Codes and Standards Enhancement (CASE) Initiative

2025 California Energy Code

Buried Ducts and Roofs with Cathedral Ceilings

Image courtesy of Home Innovation Research Labs

Single Family HVAC and Envelope
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Draft CASE Report

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Executive Summary

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this draft report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in summer 2023.

*Email comments and suggestions to Simon Pallin (*spallin@frontierenergy.com*) and* info@title24stakeholders.com *by Monday, June 19, 2023. Comments will not be released for public review or will be anonymized if shared.*

Introduction

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

The Statewide CASE Team submits code change proposals to the CEC, the state agency that has authority to adopt revisions to Title 24, Part 6. The CEC will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The CEC may revise or reject proposals. See the CEC's 2025 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/2025-building-energy-efficiency.

The Statewide CASE Team gathered input from stakeholders to inform the proposals and associated analyses and justifications. Stakeholders also provided input on the code compliance and enforcement process.

- Stakeholders were engaged through public, utility-sponsored meetings and through direct engagement with industry contacts and contacts made through the Title 24 Stakeholder site. This is summarized in Appendix F.
- Very few concerns were voiced for the cathedral ceiling proposal, though questions arose about impacts for vented versus unvented ceilings. In response, this is discussed in section 3.2.2.
- There was general support for the buried duct proposal, and interest in how the measure would affect the prescriptive requirement for roof deck insulation and questions about whether it would be comparable to ducts in conditioned space. Other questions broached how duct connections to air handlers would be handled, settling and disturbance of attic insulation over time, impediments to airflow, locating ducts in unvented attics instead of burying them, and increased complexity of the measure as proposed at the first stakeholder meeting (which has changed).

The goal of this CASE Report is to present a cost-effective code change proposal for buried ducts and cathedral ceilings. The report contains pertinent information supporting the code change.

Buried Ducts

Proposal Description

Proposed Code Change

If adopted, the proposed measure would create a simplified compliance method for buried ducts (compared to the current detailed method), and would modify Table 150.1-A, making buried ducts a prescriptive requirement under the Option B path for Climate Zones 1 through 3, 5 through 7, and 16 for new single-family homes. This measure would also modify compliance software to accommodate a new set of effective R-values for fully buried ducts and remove barriers by simplifying modeling and verification procedures currently required for optional compliance using buried ducts.

Small homes 500 square feet or less would be exempt from the duct burial requirement due to lack of cost-effectiveness. Yet, small homes would be subject to increased prescriptive ceiling insulation requirements of:

- R-49 in Climate Zones 1 through 3,
- R-38 in Climate Zones 5 through 7,
- R-60 in Climate Zone 16, and
- Radiant barrier requirements in Climate Zones 1 and 16.

Additions 700 square feet or greater would require compliance with Standards Section 150.1(c), prescriptive standards/component packages, so proposed changes to Option B and D would apply. The new requirements would not apply to alterations, but the simplified compliance path could be used under the performance method.

As defined, a fully buried duct is completely surrounded by loose fill (blown-in) insulation with no exterior surface of the duct visibly exposed to the attic air. R-49 is proposed as the minimum prescriptively allowed ceiling insulation for vented attics in Climate Zones 1-3, 4-7, which would fully bury a nominal 12-inch duct. R-60 would be required in Climate Zone 16 and would fully bury a 16 inch duct. Table 1 compares current and proposed Option B and standard design requirements.

Table 1: Proposed Changes to Table 150.1-A Option B and Related Code Sections by Climate Zone (CZ)

Code	Parameter	CZ 1	CZ 2	CZ 3	CZ 5	CZ 6	CZ 7	CZ 16
Current	Roof Deck Insulation [a]	NR	NR	NR	NR	NR	NR	R-19
	Ceiling Insulation [a]	R-38	R-38	R-30	R-30	R-30	R-30	R-38
	Radiant Barrier [a]	NR	REQ	REQ	REQ	REQ	REQ	NR
	Ducts	R-8	R-8	R-6	R-6	R-6	R-6	R-8
Proposed	Roof Deck Insulation [a]	NR	NR	NR	NR	NR	NR	NR
	Ceiling Insulation [a]	R-49	R-49	R-49	R-49	R-49	R-49	R-60
	Radiant Barrier [a]	REQ	REQ	REQ	REQ	REQ	REQ	REQ
	Ducts [b]	R-6	R-6	R-6	R-6	R-6	R-6	R-6

a. Applies to Option B only.

b. Ducts must be fully buried in ceiling insulation in accordance with the exceptions added to Section 150.1(c)1A and Section 150.1(c)9C on buried duct requirements. See proposed language in Section 5.2.

Updates to compliance software would simplify modeling procedures, replacing detailed entry of information about each duct segment with only the diameter of the largest duct. The requirement to verify each duct segment would also be replaced by verifying the diameter of the largest duct and that all ducts are fully covered by ceiling insulation. These changes are intended to reduce existing barriers to buried duct applications whether used to meet prescriptive requirements or for performance-based compliance in Climate Zones 4 and 8-15, providing builders with an alternative to mandatory R-4 roof deck insulation in those climate zones.

Some of the existing requirements, such as a level ceiling and roof framing clearance will be retained. The outside diameter of the duct plus 3.5 inches (to account for the height of the bottom truss member) must be equal to or less than the depth of the insulation (see Figure 1). For example, R-49 fiberglass loose-fill insulation (at R2.5 per inch) will fully bury an R-6, 12-inch nominal diameter duct resting on top of 2 x 4 joists or trusses. The product-specific attic insulation R-value per inch will determine the maximum allowable diameter at a given R-value, as seen in Table 19 of Section 2.3.

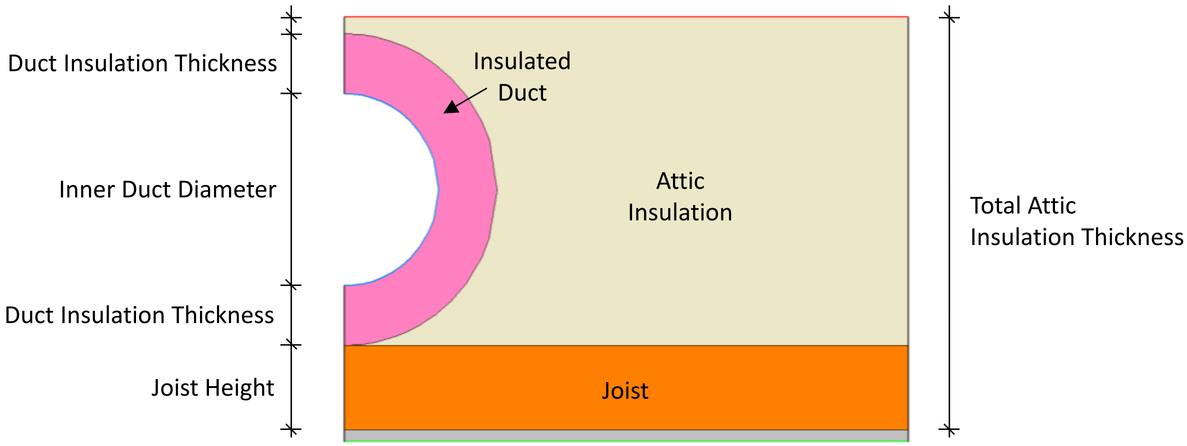

Figure 1: Insulated ducts buried within loose-fill attic insulation.

To bypass the need to enter each duct segment into compliance software, the software would apply an average R-value that represents a typical distribution system that has fully buried ducts. The HERS verifier would only need to confirm that:

- The diameter of the largest duct is as reported in the duct layout and compliance forms.
- Not more than three feet of each duct connected to the plenum is unburied.
- The duct system passes the existing mandatory leakage test requirements.
- By visual inspection all ducts are fully buried.
- For zonally controlled systems zone dampers are accessible for service.
- Markers are in place to identify the location of the ducts.

The option to utilize the existing detailed method of buried duct compliance would be retained but would utilize updated effective R-values.

Justification

Since the 2013 Title 24, Part 6 Energy Code there have been only minor changes to prescriptive requirements for roof and duct insulation in Climate Zones 1 through 3 and 5 through 7. In the 2016 Energy Code (California Energy Commission 2015), Option A, Option B and Option C were introduced as prescriptive alternatives for roofs and ceilings. Option A and Option B introduced the concept of “high performance attics” where the attic remains vented, ducts are located in the attic, and the attic is insulated at the roof deck as well as the ceiling. Option B was established as the prescriptive baseline in the performance modeling approach and required R-38 ceiling insulation and R-13 below roof deck insulation for Climate Zones 4 and 8 through 16. In the 2019

Energy Code (California Energy Commission 2018) the roof deck insulation in Option B was increased to R-19 for Climate Zones 4 and 8 through 16 and Option A was removed as a prescriptive option.

Burial of ducts in attic insulation can be a cost-effective, efficient alternative to current prescriptive approaches of locating them in conditioned space (Option C) or to creating a high-performance attic by insulating at the roof deck as required for prescriptive Option B in Climate Zones 4 and 8 through 16. Some of the barriers to the buried duct measure that was proposed and adopted in the 2008 Energy Standards were identified in a California Building Industry Association (CBIA) letter posted to the docket for the 2008 Title 24, Part 6 standards rulemaking (CBIA 2008). This letter recognized the value of burying ducts but listed multiple reasons that builders avoid the buried duct credit. Overly conservative effective duct R-values (listed in Tables 15-20 of the ACM Reference Manual) and minimal energy savings may also be responsible for diminished interest in the existing buried duct compliance path.

Of the climate zones affected by proposed prescriptive requirements, (1 through 3, 5 through 7, and 16), R-30 ceiling insulation is currently required in Climate Zones 3 and 5 through 7, and R-38 is required in zones 1, 2, and 16. R-19 roof deck insulation is only required in Climate Zone 16. The combination of burying the ducts and increasing the R-value of ceiling insulation to R-49 or greater (R-60 in Climate Zone 16) makes the proposed code change cost-effective in all the selected climate zones.

Buried ducts with R-6 duct insulation have been shown to perform as well or better than those with R-8 and using R-6 also reduces costs. The reason for the performance improvement is that less duct insulation allows for more attic insulation coverage above (deeper burial) and puts the duct air passages physically closer to the conditioned space. This geometric effect results in cost savings in climate zones where R-8 is required under prescriptive Option B, which includes Climate Zones 1 and 2.

The buried duct measure was not determined to be sufficiently cost effective relative to the prescriptively required R-19 roof deck insulation under Option B for Climate Zones 4 and 8 through 15. However, in these Climate Zones, mandatory roof deck insulation is exempt under the compliance pathway for homes designed with buried ducts. Thus, builders may choose to combine this performance pathway with other efficiency improvements, especially where construction conditions make insulating the roof deck challenging and costly.

Background Information

Ducts and ceiling surfaces are exposed to temperatures unlike any other building component of a home, especially in warmer climate zones. Attic temperatures may be significantly different from outdoor temperatures – up to 45°F in summer (Statewide CASE Team 2020a) – and attic temperatures can fluctuate as much as 80°F during the day. Such extremes can have a profound effect on attic duct heat transfer and overall cooling system efficiency and can result in large temperature gradients between the attic and ducts carrying conditioned air.

Research completed under the U.S. Department of Energy (DOE) Building America program evaluated the energy impact of burying ducts in ceiling insulation using measured data from California homes, finite difference analysis, and other modeling (Griffiths 2004). This led to a code change proposal introduced in the 2008 Energy Code to include buried ducts as an optional performance measure. As part of this activity, Tables 15-20 were added to the ACM Reference Manual and include effective R-values for ducts with varying amounts of blown insulation coverage, types of insulation, and duct diameter and R-value. The data from these tables are used by the compliance software, along with entered duct diameters and lengths, to calculate distribution efficiency and HVAC system energy use. Another related building code for buried ducts is included in International Energy Efficiency Code (IECC) Sections R403.3.2 and R403.3.3.1 as detailed in section 2.1.1.3.

Today, builders typically don't use the buried duct compliance option in place of high performance attics (HPA), which are vented attics that are insulated both at the roof deck and the ceiling. The HPA prescriptive requirement was introduced as Option B in the 2016 code cycle as a lower cost, builder-friendly alternative to Option C, which locates ducts inside conditioned space (abbreviated DCS). In fact, a review of 2022 CalCERTS registry data revealed that only eleven CF3R-CH-29-H compliance documents for buried ducts were fully completed and submitted. Reasons for low utilization of the existing buried duct path are several: software compliance requires entry of detailed duct design information and system drawings, savings may be underestimated (see Section 2.3.1.2), and verification processes may be seen as onerous. The proposed measure is designed to lessen these barriers by simplifying numerous aspects compliance and verification while providing greater energy savings than the existing buried duct compliance path, as detailed in section 2.1.1.2.

Scope of Code Change Proposal

Table 2 summarizes the scope of the proposed changes and which sections of the Energy Code, Reference Appendices, Alternative Calculation Manual (ACM) Reference Manuals, and compliance documents that would be modified as a result of the proposed change.

Table 2: Scope of Code Change Proposal – Buried Ducts

Type of Requirement	Change in mandatory requirements in Climate Zones 4 and 8-16, new prescriptive requirement in Zones 1-3, 5-7, and 16.
Applicable Climate Zones	All climate zones
Modified Section(s) of Title 24, Part 6	150.0(a)1,150.1(c)1,150.1(c)9, Table 150.1-A, 150.2(a)1
Modified Title 24, Part 6 Appendices	RA2.3.1, RA3.1.4
Would Compliance Software Be Modified	Yes. Section 2.4.7, including R-values listed in Tables 15-20 . A method to estimate duct surface areas and effective R-values in lieu of requiring each duct segment will be added to software.
Modified Compliance Document(s)	CF1R-NCB-01, CF1R-PRF-01-E, CF2R-MCH-21-H, CR2R-MCH-29-H, CF3R-MCH-21-H, CF3R-MCH-29-H

Market Analysis and Regulatory Assessment

Current Market Structure and Technical Feasibility

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends, as described in section 2.2.1. Results, primarily from registry data, builder interviews, and support CASE team field experience, show that most new home builders suspend ducts in vented attic spaces, with some applying insulation to the roof deck where prescriptively required in warmer climate zones. As explained in section 2.1.1.1, the relative lack of buried ducts as opposed to suspended ducts may be due to barriers in the compliance process, rather than technical or market concerns. The market itself is relatively mature. Materials needed to bury ducts in ceiling insulation (blown-in ceiling insulation, flex ducts, strapping, branches, boots, and elbows) are in common use in construction. When relevant industry actors (see Table 49) have the knowledge of what is required to fully bury ducts, technical feasibility constraints are minimal.

Proper duct burial, however, is a somewhat specialized skill. It involves designing duct system sizing and placement that allows for full burial and while serving the heating and cooling needs of the building. Sizing tools are available that can expedite this sizing while optimizing system components and economizing on materials, such as CalGreen Title 24, Part 11 Section 4.507.2 and ACCA Manuals J, S, and D, though there are some challenges as outlined in 2.2.2.1. Other tools used, per stakeholder feedback, include Table 150.1-B and Table 150.1-C alternative to measuring airflow and fan efficacy. Whatever sizing method is used, the buried duct compliance path will require a duct layout so that the largest duct diameter can be identified along with the depth of ceiling insulation to be installed. As part of the development of this proposal, readily achievable attic/distribution system features (duct and ceiling insulation, duct diameter, and duct layout) that allow for full duct burial were identified and are described in section 2.2.2.1.

Other than ensuring complete burial, the main deviation from typical suspended duct installations is that ducts are not suspended from trusses using sheet metal straps but are deployed over the top of truss bottom cords and the ceiling. This necessitates certain spacing and placement considerations relative to trusses for structural support, per CMC Section 603.4 duct installation requirements. Stepped ceilings and other structural complications may require installation of insulation dams to achieve coverage. Duct location markers would be required to prevent crushing should a person attempt to walk across an attic after insulation is applied.

Market Impacts

Market impacts detailed throughout Section 2.2.3 include a breakdown of the number, type, vintage, and occupancy of existing and newly constructed homes, which is critical for developing meaningful estimates of the economic impacts associated with proposed code changes. Section 2.2.3 also provides an overview of the companies and employees in the California residential construction industry, along with the single-family subsectors expected to be impacted by the proposal, resulting in the following conclusions:

- Particular subsectors of single family residential builders will likely be impacted, which is expected as it is within the normal practices of these businesses to adjust to changes in building codes, but employment of building inspectors is not expected to be impacted, nor are regulations applicable to builders regarding occupational safety and health. See section 2.2.3.1 for details.
- Building designers/energy consultants will need to become familiar with an added prescriptive requirement in 7 of the 16 climate zones (or, in the other 9 climate zones, an additional compliance pathway). Designers who opt for this compliance pathway may require expertise from HVAC specialists to accommodate a properly sized duct design, but they may also avoid the expertise needed for other pathways such as additional framing needs for ducts in conditioned space (DCS) or meeting insulation requirements for HPAs. Such design practice adjustments to comply with changing building codes is within the normal practices of building designers.
- Recent information obtained by Energy Commission staff indicates that CalOSHA will require fall protection for contractors installing insulation under roof decks. Though this requirement only affects installation of insulation to meet Option B insulation roof deck requirements in Climate Zones 4 and 8 through 16,

the added cost of providing scaffolding may drive some builders to adopt the proposed buried duct compliance option.

- For California residents, the proposed code changes would result in net savings of about $25-$129 per year relative to homeowners whose single-family homes are minimally compliant with the 2022 Title 24, Part 6 requirements.
- No significant impact on California component retailers is expected, however minor impacts are discussed in section [Impact on Building Component Retailers (Including Manufacturers and Distributors)].

Economic Impacts

Statewide economic impacts were estimated using the IMPLAN model software[1] per the methodology described in section 2.2.4, which also displays results for the California residential construction and building designers/energy consultants sectors. It should be noted that the IMPLAN model is a simplification of extremely complex actions and interactions of individuals, businesses, and other organizations as they respond to changes in energy efficiency codes. No significant impacts are anticipated for the buried ducts proposal; however it may open the door to vendors of software products that can facilitate the design of residential ducting systems that comply with ACCA sizing requirements. Costs of enforcement to both state and local governments associated with this proposal are not expected to exceed the standard, budgeted amounts already allocated for triannual building code updates. Outside of this, no measurable impact on California's General Fund, any state special funds, or local government funds is expected. Similarly, there are no relevant mandates, costs, savings, or fiscal impacts to local, state, or federal agencies, including school districts, as this measure applies only to single family construction.

Regulatory Context

The regulatory context for this proposal centers on the existing 2022 Energy Code, which contains a compliance option that allows modeling of ducts that are partly, fully, or deeply buried in attic insulation as well as effective duct R-values (Tables 15 through 20 of the 2022 ACM Reference Manual). To qualify for this compliance credit, the compliance software user must enter detailed duct data and must meet numerous technical requirements. Proposed changes will eliminate references to partly, fully, and deeply buried ducts and the associated incremental changes in effective R-value and move to a dynamic approach that only requires ducts to be fully covered. Other relevant regulations include California Title 24, Part 11 (CalGreen) code Section 4.507.2, which requires that HVAC duct systems be sized in accordance with ACCA Manual D or other

[1] IMPLAN employs economic data and advanced economic impact modeling to estimate economic impacts for interventions like changes to the California Title 24, Part 6 code. For more information on the IMPLAN modeling process, see www.IMPLAN.com.

equivalent methods, and the 2021 International Energy Conservation Code (IECC), Section R403.3.6 which describes a model code for buried ducts (see section 2.1.3.3 for code language). Lastly, a code change proposal is under consideration for the 2025 code cycle which would require documentation of duct design. If approved, it could be used to identify the diameter of properly sized ducts to ensure complete coverage.

Cost Effectiveness

The proposed code changes were found to be cost effective for all climate zones where it is proposed to be required. The benefit-to-cost (B/C) ratio over the 30-year period of analysis ranged between 0.89 and infinite depending on climate zone. See more details in section 2.4.5.[2] California consumers and businesses would save more money on energy than they would spend to finance the efficiency measure. As a result, over time this proposal would leave more money available for discretionary and investment purposes once the initial cost is paid off. See section 2.4.5 for the methodology, assumptions, and results of the cost-effectiveness analysis.

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

Table 3 presents the estimated impacts of the proposed code change that would be realized statewide during the first 12 months that proposed requirements are in effect.

