn page) two weeks before each meeting to reach out to individuals and larger organizations and channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted in to the listserv.

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

Exported webinar meeting data captured attendance numbers and individual comments, and recorded outcomes of live attendee polls to evaluate stakeholder participation and support.

Statewide CASE Team Communications and Outreach

The Statewide CASE Team held personal communications over email and phone with numerous stakeholders when developing this report. Contractors contacted and surveyed on installation practices related to variable capacity systems and zoning are listed in Table 22. Those firms that responded to questionnaires are indicated by a letter in parenthesis following the company name that corresponds to the contractor designations in Table 4.

Bruce Severance of Mitsubishi submitted comments to the docket (Mitsubishi TN 230978 2019) and contacted the Statewide Utility CASE team by telephone to discuss this measure and related concerns. Mr. Severance followed up with an emailed letter to the Statewide CASE Team on April 3, 2020 and the Statewide CASE Team issued a response on May 12, 2020.

A telephone call was held with the National Resources Defense Council on January 28, 2020 to discuss their comments submitted to the docket (NRDC TN 230881 2019).

Table 22: List of HVAC Contractors Engaged During Outreach

Contact Name	Company	Location
Vinni Nasca	Sonray (B)	Rocklin
Dwayne Knickerbocker	Brower Mechanical (C)	Rocklin
Mark Radcliff.	Blue Mountain Inc	Vacaville
Kevin Burgeson	Burgeson’s Heating & Air Conditioning (D)	Inland Empire
Bob Deal	Deal Mechanical	Sacramento
Patty Forno	JC Heating & Air	Santa Cruz
Matt	J&M Air Conditioning (E)	San Jacinto
Mike	Johnson Air	Clovis
Marty Johnson	BJ Heating & Air	Woodland
Bob Radcliff	Villara (A)	Rancho Cordova
Chris Beeker	Klondike Air	Costa Mesa
George	iComfort Heating and Air Conditioning	San Fernando
Howard Phillips	Dependable Graham	Costa Mesa
David Krueger	Greiner Heating and Air Conditioning	Dixon
Donald Lemons	Christian Brothers Mechanical	Mira Loma
Curt Yaeger	Yaeger Services (F)	Orange