First-year statewide energy impacts are represented by the following metrics: electricity savings in gigawatt-hours per year (GWh/yr), peak electrical demand reduction in megawatts (MW), natural gas savings in million therms per year (million therms/yr), source energy savings in millions of kilo British thermal units per year (million kBtu/yr), and lifecycle energy savings in millions of kilo British thermal units per year (million kBtu/yr). See Section 2.5 for more details on the first-year statewide impacts. Section 2.3.2 contains details on the per-unit energy savings.

Avoided GHG emissions are measured in metric tons of carbon dioxide equivalent (metric tons CO2e). Assumptions used in developing the GHG savings are provided in Section 2.5.2 of this report. The monetary value of avoided GHG emissions is included in the Long-term Systemwide Cost (LSC) Hourly Factors provided by CEC and is thus included in the cost-effectiveness analysis.

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

[2] The benefit-to-cost (B/C) ratio compares the benefits or cost savings to the costs over the 30-year period of analysis. Proposed code changes that have a B/C ratio of 1.0 or greater are cost effective. The larger the B/C ratio, the faster the measure pays for itself from energy cost savings.

As it applies to new construction, this code change proposal will increase the stringency of the standards by the addition of prescriptive requirements for Buried Ducts in Climate Zones 1-3 and 5-7, and 16.

Table 3: Summary of Impacts for Buried Ducts in New Homes

Category	Metric	New Construction & Additions
Cost Effectiveness	Benefit-Cost Ratio Range (varies by climate zone and building type)	0.89 – infinite
Statewide Impacts During First Year	Electricity Savings (GWh)	0.48
	Peak Electrical Demand Reduction (MW)	0.17
	Natural Gas Savings (Million Therms)	0.09
	Source Energy Savings (Million kBtu)	9.24
	LSC Electricity Savings (Million 2026 PV$)	$4.20
	LSC Gas Savings (Million 2026 PV$)	$10.63
	Total LSC Savings (Million 2026 PV$)	$14.83
	Avoided GHG Emissions (Metric Tons CO_2e)	583
	Monetary Value of Avoided GHG Emissions ($)	$71,822
	On-site Indoor Water Savings (Gallons)	0
	On-site Outdoor Water Savings (Gallons)	0
	Embedded Electricity in Water Savings (kWh)	0
Per home Impacts During First Year	Electricity Savings (kWh)	41.92
	Peak Electrical Demand Reduction (W)	15.37
	Natural Gas Savings (kBtu)	748
	Source Energy Savings (kBtu)	811
	LSC Savings (2026 PV$)	$1,301
	Avoided GHG Emissions (kg CO_2e)	51.18
	On-site Indoor Water Savings (Gallons)	0
	On-site Outdoor Water Savings (Gallons)	0
	Embedded Electricity in Water Savings (kWh)	0

Compliance and Enforcement

Overview of Compliance Process

The compliance process is described in section 2.1.4. Impacts that the proposed measure would have on market actors is described in these same sections as well as Appendix E. 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 key issues related to compliance and enforcement are summarized below:

- Overcoming resistance to the application of Buried Ducts is an important element of this proposal; will simplifying compliance and verification requirements be sufficient to reduce barriers?
- Title 24, Part 11 requirements for submitting Manual D or equivalent duct sizing calculations have not typically been observed and will be necessary for the success of the proposed Buried Duct measure.
- Some degree of education of builders, HVAC designers and installers, and HERS inspectors will be needed.

Field Verification and Diagnostic Testing

The proposed simplified compliance path applies some of the verification and testing requirements required under the current detailed buried duct compliance option, including:

- Submitting a duct system layout that is designed using ACCA Manual D (or similar method) with the compliance documents.
- Duct leakage testing and verification of duct sealing.
- Verification that markers are installed to show duct locations.

What is not required by the simplified compliance approach is verification of the duct diameter, length, and depth and type of insulation for each duct segment. Added verification requirements include:

- Specifying the diameter of the largest duct and verifying that the nominal diameter does not exceed what is shown in the duct layout and that the outside diameter does not exceed the depth of the attic insulation.
- For zonally controlled systems only, verification that zone dampers are in accessible locations.
- Following installation of insulation, verifying that all ducts are fully covered (not visible) and that no more than 3 feet of any supply duct is above attic insulation (excluding the plenum).

Testing and verification methods would require duct testing to be completed at rough-in with the air handler installed and attached to the ductwork. A separate inspection would be required to verify duct coverage, which would take the place of the QII inspection of attic insulation that is currently required under the buried duct performance path.

Cathedral Ceilings

Proposal Description

Proposed Code Change

This proposed code change outlines a new alternative prescriptive compliance pathway for constructing cathedral ceilings – otherwise known as cathedral roofs, or rafter roofs – in single-family new construction and additions. Cathedral ceilings are exterior assemblies where the interior ceiling surface is parallel to the roof surface and separated by framing. Cathedral ceilings are not to be associated with vaulted ceilings for which the ceiling is dropped below the roof construction and does not align with the roof pitch. Cathedral ceilings may be flat or sloped as well as vented or unvented. With no prescriptive path for cathedral ceilings in the current code, builders must use the performance pathway.

This proposal would add a new prescriptive option to Table 150.1-A. Cathedral ceilings would be required to have a maximum U-factor of 0.026 (or a minimum R-value of 38) across all California Climate Zones. In addition to the insulation requirements, the proposal requires compliance with Section 150.1(c)9B, which requires Verified Low Leakage Ducts in Conditioned Space, per Residential Reference Appendix Section RA3.1.4.3.8. The R-38 insulation requirement was defined based on equivalency with Option B of Table 150.1-A, Chapter 8 of Title 24, Part 6.

As a prescriptive alternative path to cathedral ceiling construction, adherence to these guidelines is optional for builders. The proposed code additions will not modify field verification tests since cathedral ceilings are a common roof design and already constructed and verified regularly. This proposal simply codifies guidelines to reach equivalent performance with other prescriptive options.

CBECC-Res and other modeling software currently have the capacity to model cathedral ceilings. This process would remain unchanged, however using the performance approach a project with a cathedral ceiling would be compared against a baseline with a cathedral ceiling that meets the proposed prescriptive requirements.

Justification

Cathedral ceilings are a regularly employed design for many single-family homes. They are also becoming increasingly common with the growing stock of small homes and Accessory Dwelling Units (ADUs) as they allow small spaces to feel and look larger, a trend that is expected to continue in California (UC Berkeley Center for Community Innovation 2021). The structure of cathedral ceilings lends itself to unique considerations regarding insulation, making roof deck (above or below) insulation the industry standard. This proposal would provide a clear compliance path for homes with cathedral ceilings allowing projects more flexibility in choosing compliance approaches and providing clear minimum requirements to meet code, benefitting market actors like designers, builders, and insulation installers. Stakeholder support was voiced for this proposal during the February 14, 2023 Utility Sponsored Stakeholder Meeting (Statewide CASE Team 2023) and the October 27, 2022 residential Welcome to the 2025 Energy Code Cycle Stakeholder Meeting (Statewide CASE Team 2022). This may particularly benefit small homes or accessory dwelling units (ADUs), as discussed in the section 3.1.2.2.

Background Information

Due to the physics of architectural features such as cathedral ceilings, if not properly designed they can result in an increased thermal load from the outdoor environment and thus higher demand for heating and cooling. When HVAC ducts are in conditioned space, as is often the case, HVAC distribution losses are reduced.

During initial outreach to stakeholders early in the 2025 code cycle, a group of small home/ADU advocates and members of the design community voiced the issue that small homes with cathedral ceilings receive a penalty in the performance model which can be challenging to overcome. As mentioned above, cathedral ceilings, coupled with ductless HVAC systems, are common in small homes for various space-optimizing reasons. For smaller homes with cathedral ceilings, the roof design and geometry may also prevent from running ducts in the space above the roof bridge. This measure addresses these concerns by developing a reasonable prescriptive path for this design feature. Unlike single family construction, which is often characterized by relatively large subdivisions and use of the performance compliance pathway, ADU’s are often constructed as a remodel from an unconditioned garage to a conditioned ADU. As such, there is a desire for “cookbook” approaches towards these types of projects.

Scope of Code Change Proposal

Table 4 summarizes the scope of the proposed changes and which sections of standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents that would be modified as a result of the proposed change.

Table 4: Scope of Code Change Proposal – Cathedral Ceilings

Type of Requirement	Alternative to Prescriptive Requirements for New Homes, Compliance Option for Additions
Applicable Climate Zones	All climate zones
Modified Section(s) of Title 24, Part 6	150.0150.1(c)1A, Table 150.1-A
Modified Title 24, Part 6 Appendices	n/a
Would Compliance Software Be Modified	Yes
Modified Compliance Document(s)	CF2R-ENV-03-E, CF1R-NCB-01, CF1R-ADD-01-E, CF1R-ADD-02-E, CF2R-ADD-02-E

Market Analysis and Regulatory Assessment

Current Market Structure and Technical Feasibility

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends as detailed in section 3.2.1. The analysis shows that the market for architectural features such as cathedral ceilings is well established in terms of materials and labor, as such features have been regularly employed in home construction for many years. Relevant market actors including designers, contractors, manufacturers, and compliance officials, would be the same as other ceiling and roof related construction. The same holds for materials and processes used to construct cathedral ceilings. Cathedral ceilings [by def, i.e. not same as vaulted] can accommodate cavity insulation between roof rafters and/or as continuous insulation above or below the roof deck.

When technical and practical considerations were examined by the CASE team and stakeholders, the primary concern was how the proposal would impact unvented (or sealed) ceilings, as such structures may very much resemble a cathedral ceiling since the roof rafter cavities are insulated. In addition, it is more feasible to construct unvented enclosed rafter assemblies when rafter bays are obstructed by hip roofs, dormers, skylights etc. Sealed/unvented cathedral ceilings have been susceptible to accumulated moisture in hot and humid climates if not properly designed (Boudreaux, Pallin Jackson 2013). Based on a literature review of thermal, moisture, and energy performance of sealed attics by Lawrence Berkeley National Laboratory (Less, Walker Levinson 2016), this risk is considered low in the hot-dry, highly populated regions of California, where most new home construction occurs. It also finds that air impermeable insulation meeting requirements of the International Residential Code (2012) can help.

Due to the negligible differences in heat flow between the roof surface and the inside of the cathedral ceiling in vented and unvented/sealed roofs, this proposal does not differentiate between vented and unvented; most must meet both the insulation levels required to meet energy code compliance (currently as documented in the performance compliance report) as well as applicable requirements from Chapter 8 of the California Residential Code (CRC) (the International Residential Code – or IRC – with California amendments)[3] which addresses moisture issues associated with attics and cathedral ceilings. The relevant CRC requirements are detailed in Section 3.2.2.

In some cases, vented assemblies may not be able to meet the proposed prescriptive requirements with cavity insulation alone. An air gap of at least one inch is required between the insulation and the roof sheathing, which is equivalent to about R-3.5 for fiberglass batt insulation. In these instances, designers can either increase the depth of the framing to fit more cavity insulation or apply a small amount of continuous above roof deck insulation.

In general, these considerations are not new to builders familiar with cathedral ceiling construction but may be for others as they become acquainted with the proposed code. Other technical or market considerations identified by the Statewide CASE team and consulted stakeholders are summarized in Section 3.2.2.

Fiscal Impacts

The code change proposal introduces prescriptive alternative requirements that are equivalent to existing prescriptive requirements. As such, there are no direct energy, market, economic, or fiscal impacts.

Regulatory Context

Aside from the CRC code noted above, this proposal overlaps with section R402.2.2 of the 2021 International Energy Conservation Code (IECC) provides a prescriptive path for structures such as cathedral ceilings. See section 3.1.4.3 for more information on IECC requirements. There are no other local, state or federal laws or regulations, nor industry standards, relevant to this proposal.

Cost Effectiveness

The code change proposal would not modify the stringency of the existing California Energy Code, so the CEC does not need a complete cost-effectiveness analysis to approve the proposed change. Instead, a summary of cost implications is present in section 3.4. Basically, costs associated with this proposal are not expected to increase

[3] https://up.codes/viewer/california/ca-residential-code-2022/chapter/8/roof-ceiling-construction#8

that of the standard design (or prescriptive baseline—i.e. Option B, Section 150.1, Table 150.1-A).

The primary intent of this proposal is not to drive action in the construction industry, but rather to codify existing practices into the compliance structure via a prescriptive pathway. This simplification may help lower costs for builders, especially for smaller projects and perhaps construction companies that more often rely on the prescriptive performance pathway.

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

The code change proposal would not modify the stringency of the existing California Energy Code, 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 this section of the CASE Report. As discussed in Section 3.3, although the energy savings are limited, the measure would provide a compliance option which would particularly support builders of small homes/ADUs to meet California's growing housing demand, as informed through direct stakeholder engagement.

Compliance and Enforcement

Overview of Compliance Process

The compliance process would not change, as described in section 3.1.5. Impacts that the proposed measure would have on market actors is described in section 3.1.5 and Appendix E. The Statewide CASE Team worked with stakeholders to identify the impacts this process would have on various market actors; no impacts or challenges to compliance and enforcement have been identified, either by the CASE team or engaged stakeholders.

Field Verification and Diagnostic Testing

There are no new field verification and diagnostic testing requirements as part of this proposal.

Addressing Energy Equity and Environmental Justice

The Statewide CASE Team recognizes, acknowledges, and accounts for a history of prejudice and inequality in disproportionately impacted populations (DIPs) and the role this history plays in the environmental justice issues that persist today. DIPs refer to the areas throughout California that most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes, as well as high incidence of asthma and heart disease. DIPs also incorporate race, class, and gender since these intersecting identity factors affect how people frame issues, interpret, and experience the world.[4] While the term disadvantaged communities (DACs) is often used in the energy industry and state agencies, the Statewide CASE Team chose to use terminology that is more acceptable to and less stigmatizing for those it seeks to describe (DC Fiscal Policy Institute 2017).

Including impacted communities in the decision-making process, ensuring that the benefits and burdens of the energy sector are evenly distributed, and grappling with the unjust legacies of the past all serve as critical steps to achieving energy equity. Code change proposals must be developed and adopted with intentional screening for unintended consequences, otherwise they risk perpetuating systemic injustices and oppression.

The Statewide CASE Team assessed the potential impacts of the proposed measure, and based on a preliminary review, the measure is unlikely to have significant impacts on energy equity or environmental justice, therefore reducing the impacts of disparities in DIPs. This is due mainly to the fact that both proposals are compliance options that builders can choose to utilize, so flexibility remains rather than a one-size-fits all approach. It is also related to the fact that proposals focus on single-family new construction (and additions for cathedral ceilings). While the housing market plays a huge role in energy equity and environmental justice, most of the factors impacting this issue exist largely outside energy code [Jeremiah's article?]. The Statewide CASE Team does not recommend further research or action at this time but is open to receiving feedback and data that may prove otherwise. Additional details addressing energy equity and environmental justice can be found in Section 4 of this report.

[4] Environmental disparities have been shown to be associated with unequal harmful environmental exposure correlated with race/ethnicity, gender, and socioeconomic status. For example, chronic diseases, such as respiratory diseases, cardiovascular disease, and cancer, associated with environmental exposure have been shown to occur in higher rates in the LGBTQ+ population than in the cisgender, heterosexual population (Goldsmith and Bell 2021). Socioeconomic inequities, climate, energy, and other inequities are inextricably linked and often mutually reinforcing.

1. Introduction

This is a draft report intended to allow for public review and comment before the Final Report is issued. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented. When possible, include supporting data and justifications in addition to comments. The Statewide CASE Team will review all suggestions and consider them when revising and refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in summer 2023.

Email comments and suggestions to Simon Pallin (spallin@frontierenergy.com) and info@title24stakeholders.com by Monday, June 19, 2023. Comments will not be released for public review or will be anonymized if shared with stakeholders.

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support the California Energy Commission's (CEC's) efforts to update California's Energy Code (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The 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 Codes and Standards Enhancement program goal is to prepare and submit proposals that would result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposal presented herein are a part of the effort to develop technical and cost-effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

The CEC is the state agency that has authority to adopt revisions to Title 24, Part 6. One of the ways the Statewide CASE Team participates in the CEC's code development process is by submitting code change proposals to the CEC for consideration. CEC will evaluate proposals the Statewide CASE Team and other stakeholders submit and may revise or reject proposals. See the CECs 2025 Title 24 website for information about the rulemaking schedule and how to participate in the process.

The goal of this CASE Report is to present a code change proposal for a buried duct new construction prescriptive compliance option and compliance credits for additions and alterations. In addition, this CASE Report presents potential energy savings from highly insulated attics, both as a stand-alone measure, but also in conjunction with buried ducts. The report contains pertinent information supporting the proposed code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with many industry stakeholders including builders, residential HVAC system designers and contractors, 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 February 14, 2023.

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

Section 2 – Buried Ducts:

- Section 2.1 – 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 2.2 – Market Analysis includes a review of the current market structure. Section 2.2.2 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 2.3 – 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 2.4 – Cost and Cost Effectiveness presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of the materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs, i.e., equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.
- Section 2.5 – First-Year Statewide Impacts presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2025 code takes effect. This includes the amount of energy that would be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also reported in this section.

Section 3 – Cathedral Ceilings:

- Section 3.1 – 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 3.2 – Market Analysis includes a review of the current market structure. Section 3.2.2 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 3.3 – Energy Savings presents a comparison of the per-unit Long-term Systemwide Cost (LSC) impacts of the measure relative to current code requirements
- Section 3.4 – Cost and Cost Effectiveness presents an abbreviated discussion of the cost impacts of the proposal. Cost-effectiveness analysis is not provided as this measure does not modify the stringency of the existing California Energy Code.
- Section 3.5 – First-Year Statewide Impacts are not provided as this measure does not modify the stringency of the existing California Energy Code.

The following is a brief summary of Sections and Appendices that are included in the report and applies to all measures.

- Section 4 – Addressing Energy Equity and Environmental Justice presents the potential impacts of proposed code changes on disproportionately impacted populations (DIPs), as well as a summary of research and engagement methods.
- Section 5 – Proposed Revisions to Code Language concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Energy Code, Reference Appendices, and Alternative Calculation Manual (ACM) Reference Manual. Generalized proposed revisions to sections are included for the Compliance Manual and compliance documents.
- Section 6 – 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: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software (if any).
- Appendix D: Environmental Analysis presents the methodologies and assumptions used to calculate impacts on GHG emissions and water use and quality.
- Appendix E: Discussion of Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: Energy Cost Savings in Nominal Dollars presents energy cost savings over the period of analysis in nominal dollars.
- Appendix H: Effective R-values of Buried Ducts presents details of analysis of the effective R-value for buried ducts.
- Appendix I: Attic Temperature Simulation Inputs presents details on attic temperatures used in the buried duct simulations.

The California IOUs offer free energy code training, tools, and resources for those who need to understand and meet the requirements of Title 24, Part 6. The Codes and Standards Enhancement program recognizes that building codes are one of the most effective pathways to achieve energy savings and GHG reductions from buildings – and that well-informed industry professionals and consumers are key to making codes effective. With that in mind, the California IOUs provide tools and resources to help both those who enforce the code, as well as those who must follow it. Visit EnergyCodeAce.com to learn more and to access content, including a glossary of terms.

2. Buried Ducts

2.1 Measure Description

This measure proposes three code changes:

1. **Ducts fully buried in attic insulation to become prescriptive** – In Climate Zones 1 through 3, 5 through 7, and 16 replace the prescriptive Option B, Section 150.1, Title 24, Chapter 6 to require that ducts are fully buried within attic insulation. The measure would substantially increase the effective R-value of ducts by increasing the thermal barrier between the conditioned air inside the ducts and the attic environment. The increased depth of attic insulation that is required to cover the ducts also reduces energy losses between the attic and the conditioned space. The proposed changes to Table 150.1-A are shown in Table 5. This proposal does not impact current prescriptive requirements in Climate Zones 4, and 8 through 15.
2. **Exempt mandatory roof deck requirements when ducts are fully buried in attic insulation** – Changes mandatory requirements of Section 150.0(a)1, eliminating the roof deck insulation requirement of a 0.184 U-factor for Climate Zones 4 and 8 through 15 when ducts are fully buried. Exempt Climate Zone 16 from any roof deck insulation requirement because of the proposed updates to the prescriptive requirements as described by [1].
3. **Introduce new simplified compliance path and verification procedures** – Update effective R-values as listed in Tables 15 through 20 of the Single Family Residential Alternative Calculation Method Reference Manual (ACM Manual), which will be used for the existing detailed distribution method and the newly proposed simplified compliance path.

2.1.1 Proposed Code Change

Key to the proposed code change is creating a simpler compliance path and verification procedures that will overcome barriers to the application of buried ducts and that will realize significant improvements in the efficiency of ducted distribution systems as well as reduce thermal losses through ceilings. If adopted, the proposed measure would modify Table 150.1-A, making buried ducts a prescriptive requirement under the Option B path for Climate Zones 1 through 3, 5 through 7, and 16 for new single-family homes. It would also add an exception to Section 150.0(a)1 that would open a performance path alternative for Climate Zones 4 and 8 through 15 that would bypass the mandatory requirement for R-4 deck insulation in those climate zones. This measure would also modify compliance software to accommodate an improved set of effective R-values for fully buried ducts, resulting in greater credit than provided by the current R-values listed in the Residential ACM Manual.

Table 5 compares current and proposed Option B requirements. A fully buried duct is defined as surrounded by loose fill (blown-in) insulation and no exterior surface of the duct visibly exposed to the attic air. Commonly used duct diameters (12 inches or smaller) in single family homes will require at least R-49 attic insulation to ensure ducts can be fully buried. Therefore, R-49 is proposed as the minimum prescriptively allowed ceiling insulation R-value for vented attics in affected climate zones.

Table 5: Proposed Changes to Table 150.1-A Option B and Related Code Sections by Climate Zone (CZ)

Code	Parameter	CZ 1	CZ 2	CZ 3	CZ 5	CZ 6	CZ 7	CZ 16
Current	Roof Deck Insulation	NR	NR	NR	NR	NR	NR	R-19
	Ceiling Insulation	R-38	R-38	R-30	R-30	R-30	R-30	R-38
	Radiant Barrier	NR	REQ	REQ	REQ	REQ	REQ	NR
	Ducts	R-8	R-8	R-6	R-6	R-6	R-6	R-8
Proposed	Roof Deck Insulation	NR	NR	NR	NR	NR	NR	NR
	Ceiling Insulation	R-49	R-49	R-49	R-49	R-49	R-49	R-60
	Radiant Barrier	REQ	REQ	REQ	REQ	REQ	REQ	REQ
	Ducts[a]	R-6	R-6	R-6	R-6	R-6	R-6	R-6

[a] Ducts must be fully buried in ceiling insulation in accordance with the exceptions added to Section 150.1(c)1A and Section 150.1(c)9C on buried duct requirements. See proposed language in Section 5.2.

Compared to existing detailed buried duct compliance requirements, proposed changes designed to simplify compliance and verification procedures that can be applied to both prescriptive and performance paths include:

- Replacing the requirement to enter each duct segment into compliance software with entry of only the diameter of the largest duct.
- Substituting field verification of the diameter of the largest duct for verifying the diameter, length, and R-value of each duct segment.
- Replacing the requirement for QII with visual verification that all ducts are fully buried.

To ensure ducts are fully buried it will be necessary for the HVAC designer to ensure that the outside diameter of the largest duct plus 3.5 inches is less than the height of the insulation, and to avoid crossing ducts over other which could result in ducts being exposed. This will require more coordination between the builder and/or insulation contractor and the designer. Full burial may also necessitate dams to hold insulation in place where ceiling heights change.

Small homes 500 square feet or less would be exempt from the duct burial requirement based on lack of cost-effectiveness, but would be subject to increased prescriptive requirements of:

- R-49 ceiling insulation in Climate Zones 1 through 3,
- R-38 ceiling insulation in Climate Zones 5 through 7,
- R-60 ceiling insulation in Climate Zone 16, and
- Radiant barrier requirements in Climate Zones 1 and 16.

Additions greater than 700 square feet would require compliance with Standards Section 150.1(c), prescriptive standards/component packages, so proposed changes to Option B and D would apply. The new requirements would not apply to alterations or additions 700 square feet or less but the simplified compliance path could be used under the performance method.

The outside diameter of the duct plus 3.5 inches (to account for the height of the bottom truss member) must be equal to or less than the depth of the insulation, see Figure 2. For example, R-49 fiberglass (R2.5/inch) loose-fill insulation will fully bury an R-6, 12-inch duct diameter resting on top of a 2 x 4 inches joist. The product-specific attic insulation R-value per inch will determine the maximum allowable diameter at a given R-value, as seen in Table 19 of Section 2.3.

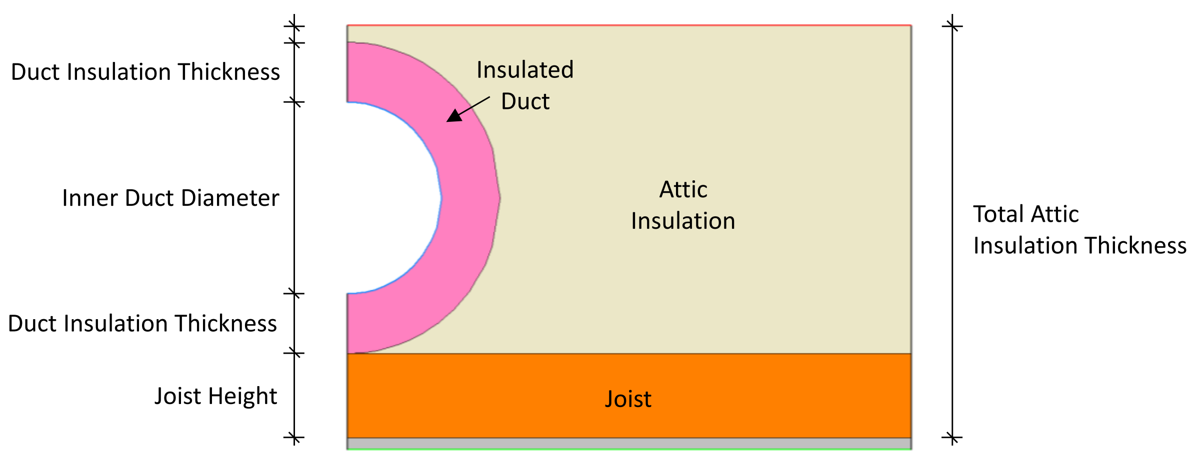

Figure 2: Insulated ducts buried within loose-fill attic insulation.

Some of the existing requirements, such as completing a duct layout that is designed using ACCA Manual D or similar methods would be retained. HERS testing and verification would need to confirm that:

- The diameter of the largest duct is as reported in the duct layout and compliance forms.
- Not more than three feet of each duct connected to the plenum is unburied.

- The duct system passes the existing mandatory leakage test requirements.
- By visual inspection all ducts are fully buried.
- For zonally controlled systems zone dampers are accessible for service.
- Markers are in place to identify the location of the ducts.

If adopted, the proposed measure would simplify compliance modeling by adopting a method for estimating duct surface area and effective R-value that minimizes the need for multiple inputs, and correspondingly simplify verification. Both are strategies that would reduce current barriers to buried duct applications. To bypass the need to enter each duct segment into compliance software, the software would apply an average effective R-value that represents a typical distribution system that has fully buried ducts. For Climate Zones 4 and 8 through 15, the inclusion of the simplified pathway in compliance software and documents would encourage builders desiring to install buried ducts as an alternative to roof deck insulation. The option to utilize the existing detailed method of buried duct compliance would be retained but would utilize updated effective R-values.

2.1.1.1 Justification

Since the 2013 Title 24, Part 6 Energy Code there have been only minor changes to prescriptive requirements for roof and duct insulation in Climate Zones 1 through 3 and 5 through 7. In the 2016 Energy Code (California Energy Commission 2015), Option A, Option B and Option C were introduced as prescriptive alternatives for roofs and ceilings. Option A and Option B introduced the concept of “high performance attics” where the attic remains vented, ducts are located in the attic, and the attic is insulated at the roof deck as well as the ceiling. Option B was established as the prescriptive baseline in the performance modeling approach and required R-38 ceiling insulation and R-13 below roof deck insulation for Climate Zones 4 and 8 through 16. In the 2019 Energy Code (California Energy Commission 2018) the roof deck insulation in Option B was increased to R-19 for Climate Zones 4 and 8 through 16 and Option A was removed as a prescriptive option.

Burial of ducts in attic insulation can be a cost-effective, efficient alternative to current prescriptive approaches of locating them in conditioned space (Option C) or to creating a high-performance attic by insulating at the roof deck as required for Option B in Climate Zones 4 and 8 through 16.

Current requirements for verification of duct lengths, diameters, and the extent of burial of each duct segment create a barrier to the use of buried ducts. This was confirmed in a California Building Industry Association (CBIA) letter posted to the docket for the 2008 Title 24, Part 6 standards rulemaking (CBIA 2008). The letter cited the amount of time needed for the HERS Rater to measure all duct lengths and diameters, the requirement for airflow, “tight ducts”, and insulation QII verification, and confusion over conflicting verification requirements between the compliance documents and Residential Appendices as reasons why the industry was ignoring the measure at that time. Overly conservative effective duct R-values (listed in Tables 15-20 of the ACM Reference Manual) further diminish interest in the existing buried duct compliance path.

Of the climate zones affected by this measure (1 through 3, 5 through 7, and 16), R-30 ceiling insulation is prescriptively required in Climate Zones 3 and 5 through 7, and R-38 is required in zones 1, 2, and 16. Of these climate zones, R-19 roof deck insulation is only required in Climate Zone 16. The combination of burying the ducts and increasing the R-value of ceiling insulation to R-49 or greater (R-60 in Climate Zone 16) makes the proposed code change cost-effective in all the selected climate zones. Buried ducts with R-6 duct insulation have been shown to perform as well or better than those with R-8. The reason for that is that less duct insulation results in more attic insulation coverage and that the inner duct and conditioned air are physically closer to the conditioned space with a smaller outside duct diameter. This geometric effect results in cost savings in climate zones where R-8 is required under prescriptive Option B, which includes Climate Zones 1 and 2.

In Climate Zones 4 and 8 through 15, where there is no prescriptive code change proposal, projects would be exempt from the mandatory roof deck insulation under the compliance pathway if they bury ducts. Thus, builders may choose to combine this performance pathway with other efficiency improvements, especially where construction conditions make insulating the roof deck challenging and costly.

2.1.1.2 Background Information

In warmer climate zones, summer attic temperatures may exceed outdoor air temperatures by up to 45°F (Statewide CASE Team 2020a), which has a profound effect on attic duct heat transfer and overall cooling system efficiency. The attic temperature can fluctuate as much as 80°F during the day, resulting in large temperature gradients between the attic and ducts carrying conditioned air. During the heating season, night sky radiation can cause the roof surface materials to drop below the outside air temperature and can cause attic temperatures to drop below that of outside air (Hagentoft 2001). Thus, ducts and ceiling surfaces are exposed to temperatures unlike any other building component of a home.

Research completed under the U.S. Department of Energy (DOE) Building America program evaluated the energy impact of burying ducts in ceiling insulation using measured data from California homes, finite difference analysis, and other modeling (Griffiths 2004). This led to a code change proposal introduced in the 2008 Energy Code to include buried ducts as an optional performance measure. Tables for determining the effective R-value for various levels of attic insulation, insulation type, duct R-value, and duct diameter were developed and are included in Tables 15-20 of the ACM Reference Manual. The tables include effective R-values for ducts with varying amounts of blown insulation coverage, types of insulation, and duct diameter and R-value. The data from these tables are used by the compliance software, along with entered duct diameters and lengths, to calculate distribution efficiency and HVAC system energy use.

Today, builders typically don't use the buried duct compliance option to avoid insulating the roof deck. High performance attics, which are vented attics that are insulated both at the roof deck and the ceiling, were introduced as prescriptive Option B in the 2016 code cycle as a lower cost, builder-friendly alternative to locating ducts inside conditioned space (or Option C, abbreviated DCS).

A review of 2022 CalCERTS registry data revealed that only eleven CF3R-CH-29-H compliance documents for buried ducts were fully completed and submitted. Reasons for low utilization of the existing buried duct path are several. Software compliance requires entry of detailed duct design information, including duct diameters, lengths, duct insulation, and attic insulation for each duct segment. This information is then used by the model to reference and apply the effective R-values listed in ACM Reference Manual tables. The ACM Reference Manual tables use R-values are lower than those determined from recent calculations using the THERM model, resulting in lower modeled energy savings (see Section 2.3.1.2 for an explanation of these differences).

Further, the Certificate of Compliance must include a scaled drawing showing the location of equipment and supply and return grilles, duct size and R-value, and the location of each duct segment and other details. The duct design must be based on Air Conditioning Contractors of America (ACCA) Manual D (or equivalent). All fully buried ducts are required to have vertical markers placed every 8 feet.

Verification requirements also add a disincentive. As required by Residential Reference Appendix Section RA3.1.4.1.6, field verification of the design is required prior to application of insulation, duct sealing, and insulation quality (QII). Markers noting the location and depth of insulation are required in accordance with Residential Reference Appendix Sections RA3.1.4.1.5 and RA3.1.4.1.6. Subject matter experts agree that these barriers combine to contribute to the minimal use of buried ducts by builders.

CASE team member Mike MacFarland's take-away from PG&E's Central Valley Research Home projects was that, though distribution efficiency was not specifically measured, the duct designs that included minimized duct diameters and full burial had a substantial impact on reducing overall HVAC energy use. The proposed measure is designed to lessen barriers to buried ducts by simplifying compliance and verification procedures while providing greater energy savings than the existing buried duct compliance path using the following approaches:

- Reduce the number of parameters involved in the design and provide tables that prescribe the required depth of insulation and maximum duct diameters required for full coverage.
- Reduce the amount of duct design documentation required for the Certificate of Compliance.
- Update the effective duct R-values to more accurately model energy savings.
- Simplify compliance modeling by applying average effective R-values instead of requiring detailed entry of duct R-values, diameters, and lengths for each duct segment.
- Allow verification of only the maximum duct diameter rather than requiring verification of each duct segment. This can occur during rough-in by viewing the ducts from the floor below.
- Eliminate the necessity for and verification of duct burial depth markers (but retain duct location markers to prevent future damage).

2.1.1.3 Other Codes

International Energy Efficiency Code (IECC) Section R403.3.2 allows buried ducts to be considered the same as ducts located completely within conditioned space if the air handler is located within the air barrier and building thermal envelope, if duct leakage is less than or equal to 1.5 cfm per 100 square feet of conditioned floor area, if the ceiling insulation R-value installed against and above the insulated duct is equal to or greater than the proposed ceiling insulation R-value less the R-value of insulation on the duct, and if the provisions of Section R403.3.3 are met.

For supply and return ducts that are partially or completely buried, IECC Section R403.3.3 adds the requirement that duct insulation shall have an R-value of not less than R-8 and that the sum of the ceiling insulation R-value against and above the top of the duct and against and below the bottom of the duct shall not be less than R-19, excluding the R-value of the duct insulation. Sections of supply ducts that are less than 3 feet from the supply outlet do not need to comply with these requirements. Duct insulation with an R-value of R-13 or greater and a vapor retarder are required only for IECC Climate Zones 0A, 1A, 2A, and 3A, which do not include California.

Section R403.3.3.1 allows an effective R-value of R-25 to be used in the Total Building Compliance Option if they are installed in accordance with Section 403.3.3, are located within 5.5 inches of the ceiling, are surrounded by attic insulation having an R-value of R-30 or greater, and located such that the top of the duct is less than 3.5 inches below the top of the insulation.

2.1.2 Summary of Proposed Changes to Code Documents

The proposed buried duct measure revises the prescriptive Option B path as detailed in Subchapter 8 Section 150.1(c) for roof/ceiling insulation in Climate Zone 1 through 3, 5 through 7, and 16. The Option B revision would require full burial of ducts in attic insulation having an R-value of 49 or greater (R-60 in Climate Zone 16).

No prescriptive changes are proposed under Section 150.2 for additions or alterations involving full duct replacement but would apply to additions exceeding 700 square feet. However, this code change proposal would allow for compliance credit to be taken for replacement buried ducts if the performance path is utilized.

The sections below summarize how the Energy Code, Reference Appendices, ACM Manual, and compliance documents would be modified by the proposed change.[5]

2.1.2.1 Specific Purpose and Necessity of Proposed Code Changes

Each proposed change to language in Title 24 Part 6 and the Reference Appendices to Part 6 are described below. See Section 5.2 of this report for marked-up code language. All of the proposed changes are supported by cost-effective energy savings.

Section: 150.0(c)1A

Specific Purpose: The specific purpose is to replace the requirement for roof deck insulation in Climate Zone 16 with a requirement that ducts be buried. Also, add an exception to mandatory roof deck insulation for ventilated attics with buried ducts.

Necessity: This change applies to all Climate Zones with a mandatory requirement of roof deck insulation and is necessary to eliminate if the ducts are buried in ceiling insulation. This increases energy savings without increasing costs.

Section: 150.1(c)1A

Specific Purpose: Modify Option B to include the prescriptive requirement for R-49 (R-60 in Climate Zone 16) ceiling insulation and buried ducts in Climate Zones 1 through 3, 5 through 7, and 16.

Necessity: This change is necessary to clarify which climate zones are impacted by changes to Table 150.1-A and Section 150.1(c)9 and improves energy savings in these climate zones.

[5] Visit EnergyCodeAce.com for trainings, tools and resources to help people understand existing code requirements.

Section: 150.1(c)9

Specific Purpose: This section is referenced from proposed changes to Section 150.1(c)1A and Table 150.1-A and adds a third prescriptive requirement (Section 150.1(c)9C) that provides for buried ducts as a space conditioning distribution systems requirement.

Necessity: This change is necessary as buried ducts requirements are implemented in Option B of Table 150.1-A and provide a reference to the Reference Appendix section that describes verification and testing requirements for them.

Table: 150.1-A

Specific Purpose: Reflect changes proposed for Option B in Climate Zones 1 through 3, 5 through 7, and 16 by inserting a row that references Section 150.1(c)9C.

Necessity: Adopt cost-effective updates to the prescriptive requirements for these climate zones.

Section: Residential Reference Appendix RA3.1.4.1.5 and RA3.1.4.1.6

Specific Purpose: Update the compliance and verification requirements to satisfy the prescriptive buried duct requirement.

Necessity: This change is necessary to streamline the buried duct requirements and increase adoption of the measure.

2.1.2.2 Specific Purpose and Necessity of Changes to the Single-Family Residential ACM Reference Manual

The purpose and necessity of proposed changes to the Single-Family Residential ACM Reference Manual are described below. See Section 5.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Section: 2.4.7 Distribution Systems

Specific Purpose: The primary purpose is to modify Section 2.4.7 of the ACM Reference Manual to accommodate buried ducts as another distribution system type and to provide specifications including the duct location above the ceiling, the required extent of insulation coverage, the amount of duct that is allowed to be uninsulated, allowable air leakage, methods to determine the surface area and effective R-value, and verification and reporting requirements. This would involve changes to Tables 11 through 13.

Under the new prescriptive definition of buried ducts, it would no longer be necessary to complete a detailed entry of duct diameter, R-value, length, and the R-value of covering attic insulation for each duct segment. The proposed method for modeling prescriptive buried ducts would include assumptions for the weighted average effective R-value. The current assumptions of duct surface area used for the Standard Design are likely to be retained and used for buried duct modeling. Coordination with the Software Team is required to identify specific changes to compliance software code.

It is not proposed to eliminate the existing detailed compliance path. The existing ACM Reference Manual Tables 15 through 20 that are utilized by compliance software to determine the effective R-value would be modified to update the R-values using revised values determined by THERM analysis. Effective R-value is a continuum that relates to the size of duct relative to attic insulation depth. For this reason, definitions of partially, fully, and deeply buried ducts will be eliminated.

Necessity: Defining buried ducts under the proposed simplified, prescriptive approach necessitates the changes listed above. To minimize confusion, it will be necessary to clearly distinguish between the new prescriptive buried duct definition and the existing compliance path, which is proposed to be maintained despite its minimal use (only eleven fully completed CF3Rs were submitted in 2022). Tables 11 through 13 of the ACM Reference Manual do not reference buried ducts, which are only described in the context of the current compliance path, and it will be necessary to add the buried duct type to the other listed distribution system types in these tables. These changes are necessary to recognize buried ducts as a third prescriptive alternative to ducts in conditioned space and high performance attics and to identify the modeling approach for incorporating effective duct R-value, such as the amount of duct that is allowed to be above attic insulation where it connects to plenums.

2.1.2.3 Summary of Changes to the Single-Family Residential Compliance Manual

Chapter 4 of the Single-Family Residential Compliance Manual would be revised. Section 4.4, Air Distribution System Ducts, Plenums, Fans, and Filters would be modified to describe the buried duct prescriptive option and related installation requirements and verification procedures. Information would be included that clearly differentiates the proposed simplified compliance path from the current detailed compliance option. The Compliance Manual would include requirements for ceiling insulation levels, how alternative duct designs such as radial layouts can facilitate full burial, and how to provide zoning. Information about ACCA design manuals and availability of automated sizing and duct design software such as (Kwik Model© would be provided. References to the Residential Reference Appendices that provide detailed verification procedures will also be included. Guidance on the use of the buried duct option for performance compliance in climate zones where it is not prescriptively required would also be provided.

2.1.2.4 Summary of Changes to Compliance Documents

The proposed code change is expected to require modification of the compliance documents listed below.

- CF1R-NCB-01: Prescriptive Newly Constructed Buildings and Additions Equal to or Greater than 1,000 ft^2
- CF1R-PRF-01-E: Performance Compliance Method
- CF2R-MCH-21-H: Mechanical-HERS Duct Location Verification
- CR2R-MCH-29-H: Mechanical-HERS Duct Surface Area Reduction; R-Value; Buried Ducts Compliance Credit
- CF3R-MCH-21-H: Mechanical-HERS Duct Location Verification
- CF3R-MCH-29-H: Mechanical-HERS Duct Surface Area Reduction; R-Value; Buried Ducts Compliance Credit

2.1.3 Regulatory Context

2.1.3.1 Determination of Inconsistency or Incompatibility with Existing State Laws and Regulations

The existing 2022 Energy Code contains a compliance option that allows modeling of ducts that are partly, fully, or deeply buried in attic insulation and use of effective duct R-values that are based on the duct diameter, and amount and type of insulation that is applied over them. The R-values utilized by the compliance software are listed in Tables 15 through 20 of the 2022 ACM Reference Manual. The compliance software user must enter the duct size, R-value, length, and diameter of each duct segment using the same schedule as used to obtain duct surface area credits.

To qualify under existing requirements, ducts must meet the minimum mandatory insulation level of R-6 and be installed not more than 3.5 inches above or directly over ceiling drywall (between truss bottom cords). Further, credit is only allowed if the ceiling is level and where there is at least 6 inches of space between the duct outer jacket and roof sheathing and attic insulation is at a uniform depth. To qualify as deeply buried, ducts must have at least 3.5 inches of attic insulation covering the top of the duct insulation jacket. Mounding of insulation is not allowed, but containment systems can be used to provide for deeper burial if the walls of the containment are at least 7 inches wider than the duct diameter and extend at least 3.5 inches above the duct outer jacket. Proposed changes will eliminate references to partly, fully, and deeply buried ducts and the associated incremental changes in effective R-value and move to a dynamic approach that only requires ducts to be fully covered.

Under the existing code, field verification is required to ensure the duct system is installed in accordance with the duct design, including the location, diameter, R-value, and length of each duct segment, and the extent of duct burial in insulation. The installer must certify that the ducts are installed in accordance with the CF1R-PRF-01-E and the HERS inspector is responsible to verify that each duct segment is installed according to the CF2R-MCH-29-H. QII of attic insulation and duct leakage are also required to be verified.

Title 24, Part 11 (CalGreen) code Section 4.507.2 requires that HVAC duct systems be sized in accordance with ACCA Manual D or other equivalent methods. Another code change proposal under consideration for the 2025 code cycle would require documentation of duct design. If approved as a requirement within Title 24, Part 6, it could be used to identify the diameter of properly sized ducts to ensure complete coverage.

This proposal is not relevant to other parts of the California Building Standards Code (https://www.dgs.ca.gov/BSC/Codes). Changes outside of Title 24, Part 6 are not needed. There are no known state or local ordinances that would prevent implementation of the proposed changes.

2.1.3.2 Duplication or Conflicts with Federal Laws and Regulations

There are no relevant federal laws or regulations.

2.1.3.3 Difference From Existing Model Codes and Industry Standards

The 2021 International Energy Conservation Code (IECC), Section R403.3.6 describes a model code for buried ducts. The language of this section is brief and is repeated below:

R403.3.6 Ducts buried within ceiling insulation

1. The supply and return ducts shall have an insulation R-value not less than R-8.
2. At all points along each duct, the sum of the ceiling insulation R-value against and above the top of the duct, and against and below the bottom of the duct, shall be not less than R-19, excluding the value of the duct insulation.
3. In Climate Zones 1A, 2A, and 3A, the supply ducts shall be completely buried within ceiling insulation, insulated to an R-value of not less than R-13 and in compliance with the vapor retarder requirements of Section 604.11 of the International Mechanical Code or Section M1601.4.6 of the International Residential Code, as applicable.
   Exception: Sections of the supply duct that are less than 3 feet (914 mm) from the supply outlet shall not be required to comply with these requirements.

R403.3.6.1 Effective R-value of deeply buried ducts

Where using a simulated energy performance analysis, sections of ducts that are installed in accordance with Section R403.3.6; located directly on, or within 5.5 inches (140 mm) of the ceiling; surrounded with blown-in attic insulation having an

R-Value of R-30 or greater; and located such that the top of the duct is not less than 3.5 inches (89 mm) below the top of the insulation; shall be considered as having an effective duct insulation R-value of R-25.

As opposed to the performance based IECC code, the proposed compliance path utilizes the capabilities of the compliance model to provide for more options than those defined in IECC Section R403.3.6.1. It also provides a more detailed approach for estimating an average R-value as a function of the diameter and depth of burial of the ducts and associated requirements for duct sealing and verification and is better supported by analysis. There are no other relevant industry standards or model codes.

2.1.4 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.

The compliance verification activities related to this measure that need to occur during each phase of the project are described below:

- **Design Phase:** The designer will complete sizing calculations using ACCA Manuals J, D, and S, or comparable methods. The designer will provide documentation of the air distribution system which shall be included in the Certificate of Compliance either as a duct diagram or room-by-room list that includes the diameter and R-value of each duct, and amount of ensure full coverage from tables presented in the Reference Appendices. The designer or energy consultant will complete compliance calculations using CBECC-Res or other approved software, post the CF1R compliance documents to the registry, and provide the plans and Certificate of Compliance (COC) to the builder. The largest duct diameter and insulation type and R-value will be listed in the COC. It will not be necessary to enter the detailed duct designs into modeling software as is currently required for the buried duct compliance option. The software will calculate an average effective R-value and duct loss using the entered maximum duct diameter, insulation depth, and the same duct surface area as is used for the performance baseline.
- **Permit Application Phase:** The builder will submit plans and COC to the permitting agency and will respond to plan check comments as required. The builder will also have the responsibility to ensure the compliance documents have been uploaded to the registry.
- **Construction Phase:** The HVAC contractor will install the equipment and ductwork in accordance with the plans and after installation of ceiling drywall the

insulation contractor will apply the specified depth and R-value of attic insulation. The HVAC contractor will be responsible for installing and commissioning the remaining components of the system and completion of CF2R compliance documents. Following completion of attic insulation, the insulation contractor and HERS Rater will sign off on the CF2R documents. The building official will also verify that ducts are supported as required by California Mechanical Code (CMC) Section 603.4.

- **Inspection Phases:** HERS inspections for buried ducts will occur in two stages and at times when raters will already be present in the home for other required verifications. As noted, after ducts have been installed at rough-in, the HERS rater will verify that the duct layout including duct sizes and R-values are consistent with the Certificate of Compliance and that the ducts are laid over the lower truss cords and are not suspended. In most cases this inspection can be completed by viewing the ducts from the floor below. At the same time, a duct leakage test will be completed in accordance with RA3.1.4.3.2, which will allow leaks to be corrected prior to installation of ceiling insulation. A second inspection will occur coincident with the air sealing procedures in RA3.1.4.3.3 and the verification of attic insulation. A visual check to verify that ducts are fully covered will also be made. Following these verifications, HERS Raters will make the appropriate entries in the CF3R compliance documents and submit them to the registry.

Compliance and enforcement will be simpler than what is required for the current buried duct performance path that requires verification of each duct section. Compliance documents (see Section 2.1.2.4) will be modified to document the inspections and verifications. For example, CF2R-MCH-21-H (Duct Location) and corresponding CF3R documents would be modified to reference buried ducts as distinct distribution types.

Most of the added work will fall on the designers, but design software is available that facilitates rapid calculation of loads and equipment and duct sizing and that automates drawings of duct layouts. Designers will now be required to document duct designs on the plans. Duct design is already a requirement under Title 24, Part 11; however, the design is not often reviewed or verified. The largest duct diameter will need to be provided to the energy modeler as this will be a new input into the software. The measure would not impose any added burden on building officials.

Insulation contractors and HVAC installers should coordinate to ensure ducts are fully covered. Site superintendents should facilitate coordination between insulation and HVAC contractors to ensure markers are in place to identify duct locations, and that ducts are not moved or stepped on while the attic is being insulated.

2.2 Market Analysis

2.2.1 Current 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, CEC 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 public stakeholder meeting that the Statewide CASE Team held on February 14, 2023.

Registry data and builder interviews support CASE team field experience that most new home builders suspend ducts in vented attic spaces, with some applying insulation to the roof deck where prescriptively required in warmer climate zones. As explained in section 2.1.1.1, the relative lack of buried ducts as opposed to suspended ducts may be due to barriers in the compliance process, rather than technical or market concerns. The industry practice of suspending ducts has likely further solidified itself through market forces over time.

Table 6 identifies the proposed changes in prescriptive requirements for ceiling and duct insulation in the affected climate zones. Proposed changes to radiant barrier and roof deck insulation requirements are shown in Table 5.

Table 6: Proposed Change in Ceiling and Duct Insulation R-Values

Climate Zone	Minimum Prescriptive Ceiling Insulation		Minimum Prescriptive Duct Insulation	
	Current	Proposed	Current	Proposed
1	R-38	R-49	R-8	R-6
2	R-30	R-49	R-8	R-6
3	R-30	R-49	R-6	R-6 (no change)
5	R-30	R-49	R-6	R-6 (no change)
6	R-30	R-49	R-6	R-6 (no change)
7	R-30	R-49	R-6	R-6 (no change)
16	R-38	R-60	R-8	R-6

2.2.2 Technical Feasibility and Market Availability

2.2.2.1 Technical Feasibility

The successful realization of energy savings from buried ducts hinges on proper installation and reducing perceived and real barriers related to cost and level of difficulty. The materials needed to bury ducts in ceiling insulation are in common use in construction. With industry knowledge of what is required to install ducts, so they are fully buried, technical feasibility constraints are minimal.

Designing duct systems to be fully buried requires knowing the insulation depth and the diameter of the largest duct. Manufacturer coverage tables for loose fill insulation may be based on a higher R-value per inch than values assumed in this CASE report and thus require less coverage to achieve the desired R-value. The installer's certificate of installation must clearly specify the depth as well as the R-value, and a depth may be required that exceeds the targeted R-value for the ceiling assembly. To avoid sloughing, loose fill insulation should not be used with ceilings having a slope greater than 2:12 (9.6°). For homes with complex ceiling geometries, maintaining loose fill insulation leveled may be challenging. Where a mix of buried ducts and unburied ducts are required, for example to serve rooms with vaulted ceilings, the detailed duct design method in the compliance software must be used.

Ducts must be small enough in diameter to enable coverage by the desired R-value of insulation yet serve the heating and cooling needs of the building. Compliance with CalGreen (Title 24, Part 11 Section 4.507.2) requirements for sizing building loads, systems, and ducts in accordance with ACCA Manuals J, S, and D (or similar methods) ensures that ducts are properly sized and are useful to identify the size of ducts that are needed to permit full burial. Enforcement of the CalGreen requirements could introduce a compliance barrier, but sizing tools are available that can expedite sizing while optimizing system components and economizing on materials.

Anecdotal information suggests that in many cases equipment is sized using the peak load from compliance software and the ducts are sized based on the required 350 cfm/ton. Lacking room-by-room loads, airflow is likely apportioned based on room floor area or other considerations. In an interview with Bob Wiseman of Canoga Park Heating and Air Conditioning it was learned that they use the Table 150.1-B and Table 150.1-C alternative to measuring airflow and fan efficacy. That exception in the code allows sizing of supply ducts without consideration of friction loss or air delivery. Whatever sizing method is used, the buried duct compliance path will require a duct layout so that the largest duct diameter can be identified along with the depth of ceiling insulation to be installed. More information on applied duct sizing practices would be useful.

Using ACCA sizing methods for the 2,100 ft^2 and 2,700 ft^2 prototypes, the CASE team determined that duct layouts can be readily designed that provide full coverage in all climate zones. When R-6 ducts and R-49 fiberglass ceiling insulation are used, keeping supply ducts to 12 inches and smaller allows full burial (assuming fiberglass insulation with 2.5 R-value per inch of insulation, see Table 19) and is easily accomplished using trunk and branch designs. The CASE team also reviewed a “radial” duct design for which every duct is directly connected to the supply plenum. This design approach allows the use of smaller diameter ducts than a trunk and branch design.

Other than ensuring complete burial, the only change to installation practice is that ducts are not suspended from trusses using sheet metal straps but are deployed over the top of truss bottom cords and the ceiling. Duct installation must comply with CMC Section 603.4, which requires that horizontal runs of flexible ducts be supported at not more than 4-foot intervals and that supports shall be rigid and not less than 1½ inches wide at the point of contact with the duct surface. When trusses are spaced 24 inches on center and ducts cross the trusses at angles greater than 30°, trusses, the CMC requirement is met. Ducts crossing the members at less than a 30° angle or that run parallel to trusses would need to be supported by straps installed between trusses to carry the ducts until drywall is installed. The amount of strapping required would be much less than required for suspended ducts. To prevent crushing the ducts should a person attempt to walk across an attic after insulation is applied, markers to identify duct location would be installed as is currently required for buried ducts.

Since it is challenging to access ducts once they are buried in insulation, it is important to ensure that leakage testing is completed prior to application of insulation. This will require HERS testing and verification is completed in two stages, first to verify ducts and second to verify insulation quality and full coverage of ducts.

2.2.2.2 Market Availability

Air distribution materials required for standard as well as buried ducts, including flex ducts, strapping, branches, boots, and elbows are commonly available, as is blown-in ceiling insulation. The need for deeper blown-in insulation to cover the ducts may increase the demand for this material but production levels which have varied with home construction rates are likely to keep up with increased demand.

Feedback from one contractor that serves production builders and who had some prior experience with buried ducts was that the labor and materials cost difference between suspending ducts and laying them over trusses is “a wash.” Mike MacFarland, a home performance contractor and member of the Statewide CASE Team, routinely designs and installs buried duct systems. His observations are that many duct designs waste flex duct due to unnecessary lengths or poor equipment placement. There is an opportunity to save costs by reducing wastage when a duct design can be followed.

2.2.3 Market Impacts and Economic Assessments

2.2.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the measures proposed by the Statewide CASE Team for the 2025 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 comprises approximately 93,000 business establishments and 943,000 employees (see Table 7). For 2022, total estimated payroll will be about $78 billion. Nearly 72,000 of these business establishments and 473,000 employees are engaged in the residential building sector, while another 17,600 establishments and 369,000 employees focus on the commercial sector. The remainder of establishments and employees work in industrial, utilities, infrastructure, and other heavy construction roles (the industrial sector).

Table 7: California Construction Industry, Establishments, Employment, and Payroll in 2022 (Estimated)

Building Type	Construction Sectors	Establish ments	Employ ment	Annual Payroll (Billions $)
Residential	**All**	**71,889**	**472,974**	**31.2**
Residential	Building Construction Contractors	27,948	130,580	9.8
Residential	Foundation, Structure, & Building Exterior	7,891	83,575	5.0
Residential	Building Equipment Contractors	18,108	125,559	8.5
Residential	Building Finishing Contractors	17,942	133,260	8.0

Source: (State of California n.d.)

The buried duct proposal is specific to ducted HVAC systems within attics, and as such would 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. With the exception of residential-style commercial spaces, such as home-to-office conversions, commercial builders are also unlikely to be impacted. 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, reflecting specialties historically associated with this type of residential design and construction. Table 8 shows the residential building subsectors the Statewide CASE Team expects to be impacted by the changes proposed in this report, including those that may see decreased activity from the reduced uptake of other compliance pathways, such as roofing contractors that may install less roof deck insulation as people choose the buried duct pathway instead of high-performance attics. The Statewide CASE Team's estimates of the magnitude of these impacts are shown in Section 2.2.4 Economic Impacts.

Table 8: Specific Subsectors of the California Residential Building Industry by Subsector in 2022 (Estimated)

Residential Building Subsector	Establish ments	Employ ment	Annual Payroll (Billions $)
New single family general contractors	12,671	58,367	4.4
New multifamily general contractors	421	6,344	0.7
New housing for-sale builders	189	3,969	0.5
Residential Remodelers	14,667	61,900	4.2
Residential Framing Contractors	741	25,028	1.3
Residential Roofing Contractors	2,600	18,918	1.1
Residential Siding Contractors	242	2,081	0.1
Other Residential Exterior Contractors	628	2,875	0.2
Residential Electrical Contractors	7,857	48,366	3.3
Residential plumbing and HVAC contractors	9,852	75,404	5.1
Other Residential Equipment Contractors	399	1,789	0.1
Residential Drywall Contractors	1,901	32,631	2.0
Residential Painting Contractors	4,869	26,402	1.3

Source: (State of California n.d.)

2.2.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes is within the normal practices of building designers. Building codes (including Title 24, Part 6) 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.

As well as adding a prescriptive requirement in 7 of the 16 climate zones, the proposed measure will offer an additional compliance pathway in the other 9 climate zones, providing more flexibility for building designers. Designers who opt for this compliance pathway may require expertise from HVAC specialists to accommodate a properly sized duct design, but they may also avoid the expertise needed for other pathways such as additional framing needs for ducts in conditioned space (DCS) or meeting insulation requirements for HPAs.

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 9 shows the number of establishments, employment, and total annual payroll for Architectural Services. The proposed code changes would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for the buried ducts proposal to affect firms that focus on single family construction.

There is not a North American Industry Classification System (NAICS)[6] code specific to 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.[7] 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 9 provides an upper bound indication of the size of this sector in California.

Table 9: California Building Designer and Energy Consultant Sectors in 2022 (Estimated)

Sector	Establishments	Employment	Annual Payroll (Millions $)
Architectural Services [a]	4,134	31,478	3,623.3
Building Inspection Services [b]	1,035	3,567	280.7

Source: (State of California n.d.)

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

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

2.2.3.3 Impact on Occupational Safety and Health

Recent information obtained by Energy Commission staff indicates that CalOSHA will require fall protection for contractors installing insulation under roof decks. Though this requirement only affects installation of insulation to meet Option B insulation roof deck

[6] 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.

[7] 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.

requirements in Climate Zones 4 and 8 through 16, the added cost of providing scaffolding may drive some builders to adopt the proposed buried duct compliance option. The proposed measure has no other anticipated impacts related to safety and health that would affect contractors, building owners and occupants.

2.2.3.4 Impact on Building Owners and Occupants Including Homeowners and Potential First-Time Homeowners

According to data from the U.S. Census, American Community Survey (ACS), there were more than 14.5 million housing units in California in 2021 and nearly 13.3 million were occupied (see Table 10). Most housing units (nearly 9.42 million) were single-family homes (either detached or attached), approximately 2 million homes were in buildings containing two to nine units, and 2.5 million homes were in multi-family buildings containing 10 or more units. The California Department of Revenue estimated that building permits for 67,300 single-family and 54,900 multi-family homes will be issued in 2022, up from 66,000 single-family and 53,500 multi-family permits issued in 2021.

Table 10: California Housing Characteristics in 2021

Housing Measure	Estimate
Total housing units [a]	14,512,281
Occupied housing units	13,291,541
Vacant housing units	1,220,740
Homeowner vacancy rate	0.7%
Rental vacancy rate	4.3%
Number of 1-unit, detached structures	8,388,099
Number of 1-unit, attached structures	1,030,372
Number of 2-unit structures	348,295
Number of 3- or 4-unit structures	783,663
Number of 5- to 9-unit structures	856,225
Number of 10- to 19-unit structures	740,126
Number of 20+ unit structures	1,828,547
Mobile home, RV, etc.	522,442

Sources: (United States Census Bureau n.d.), (Federal Reserve Economic Data (FRED n.d.)

a. Total housing units as reported for 2021; all other housing measures estimated based on historical relationships.

Table 11 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 were no building energy efficiency standards (Kenney 2019).

Table 11: Distribution of California Housing by Vintage in 2021 (Estimated)

Home Vintage	Units	Percent	Cumulative Percent
Built 2014 or later	348,296	2.4	2.4
Built 2010 to 2013	261,221	1.8	4.2
Built 2000 to 2009	1,581,839	10.9	15.1
Built 1990 to 1999	1,596,351	11.0	26.1
Built 1980 to 1989	2,191,354	15.1	41.2
Built 1970 to 1979	2,539,649	17.5	58.7
Built 1960 to 1969	1,915,621	13.2	71.9
Built 1950 to 1959	1,930,133	13.3	85.2
Built 1940 to 1949	841,712	5.8	91.0
Built 1939 or earlier	1,306,105	9.0	100.0
Total housing units	**14,512,281**	**100.0**	**–**

Sources: (United States Census Bureau n.d.)

Table 12 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 an income below $50,000 is only 37 percent, whereas the owner occupancy rate is 71 percent for households earning $100,000 or more.

Table 12: Owner- and Renter-Occupied Housing Units in California by Income in 2021 (Estimated)

Household Income	Total	Owner Occupied	Renter Occupied
Less than $5,000	353,493	113,315	240,178
$5,000 to $9,999	254,304	74,939	179,366
$10,000 to $14,999	495,287	134,633	360,654
$15,000 to $19,999	412,498	144,064	268,435
$20,000 to $24,999	467,694	169,431	298,264
$25,000 to $34,999	906,996	355,968	551,028
$35,000 to $49,999	1,319,892	560,453	759,438
$50,000 to $74,999	2,036,560	990,769	1,045,791
$75,000 to $99,999	1,662,032	920,607	741,425
$100,000 to $149,999	2,307,889	1,490,247	817,642
$150,000 or more	3,074,895	2,337,651	737,244
Total Housing Units	**13,291,541**	**7,292,076**	**5,999,465**

Source: (United States Census Bureau 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 11 and Table 12.

Estimating Impacts

For California residents, the proposed code changes would result in lower energy bills. The Statewide CASE Team estimates that on average the proposed change to Title 24, Part 6 would increase construction cost by about $450-$980 per single family home, depending on climate zone, but the measure would also result in a savings of $755-$3,865 in energy and maintenance cost savings over 30 years. This is roughly equivalent to a $1.25-$2.72 per month increase in payments for a 30-year mortgage and a $2-$11 per month reduction in energy costs. Overall, the Statewide CASE Team expects the 2025 Title 24, Part 6 Standards to save homeowners about $25-$129 per year relative to homeowners whose single-family homes are minimally compliant with the 2022 Title 24, Part 6 requirements. As discussed in Section 2.2.3.4, 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).

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

The Statewide CASE Team anticipates the proposed change would have no significant impact on California component retailers. Impacts to the production and sale of fittings, duct sizes, and insulation (blown-in fiberglass and cellulose) will be minimal.

There may be a tendency to reduce the number of branches and connect more ducts to the plenum than is typical to facilitate smaller duct diameters, which would have a minor impact on fittings and duct sizes produced and sold. By following proper duct design practices, installers can anticipate material needs and thereby use shorter ducts and reduce waste by planning for the use of remnants. However, the impact on the supply chain is deemed to be insignificant.

The measure may result in increased sales of blown-in fiberglass and cellulose insulation. This demand will be mostly limited to the affected climate zones. The new buried duct compliance path may be adopted by builders working in climate zones where it is not prescriptively required to avoid the added cost of meeting Option B or C requirements, and when they can afford the slight performance penalty. In any case, the uptake of this compliance path by builders and the resulting impact on the use of materials is very difficult to predict. Both scenarios are expected to increase sales of smaller diameter flexible ducting and carry minor cost savings for the builder.

The thermal performance of buried ducts is better for R-6 than for R-8 ducts. This is a result of R-6 ducts being physically closer to the indoor environment and having more insulation between the duct outer surface and the attic. Thus, there are lower thermal losses to the attic space. The proposed measure lowers the required duct insulation from R-8 to R-6 in Climate Zones 1, 2, and 8. As a result the market for R-8 ducts may be reduced slightly, again depending on the extent to which the measure is applied.

2.2.3.6 Impact on Building Inspectors

Table 13 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 education and 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 13: Employment in California State and Government Agencies with Building Inspectors in 2022 (Estimated)

Sector	Govt.	Establishments	Employment	Annual Payroll (Million $)
Administration of Housing Programs[a]	State	18	265	29.0
	Local	38	3,060	248.6
Urban and Rural Development Admin[b]	State	38	764	71.3
	Local	52	2,481	211.5

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

a. Administration of Housing Programs (NAICS 925110) comprises government establishments primarily engaged in the administration and planning of housing programs, including building codes and standards, housing authorities, and housing programs, planning, and development.

b. Urban and Rural Development Administration (NAICS 925120) comprises government establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

2.2.3.7 Impact on Statewide Employment

As described in Sections 2.2.3.1 through 2.2.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the

California economy. This is not to say that the proposed change would not have modest impacts on employment in California. In Section 2.2.4, the Statewide CASE Team estimated the proposed change 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 would lead to modest ongoing financial savings for California residents, which would then be available for other economic activities.

2.2.4 Economic Impacts

For the 2025 code cycle, the Statewide CASE Team used the IMPLAN model software[8], along with economic information from published sources, and professional judgement to develop estimates of the economic impacts associated with each of the proposed code changes. Conceptually, IMPLAN estimates jobs created as a function of incoming cash flow in different sectors of the economy, due to implementing a code or a standard. The jobs created are typically categorized into direct, indirect, and induced employment. For example, cash flow into a manufacturing plant captures direct employment (jobs created in the manufacturing plant), indirect employment (jobs created in the sectors that provide raw materials to the manufacturing plant) and induced employment (jobs created in the larger economy due to purchasing habits of people newly employed in the manufacturing plant). Eventually, IMPLAN computes the total number of jobs created due to a code. The assumptions of IMPLAN include constant returns to scale, fixed input structure, industry homogeneity, no supply constraints, fixed technology, and constant byproduct coefficients. The model is also static in nature and is a simplification of how jobs are created in the macro-economy.

The economic impacts for this report are only estimates and are based on limited and to some extent speculative information. The IMPLAN model provides a relatively simple representation of the California economy and, though the Statewide CASE Team is confident that the 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 aspects 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 economic impacts presented below represent lower bound estimates of the actual benefits associated with this proposed code change.

[8] IMPLAN employs economic data and advanced economic impact modeling to estimate economic impacts for interventions like changes to the California Title 24, Part 6 code. For more information on the IMPLAN modeling process, see www.IMPLAN.com.

Adoption of this code change proposal would result in relatively modest economic impacts through the additional direct spending by those in the residential building and remodeling industry, including builders, energy consultants, and HVAC contractors, as well as indirectly as residents spend some portion of the money saved through lower utility bills on other economic activities.[9] These impacts are estimated in Table 14 to Table 15.

Table 14: Estimated Impact that Adoption of the Proposed Measure would have on the California Residential Construction Sector

Type of Economic Impact	Employment (Jobs)	Labor Income	Total Value Added	Output
Direct Effects (Additional spending by Residential Builders)	9.7	$765,773	$806,951	$1,315,324
Indirect Effect (Additional spending by firms supporting Residential Builders)	2.5	$187,467	$309,033	$524,281
Induced Effect (Spending by employees of firms experiencing "direct" or "indirect" effects)	4.0	$274,024	$490,612	$780,869
Total Economic Impacts	**16.2**	**$1,227,264**	**$1,606,596**	**$2,620,473**

Source: CASE Team analysis of data from the IMPLAN modeling software.[10]

Table 15: Estimated Impact that Adoption of the Proposed Measure would have on the California Building Designers and Energy Consultants Sectors

Type of Economic Impact	Employment (Jobs)	Labor Income	Total Value Added	Output
Direct Effects (Additional spending by Building Designers & Energy Consultants)	23.2	$2,546,937	$2,521,437	$3,985,368
Indirect Effect (Additional spending by firms supporting Bldg. Designers & Energy Consultants)	9.3	$758,351	$1,053,957	$1,696,654
Induced Effect (Spending by employees of firms experiencing "direct" or "indirect" effects)	13.9	$950,423	$1,702,005	$2,708,988
Total Economic Impacts	**46.5**	**$4,255,710**	**$5,277,399**	**$8,391,010**

Source: CASE Team analysis of data from the IMPLAN modeling software.

2.2.4.1 Creation or Elimination of Jobs

The Statewide CASE Team does not anticipate that the measures proposed for the 2025 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

[9] For example, for the lowest income group, it was assumed that 100 percent of money saved through lower energy bills will be spent, while for the highest income group, it was assumed that only 64 percent of additional income will be spent.

[10] IMPLAN® model, 2020 Data, IMPLAN Group LLC, IMPLAN System (data and software), 16905 Northcross Dr., Suite 120, Huntersville, NC 28078 www.IMPLAN.com

economy. Rather, the estimates of economic impacts discussed in Section 2.2.4 would lead to modest changes in employment of existing jobs.

2.2.4.2 Creation or Elimination of Businesses in California

As stated in Section 2.2.4.1, 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 the HVAC design process, which would not excessively burden or competitively disadvantage California businesses – nor would it necessarily lead to a competitive advantage for California businesses. Therefore, the Statewide CASE Team does not foresee any new businesses being created, nor does the Statewide CASE Team think any existing businesses would be eliminated due to the proposed code changes.

2.2.4.3 Competitive Advantages or Disadvantages for Businesses in California

The proposed code changes would apply to all businesses incorporated in California, regardless of whether the business is located inside or outside of the state.[11] Therefore, the Statewide CASE Team does not anticipate that these measures proposed for the 2025 code cycle regulation would have an adverse effect on the competitiveness of California businesses. Likewise, the Statewide CASE Team does not anticipate businesses located outside of California would be advantaged or disadvantaged.

2.2.4.4 Increase or Decrease of Investments in the State of California

The Statewide CASE Team analyzed national data on corporate profits and capital investment by businesses that expand a firm's capital stock (referred to as net private domestic investment, or NPDI).[12] As Table 16 shows, between 2017 and 2021, NPDI as a percentage of corporate profits ranged from a low of 18 in 2020 due to the worldwide economic slowdowns associated with the COVID 19 pandemic to a high of 35 percent in 2019, with an average of 26 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.

[11] 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.

[12] 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.

Table 16: 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 (Percent)
2017	518.473	1882.460	28
2018	636.846	1977.478	32
2019	690.865	1952.432	35
2020	343.620	1908.433	18
2021	506.331	2619.977	19
5-Year Average	**539.227**	**2068.156**	**26**

Source: (Federal Reserve Economic Data (FRED 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, directly or indirectly, in any affected sectors of California's economy. Nevertheless, the Statewide CASE Team is able to derive a reasonable estimate of the change in investment by California businesses based on the estimated change in economic activity associated with the proposed measure and its expected effect on proprietor income, which was used a conservative estimate of corporate profits, a portion of which was assumed to be allocated to net business investment.[13]

2.2.4.5 Incentives for Innovation in Products, Materials, or Processes

The proposed regulation will open the door to vendors of software products that can facilitate the design of residential ducting systems that comply with ACCA sizing requirements. It may build on trends by some HVAC contractors to prefabricate duct systems, thus minimizing field installation time.

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

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

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,

[13] 26 percent of proprietor income was assumed to be allocated to net business investment; see Table 16.

these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

Cost to Local Governments: All proposed code changes to Title 24, Part 6 would result in changes to compliance determinations. Local governments would need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2025 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 2.1.4 and Appendix E, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

2.2.4.7 Impacts on Specific Persons

While the objective of any of the Statewide CASE Team's proposal is to promote energy efficiency, the Statewide CASE Team recognizes that there is the potential that a proposed code change may result in unintended consequences. The proposed changes are not known or expected to result in impacts on specific persons. Refer to Section 4 for more details addressing energy equity and environmental justice.

2.2.5 Fiscal Impacts

2.2.5.1 Mandates on Local Agencies or School Districts

There are no relevant mandates to local agencies or school districts as this measure applies only to single family construction.

2.2.5.2 Costs to Local Agencies or School Districts

There are no costs to local agencies or school districts as this measure applies only to single family construction.

2.2.5.3 Costs or Savings to Any State Agency

The proposed measure will impose no added costs or savings, discretionary or non-discretionary, or other fiscal impacts to any state agencies as this measure applies only to single family construction.

2.2.5.4 Other Non-Discretionary Cost or Savings Imposed on Local Agencies

There are no added non-discretionary costs or savings to local agencies because this proposal applies to single family construction only.

2.2.5.5 Costs or Savings in Federal Funding to the State

There are no costs or savings to federal funding to the state.

2.3 Energy Savings

2.3.1 Energy Savings Methodology

2.3.1.1 Key Assumptions for Energy Savings Analysis

The key assumption on which energy impacts are hinged is the effective R-value of fully buried ducts of various diameters. "Fully" is defined as ducts that are not exposed and visible above attic insulation. Effective R-values were calculated using the THERM two-dimensional heat transfer software (LBNL 2023). An insulation R-value of 2.5 per inch was modelled for R-49 blown-in fiberglass, and a duct R-value of R-6 was assumed. Despite the benefits of allowing ducts to rest on the ceiling floor, the simulation models assume all ducts resting on truss cords and thus raised 3.5 inches from the ceiling floor.

Duct designs were developed for the 2,100 ft^2 and 2,700 ft^2 residential prototype houses and load calculations were completed for seven representative climate zones. These were completed using Kwik Model™ software (Kwik Model, which incorporates Manuals J, D, and S. They showed that with minor changes to trunk and branch duct designs, ducts can be fully covered with R-49 insulation. (Radial duct designs can also be employed to reduce duct diameters). In climate zones where heat pumps are prescriptively required, airflow and duct sizing were based on cooling loads. For the remaining climate zones, sizing was based on the greater of the heating and cooling load.

In addition to energy savings resulting from improved distribution efficiency, modeling results include savings for reduced ceiling heat transfers resulting from insulation R-values that are greater than current prescriptive requirements. The effect that ducts have on displacing ceiling insulation are accounted for in the THERM analysis.

The energy savings analysis relies on results of California Building Energy Code Compliance (CBECC) software simulations, specifically the 2025 research version of CBECC-Res, to estimate energy use for single family prototype buildings (California Energy Commission n.d.). The duct R-values calculated in THERM were applied in CBECC-Res to estimate the impacts. The Statewide CASE Team simulated the energy impacts in every climate zone and applied the climate-zone specific Long-term Systemwide Cost (LSC) hourly factors when calculating energy cost impacts.

There is mixed feedback on energy cost savings from stakeholders. Though, the majority believes that installing ducts above the ceiling and burying them in insulation will result in energy savings compared to having them suspended.

The Statewide CASE Team gathered stakeholder input to inform the energy savings analysis, as described throughout this section. See Appendix F for a summary of stakeholder engagement.

2.3.1.2 Energy Savings Methodology per Prototypical Building

The Statewide CASE Team measured per unit energy savings expected from the proposed code changes in several ways in order to quantify key impacts. First, savings are calculated by fuel type. Electricity savings are measured in terms of both energy usage and peak demand reduction. Natural gas savings are quantified in terms of energy usage. Second, the Statewide CASE Team calculated Source Energy Savings. Source Energy represents the total amount of raw fuel required to operate a building. In addition to all energy used from on-site production, source energy incorporates all transmission, delivery, and production losses. The hourly source energy values provided by CEC are strongly correlated with GHG emissions.[14] Finally, the Statewide CASE Team calculated Long-term Systemwide Cost (LSC) Savings, formerly known as Time Dependent Valuation (TDV) Energy Cost Savings. LSC Savings are calculated using hourly LSC factors for both electricity and natural gas provided by the CEC. These LSC hourly factors are projected over the 30-year life of the building and incorporate the hourly cost of marginal generation, transmission and distribution, fuel, capacity, losses, and cap-and-trade-based CO_2 emissions.[12]

The CEC 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 (California Energy Commission 2022). The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 17.

Energy savings are calculated using two new construction prototypes, a single story 2,100 square foot home and a two-story 2,700 square foot home. In Sections 2.3 and 0 results are presented for a weighted average of the 2,100 square foot and 2,700 square foot new construction prototypes since results for each of these two prototypes individually are similar. Results are weighted 43 percent for the 2100 square foot prototype and 57 percent for the 2700 square foot prototype. Results are separately

[14] See hourly factors for source energy, Long-term Systemwide Cost, and greenhouse gas emissions at https://www.energy.ca.gov/files/2025-energy-code-hourly-factors.

presented for the 500 square foot single family new construction prototype since the impacts in some cases differ significantly for the smaller prototype. See Appendix A for further details on how the weighting was derived.

Additional details on the 2,100 and 2,700 square foot single family prototypes can be found in the Single-Family Residential Alternative Calculation Method (ACM) Approval Manual (California Energy Commission 2022). The 500 square foot single family prototype is a new prototype being evaluated in this code cycle to reflect recent trends in California construction of a greater number of accessory dwelling units and small homes (UC Berkeley Center for Community Innovation 2021).

This measure proposal does not apply to alterations, except that compliance software modifications will allow it to be used for performance-based compliance for existing homes.

Table 17: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (Square Feet)	Description
One-Story Single Family (SF2100)	1	2100	Single story 3-bedroom house with attached garage, 9-ft ceilings, vented attic, and steep-sloped roof.
Two-Story Single Family (SF2700)	2	2700	Two-story 4-bedroom house with attached garage, 9-ft ceilings, 1-ft between floors, vented attic, and steep-sloped roof.
Small Single Family (SF500)	1	500	Detached single story 1-bedroom small home, 9-ft ceilings.

The Statewide CASE Team estimated LSC energy, source energy, electricity, natural gas, peak demand, and GHG impacts by simulating the proposed code change using prototypical buildings and rulesets from the 2025 Research Version of the California Building Energy Code Compliance (CBECC-Res) software.

CBECC-Res generates two models based on user inputs: the Standard Design and the Proposed Design.[15] To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building with the Standard Design representing minimal compliance with 2022 code and the Proposed Design representing the same features but is in

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

compliance with the proposed requirements. Features used in the Standard Design are described in the 2022 Single-Family Residential ACM Reference Manual.

The Proposed Design represents the same geometry as the Standard Design, but it assumes the energy features that the software user describes with user inputs. To develop savings estimates for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building with the Standard Design representing compliance with 2022 code and the Proposed Design representing compliance with the proposed requirements. Comparing the energy impacts of the Standard Design to the Proposed Design reveals the impacts of the proposed code change relative to a building that is minimally compliant with the 2022 Title 24, Part 6 requirements.

There is an existing Title 24, Part 6 requirement that covers the building system in question. It applies only to new construction, so the Standard Design is minimally compliant with the 2022 Title 24 requirements.

The Proposed Design was identical to the Standard Design in all ways except for the revisions that represent the proposed changes to the code. Since the measure is climate-zone specific, assumptions applied by climate zone are presented in Table 18.

Table 18: Modifications Made to Standard Design in Each Prototype to Simulate Proposed Code Change

Prototype ID	Climate Zone	Objects Modified	Parameter Name	Standard Design Parameter Value	Proposed Design Parameter Value
SF2100 & SF2700	1-3, 5-7, 16	Distribution system	Duct location	Attic, exposed	Attic, buried
	3, 5-7	Distribution system	Duct R-value	R-6	R-6, effective R-value per THERM calculations
	1-2, 16	Distribution system	Duct R-value	R-8	R-6, effective R-value per THERM calculations
	3, 5-7	Ceiling insulation	R-value	R-30	R-49
	1-2, 16	Ceiling insulation	R-value	R-38	R-49/R-60
SF500	5-7	Ceiling insulation	R-value	R-30	R-38
	3	Ceiling insulation	R-value	R-30	R-49
	1-2	Ceiling insulation	R-value	R-38	R-49
	16	Ceiling insulation	R-value	R-38	R-60
All SF	16	Attic roof construction	Below deck cavity insulation	R-19	R-0
	1 and 16	Attic roof construction	Radiant barrier	No	Yes

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 2025 LSC hourly factors to calculate Long-term Systemwide Cost in 2026 present value dollars (2026 PV$), Source Energy hourly factors to calculate Source Energy Use in kilo British thermal units per year (kBtu/yr), and hourly GHG emissions factors to calculate annual GHG emissions in metric tons of carbon dioxide emissions equivalent per year (MT or "tonnes" CO2e/yr). CBECC-Res also calculates annual peak electricity demand measured in kilowatts (kW).

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

Per unit energy impacts for single family buildings are presented in savings per prototype building. As described in Section 2.4.5, the Statewide CASE Team developed a weighted average savings of the two prototypes to calculate statewide savings.

Summary of Research on Duct Thermal Losses

Various methods of reducing duct loss were studied under a U.S. Department of Energy (DOE) Building America program, including locating them in conditioned space, insulating the roof deck to moderate attic temperatures, and burying them in attic insulation (Hoeschele 2015). Further research on high performance attics (insulated roof decks) as a means of improving distribution efficiency of attic ducts was completed to support the current Option B compliance option applied in hotter climate zones (Hoeschele 2017).

Originally published in 2004, ASHRAE Standard 152 defines "delivery effectiveness" as the ratio of thermal energy transferred to or from the conditioned space to the thermal energy transferred at the equipment system heat exchanger (ASHRAE Standard 152 2014). This standard includes an accounting of "thermal regain", which is the fraction of distribution system losses that are returned to the conditioned space. The CBECC-Res simulation engine applies Standard 152 concepts to determine distribution efficiency but it is not useful for calculating the thermal efficiency of buried ducts.

Under other Building America projects the R-value of buried ducts was investigated using modeling and field evaluations (Griffiths 2004). According to a follow-up report (Shapiro 2013) those results were used as the basis of Table R3-38 of the 2008 Residential Compliance Manual and the existing buried duct compliance path in Title 24, Part 6. The effective R-value in Tables 15-20 of the 2022 ACM Reference Manual are apparently built on the same work. Shapiro's report also states that the effective R-values described in the Griffiths report excluded heat transfer between conditioned space and the duct, and effective R-values were the same whether the ducts were placed directly on the ceiling or over lower truss chords or insulation. This definition of effective R-value helps explain the lower R-values in the ACM tables compared to the THERM analysis completed for this CASE report. In the later report Shapiro added a definition for “apparent R-value”, which accounts for heat transfer between the duct and conditioned space, but the tables in the ACM Reference Manual have not been updated to the “apparent R-value” definition. For purposes of this CASE report, effective and apparent R-values are defined the same.

Existing work on buried ducts fails to present the impact of assumed temperatures for the attic space, conditioned air, and in the indoor environment on the effective R-value. The work presented in this CASE report describes this phenomenon and why assumptions on boundary conditions must be agreed upon and presented in conjunction with effective R-values of buried ducts.

Modeling of Effective Duct R-Values

The THERM finite difference model used to develop effective R-values accounted for thermal transfers between the air carried in the ducts through attic insulation to attic air above, as well as downward through insulation and/or truss members to occupied space. Thermal regains resulting from heating or cooling of attic air by upward duct losses (as described in the ASHRAE standard) were not accounted for in THERM modeling. Given the thickness of insulation they would be very minor.

Initial modeling using THERM suggested that the effective R-values in the current ACM tables are overly conservative, which led to a thorough analysis of a large array of conditions. THERM simulations were conducted to calculate the effective R-value of buried ducts under two temperature conditions, a full range of duct sizes, the extent of burial, and a range of insulation R-values. THERM model parameters were varied as follows:

- Attic insulation of R-30, R-38, R-44, R-49, and R-60.
- Fiberglass and cellulose insulation with 2.5 and 3.2 respectively in R-value per inch of attic insulation.
- Ducts resting on the ceiling drywall, resting on 3.5-inch truss cords, and rested on 3.5 inches of attic insulation above the ceiling floor.
- R-4.2, R-6 and R-8 duct insulation.
- Attic temperatures of 47°F to simulate heating conditions and 107°F to simulate cooling conditions.

The HVAC equipment and ducts were sized using the Kwik Model software and varied by building type and climate.

Figure 3 represents a buried duct resting on the upper surface of the ceiling drywall. For modeling purposes ducts were assumed to be fully covered with insulation and positioned at the ceiling level or over the top of 2x4 truss cords. Modeling accounted for heat transfers upwards to the attic space and downward to living space, the latter of which was counted as a reduction of thermal losses since energy flows between the duct and the interior space will contribute to condition the indoor environment. The closer the proximity of the duct to the ceiling surface the greater the ratio of beneficial downward to upward heat transfers.

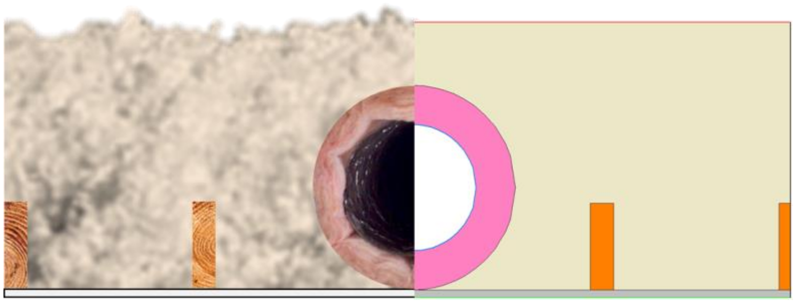

Figure 3: Realistic illustration of a buried duct (left side) and how ducts were modeled using a discrete depth of ceiling insulation (right side).

Modeling evaluated the three duct positions represented in Figure 4. (1) ducts running in parallel with trusses and resting on top of the ceiling drywall, (2) ducts running perpendicular to joists and resting on top of the ceiling joists, and (3) ducts running perpendicular or parallel to ceiling joists and resting on blown-in insulation.

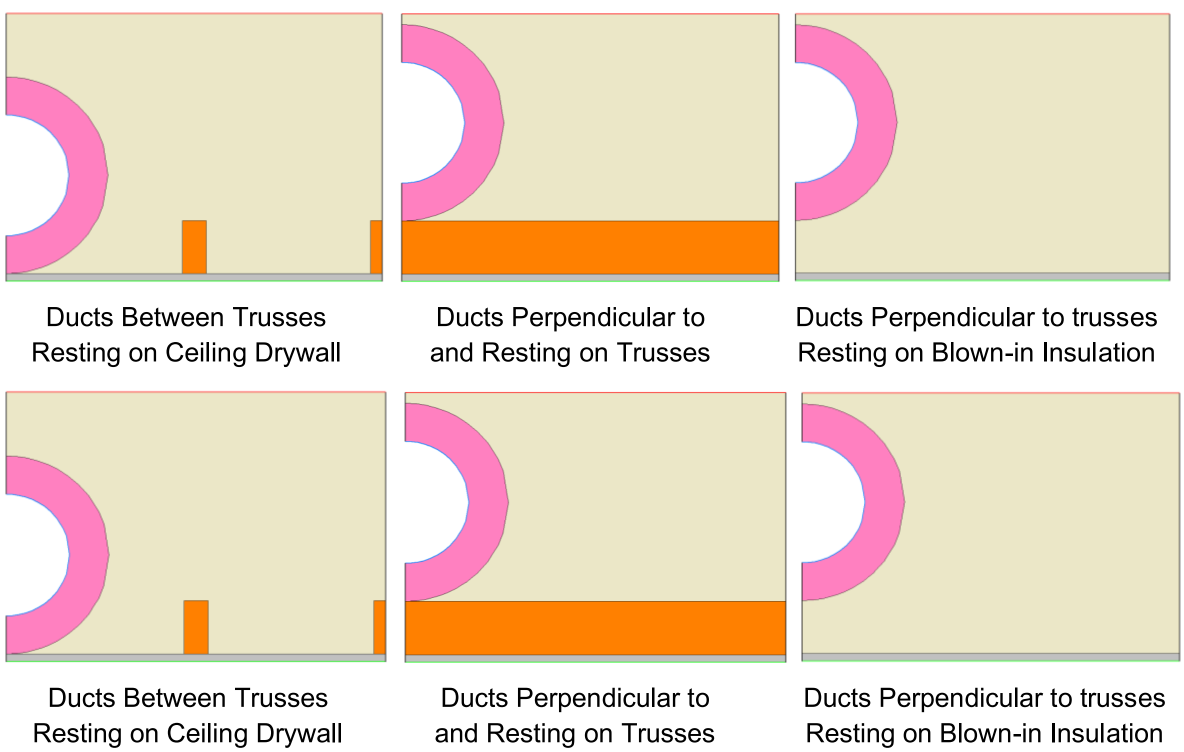

Figure 4: Simulation cases to represent location of ducts buried in insulation.

Where the ducts sit on top of the ceiling drywall, the effective R-value is the highest because heat is most readily conducted between the ducts and conditioned space. For the case where the ducts rest on the insulation, the effective R-value is the lowest, and where the duct rests on a truss heat is more readily conducted downward through the rafter and ceiling. In all the analysis cases the ducts are raised 3.5 inches above the ceiling drywall, which is the typical height of a truss bottom cord.

The required depth of blown-in insulation needed to cover the ducts is dictated by the outside diameter of the ducts plus the 3.5-inch space needed for bottom truss cords and the R-value per inch for the insulation type. Blown-in fiberglass has an average R-value per inch of 2.5, and for cellulose it averages R-3.5 per inch (WSU 2006). Thus, a lesser depth of cellulose insulation is required compared to fiberglass resulting is less coverage of ducts given the same attic insulation total R-value. Table 19 lists the maximum allowable duct diameter that will result in full burial for different R-values of these two insulation types. Note that when R-6 ducts are used, blown fiberglass with an R-value per inch of 2.5 and total R-value of 49 will fully cover up to a 12-inch duct, while the largest duct that could be covered with blown cellulose is 8 inches.

Table 19: Maximum R-6 Duct Diameter (Inches) to Ensure Full Burial within Attic Insulation, under the Assumption that the Ducts Rest on 2x4 Lower Truss Cords.

Attic Insul. Level	R-value per Inch of Attic Insulation																
	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
	Maximum R-6 Duct Diameter (inches)																
R-30	6	6	5	5	4	4	3	3	3	Partially Buried							
R-38	10	9	8	8	7	7	6	6	5	5	4	4	4	3	3	3	3
R-44	12	12	10	10	9	9	8	8	7	7	6	6	5	5	5	4	4
R-49	14	14	12	12	10	10	10	9	9	8	8	7	7	7	6	6	5
R-60	20	18	18	16	16	14	14	12	12	12	10	10	10	10	9	9	8

Practically, it can be challenging to run ducts in parallel with the trusses and allow for ducts to rest on the ceiling floor. Though, the work presented in this report indicates that optimizing for allowing ducts to rest on the ceiling can be worthwhile since the effective R-value increases significantly compared to ducts raised at 3.5 inches.

Finding the effective R-value of partially or fully buried ducts is not necessarily a straightforward approach. The complexity derives from having three different environments to account for, and their interaction between each other causes the actual thermal resistance to become dynamic in nature. Thus, the actual R-values between the three environments cannot be defined unless first establishing the boundary conditions.

In addition, because energy flows in more than one direction, finding the effective R-values of ducts requires computer simulations. For the effective R-values presented in this report, the two-dimensional and steady-state heat transfer software THERM (LBNL 2023) was utilized. Further details about how the effective duct R-values are found is presented in Appendix H.

Previous work (Griffiths 2004) (Shapiro 2013) related to calculating effective R-values for ducts fail to explore the strong dependencies of assumed boundary condition temperatures. Mostly, the assumed attic temperature has the strongest impact, but also indoor temperature as well as duct air temperature.

Attic Temperature: 80°F

Attic Insulation R-value	Cooling					
	4"	6"	7"	8"	9"	10"
R-30	21.7	18.7	18.0	17.5	17.1	16.8
R-38	30.4	28.9	26.9	24.1	21.8	20.6
R-44	36.6	36.3	34.9	32.9	30.3	27.0
R-49	41.9	42.4	41.5	39.9	37.8	35.1
R-60	52.8	55.0	54.7	53.9	52.5	50.7

Attic Temperature: 130°F

Attic Insulation R-value	Cooling					
	4"	6"	7"	8"	9"	10"
R-30	32.8	25.9	24.1	23.0	22.2	21.5
R-38	50.7	44.8	40.1	34.5	30.0	27.7
R-44	64.7	60.1	56.0	51.0	45.2	38.7
R-49	77.1	73.6	69.9	65.3	59.9	53.9
R-60	104.0	102.9	100.0	96.2	91.6	86.2

Attic Insulation R-value	Cooling					
	4"	6"	7"	8"	9"	10"
R-30	51%	38%	34%	32%	30%	28%
R-38	67%	55%	49%	43%	38%	35%
R-44	77%	66%	60%	55%	49%	44%
R-49	84%	73%	69%	64%	59%	54%
R-60	97%	87%	83%	79%	74%	70%

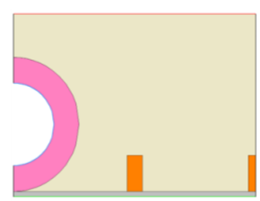

Figure 5: Impact of assumed attic temperature (80°F compared to 130°F) on effective R-values of ducts. The right-hand table presents the difference in R-value between the two cases in percent.

Figure 5 shows that the assumed attic temperature has a great impact on the effective R-value. For example, an assumed attic temperature of 130°F will result in affective R-values of buried ducts up to twice as large compared when an attic temperature is set to 80°F. Because of this strong relationship, it's crucial to agree on a temperature that is representative of an average and load weighted attic temperature. From the analysis completed for this measure, representative attic temperatures were identified as 107°F for cooling and 47°F for heating. The reasoning behind the assumed attic temperature is given in Appendix I of this report.

Table 20 presents effective R-values for two of the cases presented in Figure 4; ducts resting on the ceiling plane, and ducts resting on the blown-in insulation. In addition, three ratios are given, representing the percentages of the two cases. As an example, "75/25" means that 75% of the ducts are assumed to rest on the ceiling plane and 25% run perpendicular and rest on insulation. For the whole-house simulations of buried ducts, all ducts are assumed to be raised 3.5 inches from the ceiling. This assumption is conservative as one would except that randomly assigned duct orientation would approximately be 50/50 between parallel and perpendicular to trusses and thus allow for some ducts to rest on the ceiling plane. This also accounts for some ducts being run diagonally to trusses and would likely be elevated similar to the perpendicular orientation. Effective R-values for ducts with larger diameters than presented in Table 20 are given by Table 22 through Table 27.

Table 20: Comparison of Effective R-values of Fully Buried R-6 Ducts in R-49 Blown-in Fiberglass Insulation Relative to Duct Diameter and Position Above Drywall

Effective R-value[a] (h·ft²·F°/Btu) – Resting on ceiling compared to raised					
Duct Inside Diameter	*On Drywall*	*75/25[b]*	*50/50[b]*	*25/75[b]*	*Raised 3.5"*
4"	61.0	55.0	49.0	43.0	37.0
5"	61.1	55.4	49.6	43.9	38.1
6"	58.0	52.5	47.0	41.5	36.0
7"	52.9	47.6	42.2	36.9	31.5
8"	61.6	55.7	49.9	44.0	38.1
9"	59.9	54.3	48.7	43.0	37.4
10"	55.7	50.3	44.9	39.4	34.0

a. Attic temperature assumed at 107°F during cooling and at 47°F during heating. Weighted average heating and cooling ratios across the State were found to be 64% heating and 36% cooling.
b. Percentage of ducts resting on the drywall / percentage of ducts raised 3.5".

As currently configured, CBECC-Res doesn't allow changing effective duct R-values for each simulation timestep. Hence, a mutual and fixed value that can be used throughout the whole simulation must be decided upon. Here, the ratio between Heating and Cooling Degree Days for the different climate zones are utilized (ASHRAE 2021).Table 21 presents such ratios for each climate.

Table 21: Ratio of Heating Degree Days (HDDs) over Total Cooling and Heating Degree Days (DDs) for the California Climate Zones.

Climate Zone	Ratio of HDD to Total DD
1	99.7%
2	86.3%
3	94.4%
4	79.3%
5	85.1%
6	65.1%
7	63.4%
8	58.0%
9	50.1%
10	51.0%
11	69.9%
12	68.1%
13	60.4%
14	44.2%
15	19.8%
16	89.5%

As seen in Table 20, the effective R-value of buried ducts depends on whether the HVAC system runs in heating or cooling mode. Applying the heating ratios presented in Table 21 together with the California Climate Zone population densities, weighted average heating and cooling ratios across the State were found to be 64% heating and 36% cooling (PEC 2006).

Effective R-values for buried ducts are presented in Table 22 through Table 27 and are based on average heating and cooling ratios as given above. In addition, the attic temperature is assumed 107°F during cooling and 47°F during heating. Table 22 through Table 24 present effective R-value of ducts raised 3.5 inches from the ceiling floor and for R-4.2, R-6, and R-8 duct insulation. Whilst Table 25 through Table 27 present effective R-values for ducts resting on the ceiling floor. As discussed earlier, the overall thermal resistance, for which the effective R-value represents, is highly increased when ducts are installed on the ceiling floor compared to running on top of bottom truss cords (ceiling joists) or insulation.

Table 22: Effective Duct Insulation R-value (R-8) by Duct Diameter in Inches – Ducts Raised 3.5 Inches from Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	**R-30**	14.7	14.8	14.9	14.9	14.9	14.9	14.8	14.7	14.6	14.4	15.2	14.2	14.1	14.0
	R-38	23.3	23.0	21.9	20.0	19.1	18.6	18.1	17.5	17.0	16.6	17.4	16.0	15.8	15.6
	R-44	29.8	30.2	29.8	28.6	26.6	24.1	22.2	20.4	19.4	18.6	19.4	17.6	17.2	16.9
	R-49	35.1	36.1	36.2	35.5	34.1	32.2	29.6	24.2	22.0	20.7	21.4	19.1	18.5	18.1
	R-60	46.7	48.9	50.0	50.3	49.7	48.7	47.1	42.6	36.4	28.9	28.5	23.7	22.3	21.4
Cellulose	**R-30**	11.5	11.9	12.2	12.5	12.6	12.7	12.7	12.8	12.8	12.9	13.6	12.8	12.8	12.8
	R-38	15.0	14.9	15.0	15.0	14.9	14.9	14.8	14.7	14.5	14.4	15.2	14.1	14.0	13.9
	R-44	21.0	19.6	18.2	17.7	17.3	17.0	16.7	16.3	15.9	15.7	16.5	15.2	15.0	14.8
	R-49	26.2	25.7	24.1	21.4	20.0	19.3	18.7	17.9	17.3	16.8	17.6	16.1	15.9	15.6
	R-60	37.4	38.3	38.1	36.9	34.7	31.7	27.9	23.2	21.3	20.1	20.8	18.6	18.1	17.6

Table 23: Effective Duct Insulation R-value (R-6) by Duct Diameter in Inches – Ducts Raised 3.5 Inches from Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	**R-30**	15.7	14.7	14.3	14.0	13.8	13.6	13.5	13.2	12.9	12.7	13.4	12.4	12.2	12.1
	R-38	24.9	24.7	23.5	21.5	19.0	17.8	17.1	16.1	15.3	14.8	15.5	14.1	13.8	13.5
	R-44	31.5	32.0	31.6	30.4	28.5	25.9	22.8	19.4	17.8	16.8	17.4	15.5	15.1	14.7
	R-49	37.0	38.1	38.1	37.4	36.0	34.0	31.5	24.9	20.8	19.0	19.5	17.0	16.4	15.9
	R-60	48.9	51.2	52.3	52.4	51.9	50.8	49.2	44.7	38.5	30.5	28.0	21.8	20.2	19.1
Cellulose	**R-30**	11.0	11.2	11.3	11.4	11.4	11.4	11.4	11.4	11.3	11.2	11.9	11.1	11.1	11.0
	R-38	16.4	15.0	14.5	14.1	13.9	13.6	13.5	13.1	12.9	12.7	13.3	12.3	12.2	12.1
	R-44	23.2	22.1	19.7	17.5	16.6	15.9	15.5	14.8	14.3	13.9	14.5	13.3	13.1	12.9
	R-49	28.6	28.3	26.7	24.0	20.5	18.7	17.7	16.4	15.6	15.0	15.7	14.2	13.9	13.6
	R-60	40.1	41.2	41.0	39.7	37.7	34.8	31.1	22.9	20.0	18.3	18.9	16.5	16.0	15.5

Table 24: Effective Duct Insulation R-value (R-4.2) by Duct Diameter in Inches – Ducts Raised 3.5 Inches from Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	R-30	17.9	16.5	14.1	12.7	11.9	11.4	11.1	10.5	10.1	9.8	10.3	9.4	9.3	9.1
	R-38	27.4	27.1	26.0	24.1	21.5	18.2	15.5	13.5	12.4	11.7	12.2	10.9	10.5	10.3
	R-44	34.3	34.8	34.3	33.1	31.2	28.8	25.7	18.1	15.2	13.7	14.1	12.2	11.7	11.3
	R-49	40.0	41.0	41.1	40.3	38.9	36.9	34.4	27.9	19.5	16.2	16.2	13.6	12.9	12.3
	R-60	52.5	54.6	55.6	55.8	55.2	54.1	52.4	47.9	41.7	33.9	31.0	18.9	16.7	15.4
Cellulose	R-30	10.6	10.1	9.8	9.6	9.4	9.2	9.1	8.9	8.7	8.6	9.1	8.4	8.3	8.2
	R-38	19.9	17.9	14.6	12.9	12.1	11.5	11.1	10.5	10.1	9.8	10.3	9.4	9.2	9.1
	R-44	26.9	25.9	23.8	20.5	16.3	14.4	13.4	12.2	11.4	10.9	11.3	10.2	10.0	9.8
	R-49	32.5	32.3	30.9	28.4	25.0	20.5	16.7	14.1	12.8	12.0	12.4	11.0	10.7	10.4
	R-60	44.7	45.8	45.7	44.5	42.4	39.6	36.1	26.6	18.0	15.5	15.6	13.2	12.5	12.0

Table 25: Effective Duct Insulation R-value (R-8) by Duct Diameter in Inches – Ducts Resting on Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	R-30	29.6	28.6	26.6	23.9	22.1	21.1	20.4	19.4	18.6	18.0	18.9	17.2	16.9	16.5
	R-38	41.1	41.0	39.9	38.0	35.4	32.4	28.8	24.4	22.4	21.2	21.9	19.5	19.0	18.5
	R-44	49.7	50.2	49.6	48.2	46.1	43.6	40.6	33.1	27.0	24.4	25.0	21.7	20.9	20.1
	R-49	56.8	57.8	57.6	56.5	54.8	52.6	50.0	43.4	35.2	28.6	28.6	24.0	22.9	21.8
	R-60	72.5	74.5	75.1	74.7	73.6	72.0	70.0	64.8	58.3	50.5	48.9	32.6	29.4	26.7
Cellulose	R-30	21.2	19.4	18.7	18.2	17.8	17.5	17.3	16.8	16.4	16.1	16.9	15.6	15.4	15.2
	R-38	32.5	31.1	28.4	24.5	22.6	21.5	20.7	19.5	18.7	18.1	18.9	17.2	16.8	16.5
	R-44	40.8	40.1	38.2	35.2	31.4	26.9	24.7	22.3	20.9	19.9	20.7	18.5	18.1	17.7
	R-49	47.6	47.5	46.2	43.8	40.5	36.5	31.7	25.6	23.2	21.7	22.4	19.8	19.2	18.7
	R-60	62.4	63.6	63.2	61.8	59.6	56.6	53.0	44.1	32.8	27.6	27.8	23.4	22.2	21.3

Table 26: Effective Duct Insulation R-value (R-6) by Duct Diameter in Inches – Ducts Resting on Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	R-30	32.3	31.1	29.0	26.2	22.7	20.5	19.3	17.8	16.8	16.1	16.8	15.1	14.7	14.4
	R-38	44.4	44.0	42.7	40.7	38.1	35.0	31.3	23.8	21.0	19.3	19.8	17.4	16.7	16.2
	R-44	53.5	53.6	52.8	51.2	49.1	46.4	43.3	35.8	26.8	23.0	23.1	19.6	18.6	17.8
	R-49	61.0	61.6	61.1	59.9	58.0	55.7	52.9	46.2	37.9	28.4	27.4	22.0	20.5	19.4
	R-60	77.5	79.0	79.2	78.6	77.4	75.6	73.4	68.0	61.3	53.4	51.9	33.4	27.4	24.6
Cellulose	R-30	24.5	21.7	18.8	17.6	16.8	16.3	15.9	15.0	14.6	14.2	14.9	13.6	13.4	13.2
	R-38	36.4	34.8	32.0	28.2	23.4	21.1	19.7	17.7	16.9	16.2	16.8	15.1	14.7	14.4
	R-44	45.1	44.2	42.2	39.2	35.3	30.6	25.3	20.7	19.2	18.0	18.5	16.4	15.9	15.5
	R-49	52.3	52.0	50.4	48.0	44.7	40.6	35.8	24.4	21.8	19.8	20.4	17.7	17.0	16.4
	R-60	68.0	68.8	68.2	66.6	64.3	61.2	57.5	46.1	36.9	26.9	26.4	21.4	20.0	19.0

Table 27: Effective Duct Insulation R-value (R-4.2) by Duct Diameter in Inches – Ducts Resting on Ceiling Floor

Attic Insulation	Rating	4"	5"	6"	7"	8"	9"	10"	12"	14"	16"	18"	20"	22"	24"
Fiberglass	R-30	37.0	35.5	33.2	30.2	26.6	22.3	18.2	15.2	13.8	12.9	13.3	11.7	11.3	11.0
	R-38	50.1	49.3	47.6	45.3	42.5	39.2	35.4	26.3	18.7	16.2	16.4	13.8	13.1	12.5
	R-44	59.8	59.5	58.3	56.3	54.0	51.1	47.8	40.0	30.5	21.0	20.3	16.0	14.9	14.0
	R-49	67.9	67.9	67.0	65.4	63.3	60.7	57.7	50.7	42.3	32.2	27.9	18.7	16.8	15.5
	R-60	85.7	86.5	86.1	85.0	83.4	81.4	78.9	73.2	66.2	58.1	56.9	38.0	26.0	21.2
Cellulose	R-30	30.2	27.3	23.3	18.1	15.6	14.3	13.4	12.3	11.6	11.1	11.5	10.4	10.2	10.0
	R-38	43.1	41.3	38.4	34.5	29.7	23.9	18.9	15.5	13.9	12.9	13.3	11.7	11.3	11.0
	R-44	52.7	51.5	49.2	45.9	41.9	37.2	31.6	20.0	16.5	14.8	15.0	12.9	12.3	11.9
	R-49	60.5	59.8	58.0	55.2	51.7	47.5	42.6	30.6	20.0	16.9	16.9	14.1	13.3	12.7
	R-60	77.7	78.0	76.9	74.9	72.3	69.0	65.1	55.7	44.1	29.6	25.0	18.0	16.2	15.1

2.3.1.3 Statewide Energy Savings Methodology

The per-unit energy impacts were extrapolated to statewide impacts using the Statewide Construction Forecasts that the CEC provided. The Statewide Construction Forecasts estimate new construction/additions that would occur in 2026, the first year that the 2025 Title 24, Part 6 requirements are in effect. The construction forecast provides construction (new construction/additions and existing building stock) by building type and climate zone, as shown in Appendix A.

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

2.3.2 Per-Unit Energy Impacts Results

Energy savings and peak demand reductions per unit are presented in through Table 32. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates.

Per-unit electricity savings for the first year, shown in , are expected to range from -29 to 137 kWh per year. All savings are positive except for Climate Zone 16. The reason for negative electricity savings in Climate Zone 16 is that removing the roof deck insulation and burying the ducts results in significant heating savings but comes with a slight increase in cooling energy use. As seen in Table 29, the proposed measure reduces peak demand in electricity up to 0.054.

Energy savings benefits may have potential to disproportionately impact DIPs. Refer to Section 4 for more details addressing energy equity and environmental justice.

Table 28: First Year Electricity Savings (kWh) Per Home – Buried Ducts

Climate Zone	2100/2700 Weighted New Construction *Electricity Savings (kWh)*	500 Square Foot Small Home New Construction *Electricity Savings (kWh)*
1	20	1
2	11	4
3	137	12
4	n/a	n/a
5	10	0
6	14	4
7	25	6
8	n/a	n/a
9	n/a	n/a
10	n/a	n/a
11	n/a	n/a
12	n/a	n/a
13	n/a	n/a
14	n/a	n/a
15	n/a	n/a
16	-17	-29

Table 29: First Year Peak Demand Reduction (kW) Per Home – Buried Ducts

Climate Zone	2100/2700 Weighted New Construction *Peak Demand Reduction (kWh)*	500 Square Foot Small Home New Construction *Peak Demand Reduction (kWh)*
1	0.003	0.001
2	0.001	0.000
3	0.054	0.005
4	n/a	n/a
5	0.002	0.000
6	0.001	0.000
7	0.001	0.000
8	n/a	n/a
9	n/a	n/a
10	n/a	n/a
11	n/a	n/a
12	n/a	n/a
13	n/a	n/a
14	n/a	n/a
15	n/a	n/a
16	0.001	-0.001

Table 30: First Year Natural Gas Savings (therms) Per Home – Buried Ducts

Climate Zone	2100/2700 Weighted New Construction *Natural Gas Savings (therms)*	500 Square Foot Small Home New Construction *Natural Gas Savings (therms)*
1	29.9	1.8
2	15.3	0.7
3	0.0	0.0
4	n/a	n/a
5	13.4	0.3
6	5.1	0.0
7	4.3	0.0
8	n/a	n/a
9	n/a	n/a
10	n/a	n/a
11	n/a	n/a
12	n/a	n/a
13	n/a	n/a
14	n/a	n/a
15	n/a	n/a
16	11.8	-1.2

Table 31: First Year Source Energy Savings (kBtu) Per Home – Buried Ducts

Climate Zone	2100/2700 Weighted New Construction *Source Energy Savings (kBtu)*	500 Square Foot Small Home New Construction *Source Energy Savings (kBtu)*
1	2,851	165
2	1,459	65
3	503	45
4	n/a	n/a
5	1,291	20
6	506	5
7	422	10
8	n/a	n/a
9	n/a	n/a
10	n/a	n/a
11	n/a	n/a
12	n/a	n/a
13	n/a	n/a
14	n/a	n/a
15	n/a	n/a
16	1,068	-135

Table 32: First Year Long-term Systemwide Cost Savings (2026 PV$) Per Home – Buried Ducts

Climate Zone	2100/2700 Weighted New Construction *LSC Savings (2026 PV$)*	500 Square Foot Small Home New Construction *LSC Savings (2026 PV$)*
1	$3,982	$235
2	$2,076	$120
3	$1,239	$115
4	n/a	n/a
5	$1,839	$40
6	$764	$35
7	$799	$50
8	n/a	n/a
9	n/a	n/a
10	n/a	n/a
11	n/a	n/a
12	n/a	n/a
13	n/a	n/a
14	n/a	n/a
15	n/a	n/a
16	$1,403	-$305

2.4 Cost and Cost Effectiveness

2.4.1 Energy Cost Savings Methodology

Energy cost savings were calculated by applying the LSC hourly factors to the energy savings estimates that were derived using the methodology described in Section 2.3.1. LSC hourly factors are a normalized metric to calculate energy cost savings that accounts for the variable cost of electricity and natural gas for each hour of the year, along with how costs are expected to change over the 30-year period of analysis.

The CEC requested LSC savings over the 30-year period of analysis in both 2026 present value dollars (2026 PV$) and nominal dollars. The cost-effectiveness analysis uses LSC values in 2026 PV$. Costs and cost effectiveness using 2026 PV$ are presented in this section of the report. CEC uses results in nominal dollars to complete the Economic and Fiscal Impacts Statement (From 399) for the entire package of proposed change to Title 24, Part 6. Table 33 presents LSC savings results in nominal dollars.

2.4.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings and additions in terms of LSC savings realized over the 30-year period of analysis are presented as 2026 present value dollars (2026 PV$) in Table 33 and Table 34.

According to the LSC values, there are savings in all climate zones where buried ducts are proposed as the new prescriptive Option B and standard design. However, a negative saving is seen in Climate Zone 16 for 500 Square Foot Small Home.

Any time code changes impact cost, there is potential to disproportionately impact DIPs. Refer to Section 4 for more details addressing energy equity and environmental justice.

Table 33: 2026 PV LSC Savings Over 30-Year Period of Analysis – Per Home – New Construction and Additions – 2100/2700 Weighted

Climate Zone	30-Year LSC Electricity Savings (2026 PV$)	30-Year LSC Natural Gas Savings (2026 PV$)	Total 30-Year LSC Savings (2026 PV$)
1	$154	$3,828	$3,982
2	$80	$1,996	$2,076
3	$1,239	$0	$1,239
4	n/a	n/a	n/a
5	$80	$1,759	$1,839
6	$105	$660	$764
7	$234	$565	$799
8	n/a	n/a	n/a
9	n/a	n/a	n/a
10	n/a	n/a	n/a
11	n/a	n/a	n/a
12	n/a	n/a	n/a
13	n/a	n/a	n/a
14	n/a	n/a	n/a
15	n/a	n/a	n/a
16	-$80	$1,483	$1,403

Table 34: 2026 PV LSC Savings Over 30-Year Period of Analysis – Per Home – New Construction and Additions –Small Home

Climate Zone	30-Year LSC Electricity Savings (2026 PV$)	30-Year LSC Natural Gas Savings (2026 PV$)	Total 30-Year LSC Savings (2026 PV$)
1	$10	$225	$235
2	$30	$90	$120
3	$115	$0	$115
4	n/a	n/a	n/a
5	$5	$35	$40
6	$35	$0	$35
7	$50	$0	$50
8	n/a	n/a	n/a
9	n/a	n/a	n/a
10	n/a	n/a	n/a
11	n/a	n/a	n/a
12	n/a	n/a	n/a
13	n/a	n/a	n/a
14	n/a	n/a	n/a
15	n/a	n/a	n/a
16	-$155	-$150	-$305

2.4.3 Incremental First Cost

A breakdown of incremental costs is presented in Table 35, with details provided below. Total incremental costs will depend on climate zone, base insulation material, and other project-related factors.

Table 35: Incremental First Cost Components, Buried Ducts (Savings Presented as Negative Values)

Component	Impacted Climate Zones	Cost
R-49 vs. R-30 Insulation	3, 5-7	$0.44 per ft^2 ceiling area
R-49 vs. R-38 Insulation	1 and 2	$0.28 per ft^2 ceiling area
R-60 vs. R-38 Insulation	16	$0.55 per ft^2 ceiling area
Radiant Barrier	1, 16	$0.10 per ft^2 roof area
Roof Deck Insulation	16	-$0.75 per ft^2 roof area
Duct Design & Burial	All	-$0.652 per ft^2 duct surface area
R-6 vs. R-8 Ducts	1, 2 and 16	-$0.489 per ft^2 duct surface area
HERS Verification	All	$300 per home

Buried ducts will require more ceiling insulation than what is currently required and will therefore somewhat increase installation time together with cost of additional insulation material. For this analysis, the incremental cost from increasing attic insulation levels from R-30 to R-49 is estimated at $0.44 per square foot of ceiling area (Statewide CASE Team 2020a). Likewise, the associated incremental cost of increasing R-value from 38 to 49 is estimated at $0.28 per square foot, and $0.55 from R-38 to R-60 (Statewide CASE Team 2020a). The incremental cost includes both labor and materials.

Radiant barriers are also added to the prescriptive package for Climate Zones 1 and 16. Radiant barriers typically come pre-attached to OSB sheathing boards, which generally cost slightly more than bare sheathing. An online search of Tech Shield products (the primary manufacturer of radiant barrier sheathing) yields an incremental cost of $2.00-$3.00 for a four-by-eight-foot board (or $0.06-$0.09 per square foot). For more complicated roofing structures, the price may be up to roughly 20% higher as larger amounts of sheathing overlap are needed at roofing junctions to ensure adequate coverage at irregular roof angles. As a conservative estimate of costs, $0.10 per square foot is used in this analysis.

Not installing R-19 roof deck insulation in Climate Zone 16 is estimated to result in a cost savings of $0.78 per square foot of roof deck area. This is based on data presented in the 2019 HPA CASE Report (Statewide CASE Team 2017) along with data collected directly from builders during the 2019 CASE process and used by the Statewide Reach Codes Team in 2019 reach code cost-effectiveness studies for low-rise residential new construction (Statewide Reach Code Team 2019).

Regarding duct den, a proper duct design will allow installers to make cuts that are less wasteful and re-use duct lengths previously cut, as previously discussed in Section 2.2.2.2. In addition, a proper duct design will optimize duct runs, up to 40% according to a stakeholder. Resting ducts flat rather than suspended also slightly reduces the total duct length, and thus the associated cost. In addition, savings can be claimed on labor from not suspending the ducts, and from less strapping materials. Though, ducts would have to be secured to the bottom trusses, less strapping is needed because the ducts also rest on, and supported by, the trusses. In all, the incremental savings are estimated at $1.14 per foot length of duct manufacturer’s cost, strapping material and 0.5 hours of less labor compared to suspending ducts.

Prescriptive duct insulation is reduced from R-8 to R-6 in Climate Zones 1, 2, and 16. The estimated incremental cost used in this an7alysis is $0.489 per square foot of duct surface area for material and no incremental labor cost (Statewide CASE Team 2020a).

The proposed measure may require an additional HERS inspection because verification will be divided into two steps, the first to test for leakage before insulation is applied, and the second to verify that sealing at register boots and air handler connections is properly done and that ducts are not exposed. The incremental cost for this inspection is assumed to be $300. However, it is likely that the first inspection could be performed at the time of duct leakage testing and the second inspection at the time of QII verification.

2.4.4 Incremental Maintenance and Replacement Costs

Buried ducts are expected to have a useful life greater than the 30-year period of analysis. Therefore, there are no replacement costs included in this analysis. Protecting ducts from extreme attic temperatures, as when they are in conditioned space, is anticipated to extend the life of the plastic jacketing. No incremental maintenance cost was assumed in this code change proposal, as there would be no unique maintenance needed for buried vs. non-buried ducts.

2.4.5 Cost Effectiveness

The CEC establishes the procedures for calculating cost effectiveness. The Statewide CASE Team collaborated with CEC staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. The incremental first cost and incremental maintenance costs over the 30-year period of analysis were included. The LSC savings from electricity and natural gas were also included in the evaluation. Design costs were not included nor were the incremental costs of code compliance verification.

According to the CEC's definitions, a measure is cost effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the cost benefits realized over 30 years by the total incremental costs, which includes maintenance costs for 30 years. The B/C ratio was calculated using 2026 PV costs and cost savings.

Results of the per-unit cost effectiveness analysis are presented in Table 36 for the 2100/2700 weighted new construction prototype and Table 37 for the small home prototype.

The code change is cost effective in every climate zone where it is proposed for the 2100/2700 weighted new construction prototype. The proposal for homes 500 square feet and less is not cost-effective in Climate Zones 6 and 16. However, these two cases are very close to being cost-effective and the 30-year cost impact is very small.

Table 36: 30-Year Cost Effectiveness Summary Per Home – New Construction/Additions – 2100/2700 Weighted

Climate Zone	Benefits LSC Savings + Other PV Savings[a] (2026 PV$)	Costs Total Incremental PV Costs[b] (2026 PV$)	Benefit-to-Cost Ratio
1	$3,982	$272	14.64
2	$2,076	$65	32.16
3	$1,239	$523	2.37
4	n/a	n/a	n/a
5	$1,839	$523	3.51
6	$764	$523	1.46
7	$799	$523	1.53
8	n/a	n/a	n/a
9	n/a	n/a	n/a
10	n/a	n/a	n/a
11	n/a	n/a	n/a
12	n/a	n/a	n/a
13	n/a	n/a	n/a
14	n/a	n/a	n/a
15	n/a	n/a	n/a
16	$1,403	($984)	infinite

a. **Benefits: Long-term Systemwide Cost Savings + Other PV Savings:** Benefits include LSC savings over the period of analysis (Energy + Environmental Economics 2016, 51-53)Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost, incremental PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs, and incremental residual value if proposed residual value is greater than current residual value at end of CASE analysis period.

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

Table 37: 30-Year Cost Effectiveness Summary Per Home – New Construction/Additions – Small Home

Climate Zone	Benefits LSC Savings + Other PV Savings[a] (2026 PV$)	Costs Total Incremental PV Costs[b] (2026 PV$)	Benefit-to-Cost Ratio
1	$235	$127	1.85
2	$120	$67	1.79
3	$115	$106	1.08
4	n/a	n/a	n/a
5	$40	$40	1.01
6	$35	$40	0.89
7	$50	$40	1.26
8	n/a	n/a	n/a
9	n/a	n/a	n/a
10	n/a	n/a	n/a
11	n/a	n/a	n/a
12	n/a	n/a	n/a
13	n/a	n/a	n/a
14	n/a	n/a	n/a
15	n/a	n/a	n/a
16	-$305	-$271	0.89

a. **Benefits: Long-term Systemwide Cost Savings + Other PV Savings:** Benefits include LSC savings over the period of analysis (Energy + Environmental Economics 2016, 51-53)Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost, incremental PV maintenance cost savings if PV of proposed maintenance costs is less than PV of current maintenance costs, and incremental residual value if proposed residual value is greater than current residual value at end of CASE analysis period.

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

2.5 First-Year Statewide Impacts

2.5.1 Statewide Energy and Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction and additions by multiplying the per-unit savings, which are presented in Section 2.3.2, by assumptions about the percentage of newly constructed buildings that would be impacted by the proposed code. The statewide new construction forecast for 2026 is presented in Appendix A, as are the Statewide CASE Team’s assumptions about the percentage of new construction that would be impacted by the proposal (by climate zone and building type).

The first-year energy impacts calculation takes the number of buildings that were completed in 2026 and estimates the total savings realized within their first year of operation. The 30-year energy cost savings represent the energy cost savings over the entire 30-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

The tables below present the first-year statewide energy and energy cost savings from newly constructed buildings and additions (Table 38) by climate zone. Total values not listed by climate zone are shown in Table 39.

While a statewide analysis is crucial to understanding broader effects of code change proposals, there is potential to disproportionately impact populations that needs to be considered. Refer to Section 4 for more details addressing energy equity and environmental justice.

Table 38: Statewide Energy and Energy Cost Impacts – New Construction and Additions

Climate Zone	Statewide New Construction & Additions Impacted by Proposed Change in 2026 (Buildings)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2026 PV$)
1	359	0.01	0.00	0.01	0.97	$1.36
2	1,861	0.02	0.00	0.03	2.56	$3.64
3	3,035	0.41	0.16	0.00	1.44	$3.55
4	n/a	n/a	n/a	n/a	n/a	n/a
5	616	0.01	0.00	0.01	0.75	$1.06
6	1,719	0.02	0.00	0.01	0.83	$1.25
7	1,869	0.05	0.00	0.01	0.75	$1.42
8	n/a	n/a	n/a	n/a	n/a	n/a
9	n/a	n/a	n/a	n/a	n/a	n/a
10	n/a	n/a	n/a	n/a	n/a	n/a
11	n/a	n/a	n/a	n/a	n/a	n/a
12	n/a	n/a	n/a	n/a	n/a	n/a
13	n/a	n/a	n/a	n/a	n/a	n/a
14	n/a	n/a	n/a	n/a	n/a	n/a
15	n/a	n/a	n/a	n/a	n/a	n/a
16	1,937	-0.03	0.00	0.02	1.95	$2.55
Total	**11,396**	**0.48**	**0.17**	**0.09**	**9.24**	**$14.83**

a. First-year savings from all buildings completed statewide in 2026.

Table 39: Statewide Energy and Energy Cost Impacts – New Construction, Additions, and Alterations

Construction Type	First-Year Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (Million Therms)	First-Year Source Energy Savings (Million kBtu)	30-Year Present Valued LSC Savings (Million 2026 PV$)
New Construction & Additions	0.48	0.17	0.09	9.24	$14.83

Note: First-year savings from all alterations completed statewide in 2026.

2.5.2 Statewide Greenhouse Gas (GHG) Emissions Reductions

The Statewide CASE Team calculated avoided GHG emissions associated with energy consumption using the hourly GHG emissions factors that CEC developed along with the 2025 LSC hourly factors and an assumed cost of $123.15 per metric ton of carbon dioxide equivalent emissions (metric tons CO2e). (California Energy Commission 2020)

The monetary value of avoided GHG emissions is based on a proxy for permit costs (not social costs).[16] The Cost effectiveness Analysis presented in Section 0 of this report does not include the cost savings from avoided GHG emissions. To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the other economic impacts.

Table 40 below presents the estimated first-year avoided GHG emissions of the proposed code change. During the first year, GHG emissions of 537,450 metric tons CO2e would be avoided.

Table 40 First-Year Statewide GHG Emissions Impacts

Electricity Savings[a] (GWh/yr)	Reduced GHG Emissions from Electricity Savings (Metric Tons CO2e)	Natural Gas Savings[a] (Million Therms/yr)	Reduced GHG Emissions from Natural Gas Savings (Metric Tons CO2e)	Total Reduced GHG Emissions[b] (Metric Ton CO2e)	Total Monetary Value of Reduced GHG Emissions[c] ($)
0.48	84	0.09	499	583	$71,822

a. First-year savings from all applicable newly constructed buildings, additions, and alterations completed statewide in 2026.

b. GHG emissions savings were calculated using hourly GHG emissions factors published alongside the LSC hourly factors and Source Energy hourly factors by CEC here: https://www.energy.ca.gov/files/2025-energy-code-hourly-factors

[16] The permit cost of carbon is equivalent to the market value of a unit of GHG emissions in the California Cap-and-Trade program, while social cost of carbon is an estimate of the total economic value of damage done per unit of GHG emissions. Social costs tend to be greater than permit costs. See more on the Cap-and-Trade Program on the California Air Resources Board website: https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program.

c. The monetary value of avoided GHG emissions is based on a proxy for permit costs (not social costs) derived from the 2022 TDV Update Model published by CEC here: https://www.energy.ca.gov/files/tdv-2022-update-model

2.5.3 Statewide Water Use Impacts

The proposed code change will not result in water savings.

2.5.4 Statewide Material Impacts

As discussed in section 2.2.3.1, this proposal may have minor impacts in the type and amount of insulation produces for the California market, however being produced outside of California renders this moot from a statewide material impacts perspective, Section 2.2.3.1 also discusses how burying ducts properly poses an opportunity to reduce wasted duct material from unnecessary lengths or poor equipment placement, however the impact is expected to be marginal on a statewide level.

2.5.5 Other Non-Energy Impacts

Possible non-energy benefits from buried ducts include increased occupant comfort due to more effective conditioning and delivery of air, decreased likelihood of moisture build-up through improved duct insulation, and improved indoor environmental quality resulting from dedicated air filters within each duct and/or possible mold prevention due to the aforementioned moisture control.

3. Cathedral Ceilings

3.1 Measure Description

3.1.1 Proposed Code Change

This proposed code change outlines a new alternative prescriptive compliance pathway for constructing cathedral ceilings – otherwise known as cathedral roofs, or rafter roofs – in single-family new construction and additions. Cathedral ceilings are exterior assemblies where the interior ceiling surface is parallel to the roof surface and separated by framing. They are not to be associated with vaulted ceilings for which the ceiling is dropped below the roof construction and does not align with the roof pitch. Cathedral ceilings be flat or sloped as well as vented or unvented. With no prescriptive path for cathedral ceilings in the current code, builders must use the performance pathway.

This proposal would add a new prescriptive option to Table 150.1-A. Cathedral ceilings would be required to have a maximum U-factor of 0.026 (or a minimum R-value of 38) across all California Climate Zones. In addition to the insulation requirements, the proposal requires compliance with Section 150.1(c)9B, which requires Verified Low Leakage Ducts in Conditioned Space, per Residential Reference Appendix Section RA3.1.4.3.8. The R-38 insulation requirement was defined based on equivalency with Option B of Table 150.1-A, Chapter 8 of Title 24, Part 6.

As a prescriptive alternative path to cathedral ceiling construction, adherence to these guidelines is optional for builders. The proposed code additions will not modify field verification tests since cathedral ceilings are a common roof design and already constructed and verified regularly. This proposal simply codifies guidelines to reach equivalent performance with other prescriptive options.

CBECC-Res and other modeling software currently have the capacity to model cathedral ceilings. This process would remain unchanged, however using the performance approach a project with a cathedral ceiling would be compared against a baseline with a cathedral ceiling that meets the proposed prescriptive requirements.

3.1.2 Justification and Background Information

3.1.2.1 Justification

Cathedral ceilings are a regularly employed design for many single-family homes. They are also becoming increasingly common with the growing stock of small homes and Accessory Dwelling Units (ADUs) as they allow small spaces to feel and look larger, a trend that is expected to continue in California (UC Berkeley Center for Community

Innovation 2021). The structure of cathedral ceilings lends itself to unique considerations regarding insulation, making roof deck (above or below) insulation the industry standard. This proposal would provide a clear compliance path for homes with cathedral ceilings allowing projects more flexibility in choosing compliance approaches and providing clear minimum requirements to meet code, benefitting market actors like designers, builders, and insulation installers. Stakeholder support was voiced for this proposal during the February 14, 2023 Utility Sponsored Stakeholder Meeting (Statewide CASE Team 2023) and the October 27, 2022 residential Welcome to the 2025 Energy Code Cycle Stakeholder Meeting (Statewide CASE Team 2022). This may particularly benefit small homes or accessory dwelling units (ADUs), as discussed in the following section.

This proposal complements past code development such as the High-Performance Attics prescriptive compliance path introduced in the 2016 code cycle (Statewide CASE Team 2015) and the follow-on attic proposals introduced in the 2019 cycle (Statewide CASE Team 2017).

3.1.2.2 Background Information

Architectural features such as cathedral ceilings increase the overall building envelope area without increasing the conditioned floor area, calling for higher requirements in thermal insulation compared to traditional attic insulation. This is to say that, if not properly designed, cathedral ceilings can result in an increased thermal load from the outdoor environment and thus higher demand for heating and cooling. However, with cathedral ceilings, HVAC ducts are often in conditioned space which reduces HVAC distribution losses.

As of now, there are no specific code requirements for insulation levels in cathedral ceilings. During initial outreach to stakeholders early in the 2025 code cycle the Statewide CASE Team discussed measure proposals with a small group of small home/ADU advocates and members of the design community. One issue that was identified was that small homes with cathedral ceilings receive a penalty in the performance model which can be challenging to overcome. Cathedral ceilings, coupled with ductless HVAC systems, are common in small homes for various space-optimizing reasons. For smaller homes with cathedral ceilings, the roof design and geometry may also prevent from running ducts in the space above the roof bridge.

With housing supply and affordability, a growing concern statewide and beyond, more small homes and ADUs are being constructed. This measure addresses this growing trend by developing a reasonable prescriptive path for this design feature. Unlike single family construction, which is often characterized by relatively large subdivisions and use of the performance compliance pathway, ADU’s are often constructed as a remodel from an unconditioned garage to a conditioned ADU. As such, there is a desire for “cookbook” approaches towards these types of projects.

Hence, this measure presents an alternative prescriptive approach for roofs constructed with a cathedral ceiling. The intent is not to impact overall energy demand nor demand response nor management compared to current code.

3.1.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the Energy Code, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents would be modified by the proposed change.[17] See Section 5 of this report for detailed proposed revisions to code language.

3.1.3.1 Specific Purpose and Necessity of Proposed Code Changes

Each proposed change to language in Title 24, Part 6 is described below. See Section 5.2 of this report for marked-up code language.

Section: 100.1

Specific Purpose: Add a definition of cathedral ceilings.

Necessity: This change is necessary to clarify what assemblies qualify as cathedral assemblies.

Section: 150.1(c)1A

Specific Purpose: Add a prescriptive option D which outlines ceiling insulation requirements for cathedral ceiling assemblies referenced by climate zone in Table 150.1-A.

Necessity: This change is necessary to enable compliance through a prescriptive option for cathedral ceiling construction.

Section: Table 150.1-A

Specific Purpose: Update values to include a prescriptive option D with maximum required ceiling insulation U-factors by climate zone. Revisions and additions are also required in the accompanying footnotes.

Necessity: This change is necessary to enable compliance through a prescriptive option for cathedral ceiling construction.

[17] Visit EnergyCodeAce.com for trainings, tools and resources to help people understand existing code requirements.

3.1.3.2 Specific Purpose and Necessity of Changes to the Single-Family Residential ACM Reference Manual

The purpose and necessity of proposed changes to the Single-Family Residential ACM Reference Manual are described below. See Section 5.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Section: Section 2.5.6.1

Specific Purpose: Modify the proposed design to reflect the presence of a cathedral ceiling and its adherence to the U-factor requirements in Option D from Section 150.1(c) and Table 150.1-A for the applicable climate zone.

Necessity: This change is necessary to model the energy impacts resulting from the U-factors in Option D from Section 150.1(c) and Table 150.1-A.

3.1.3.3 Summary of Changes to the Single-Family Residential Compliance Manual

Sections 3.2, 3.4.1, 3.5.3, and 3.6 of the Single-Family Residential Compliance Manual would need to be revised. Changes would describe the new prescriptive compliance path and discuss acceptable approaches to meeting the insulation requirements.

3.1.3.4 Summary of Changes to Compliance Documents

Relevant compliance documents would need to be revised to reflect the addition of Option D from Section 150.1(c) and Table 150.1-A including its specific requirements. This includes forms used under the prescriptive pathway, including CF1R-NCB-01-E and CF2R-ENV-03-E (Insulation Installation) for newly constructed buildings, and forms CF1R-ADD-01-E, CF1R-ADD-02-E, and CF2R-ADD-02-E for prescriptive additions.

3.1.4 Regulatory Context

3.1.4.1 Determination of Inconsistency or Incompatibility with Existing State Laws and Regulations

This proposal is compatible with the cathedral ceiling requirements in Chapter 8 of the California Residential Code (CRC) (the International Residential Code with California amendments).[18] See Section 3.2.2 for further discussion on the CRC requirements. Changes to Title 24 outside of Part 6 are not needed. In addition, there are no relevant state or local laws or regulations.

3.1.4.2 Duplication or Conflicts with Federal Laws and Regulations

There are no relevant federal laws or regulations.

[18] https://up.codes/viewer/california/ca-residential-code-2022/chapter/8/roof-ceiling-construction#8

3.1.4.3 Difference From Existing Model Codes and Industry Standards

Section R402.2.2 of the 2021 International Energy Conservation Code (IECC) provides a prescriptive path for structures with no or limited attic spaces, such as cathedral ceilings, requiring R-30 insulation in all IECC climate zones; for all but climate zone 1 this reflects a reduction of what is otherwise prescriptively required (ranging from R-38 to R-49 depending on IECC climate zone). There are no other relevant industry standards or model codes.

3.1.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how to comply with the proposed code change. It also describes the compliance verification process. Section 5 shows specific changes to existing code language and Appendix E presents how the proposed changes could impact various market actors.

The compliance verification activities related to this measure that need to occur during each phase of the project are described below:

- **Design Phase:** In coordination with the homeowner, the architect/designer and/or builder utilizing the prescriptive compliance pathway specifies a ceiling and roof assembly that meets the requirements specified in Subchapter 8, Section 150.1(c)1 and Table 150.1-A.
- **Permit Application Phase:** The design professional, contractor, or homeowner applies for a permit with the applicable jurisdiction and completes, signs, and submits the necessary CF1R documents.
- **Construction Phase:** The cathedral ceiling is constructed, typically by a general contractor, rough carpenter and/or roofer.
- **Inspection Phase:** The design professional, contractor, or homeowner submits the needed Certificates of Installation (CF2R documents) and proceeds to complete necessary inspections.

The compliance process described above does not differ from the existing compliance process for cathedral ceiling construction. Also unchanged is the user experience of the modeling software, as it already contains a design option for cathedral ceilings. It is possible that the scope of inspections will expand to include ceiling insulation where it would not otherwise, as stakeholders have indicated that inspectors do not look at unvented cathedral ceiling specifications.

No challenges to compliance and enforcement have been identified, either by the Statewide CASE Team or engaged stakeholders.

3.2 Market Analysis

3.2.1 Current 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, CEC 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 February 14, 2023 (Statewide CASE Team 2023).

The market for architectural features such as cathedral ceilings is well established in terms of materials and labor, as such features have been regularly employed in home construction for many years. As with other residential ceilings, cathedral ceilings are designed by an architect, designer, or builder, and are constructed by a general contractor or rough carpenter and/or roofer. Other relevant market actors, such as manufacturers and compliance officials, would be the same as other ceiling and roof related construction. The same holds for materials and processes used to construct cathedral ceilings. In fact, this code change proposal is in part a response to current market conditions rather than an attempt to create new market drivers.

3.2.2 Technical Feasibility and Market Availability

As described in the previous section, the market for cathedral ceilings is mature, with materials and labor readily available across numerous market actors. However, the following technical and practical considerations have been identified by the Statewide CASE Team, with stakeholder input.

The structural design of cathedral ceilings will govern where the thermal insulation can be installed. For cathedral ceilings directly aligned with the roof slope, insulation can be installed between the roof rafters (cavity insulation) and/or as continuous (rigid) insulation above or below the roof deck. Vaulted ceilings, for example those constructed with scissor trusses, where the ceiling is not in the same plane as the roof, are not considered cathedral ceilings. These often have vented attic spaces above, and if so, are modeled as an attic construction in the CBECC-Res compliance software.

Stakeholder feedback indicates that when constructing unvented/sealed roofs, standard practice is to add two inches of closed cell spray foam (CCSF), as required to prevent condensation at surface of sheathing, with the remaining required R-value typically consisting of batt insulation and sometimes rigid insulation. The two inches of spray foam results in an R-value of 10 to 14 (h·ft^2·°F/Btu) depending on type of spray foam and will require additional batt- or rigid insulation to achieve R-38. For batt insulation only, R-38 will require large rafter dimensions, typically 2 x 12 inches or greater. Accommodation of this level of batt insulation is generally feasible for ceiling rafters in larger homes. Smaller homes however, may use 2x8 rafters due to the lower load-bearing needs, thus alternative insulation strategies must be considered, such as spray foam, and/or a combination with continuous insulation.

There are no differences in insulation requirements as to whether the cathedral ceiling is vented or unvented/sealed. When vented, ventilation requirements between the insulation material and the roof sheathing will result in a small air exchange, though not significantly large to reduce the heat flow between the roof surface and the inside of the cathedral ceiling. Thus, the requirement of R-38 remains the same regardless of level of ventilation.

Through other research done by the Statewide CASE team, including interviews with multiple architects, the following technical or market considerations were identified:

- Venting issues and questions of vapor barrier efficacy. Several architects don't design vented assemblies anymore.
- Rigid above deck insulation can drive up costs from qualified installers and may add installation complexities depending on architectural features.
- Roof rafter dimensions in existing buildings may reduce insulation material options or require framing alterations. However, this proposal does not impact alterations.

These considerations are not new to builders familiar with cathedral ceiling construction but may be for others as they become acquainted with the proposed code.

When properly built and insulated, cathedral ceilings can offer increased occupant comfort by ensuring adequate insulation levels, without compromising the aesthetic appeal of cathedral ceilings (the primary driver of this roof construction type). As with typical ceiling construction, minimal maintenance is needed to retain these benefits over time.

Cathedral ceilings have been susceptible to accumulated moisture in hot and humid climates if not properly designed (Boudreaux, Pallin Jackson 2013). For this reason, any thermal insulation code requirements that do not specifically define material properties can result in structural decay of sheathing and other wood-based components. In preparation for the 2016 Title 24, Part 6 code cycle, Lawrence Berkeley National Laboratory conducted a literature review of thermal, moisture, and energy performance of sealed attics (Less, Walker Levinson 2016). Sealed attics may very much resemble a cathedral ceiling since the roof rafter cavities are insulated. The take-away from the literature review was that the moisture risk in sealed and insulated California attics will increase with colder climate regions and more humid outside air in marine zones. Risk is considered low in the hot-dry, highly populated regions of California, where most new home construction occurs. The report also recommended that the air impermeable insulation requirements of the International Residential Code (2012) be used.

This proposal for a prescriptive cathedral ceiling path applies to both vented and unvented assemblies. As discussed in section 3.1.4.3, cathedral ceilings must meet both the insulation levels required to meet energy code compliance (currently as documented in the performance compliance report) as well as applicable requirements from Chapter 8 of the California Residential Code (CRC) (the International Residential Code – or IRC – with California amendments)[19] which addresses moisture issues associated with attics and cathedral ceilings. The relevant CRC requirements are as follows:

- If the cathedral ceiling is vented, each space (rafter bay) is separately cross-ventilated, [§R806.1] this will typically be a vent at the top and bottom of the rafter bay and minimum net free ventilation area shall be 1/300th of the vented space. [Exception 2§R806.2] Additionally "Not less than a 1-inch (25 mm) space shall be provided between the insulation and the roof sheathing and at the location of the vent." [§R806.3]
- If the cathedral ceiling is unvented, CRC Section R806.5 applies to what is called "unvented enclosed rafter assemblies." Primary requirements include:
    - "Interior Class I vapor retarders are not installed …on the ceiling side of the unvented enclosed roof framing assembly." Class I vapor retarders have extremely low vapor permeability (≤0.1 perms) and would trap moisture in the assembly if placed in the bottom of the cavity.
    - Sufficient air impermeable insulation is required to be installed above or below the roof deck to prevent moisture on the impermeable layer or on the roof deck. For cavities with a combination of impermeable (rigid sheet insulation or closed cell spay insulation) and air-permeable insulation, requirements can be seen in Tables R806.5 and R702.7(5) of the CRC. They show that air impermeable insulation layers must be at least R-5 for most of the state and R-10 in IRC climate zone 4B (Amador, Calaveras, El Dorado, Inyo, Lake, Mariposa, Trinity, Tuolumne), R-15 in CZ 4C (Del Norte, Humboldt), R-20 in CZ 5 (Lassen, Nevada, Plumas, Siskiyou), and R-25 in CZ 6 (Alpine, Mono). The impermeable insulation assembly is adjacent to the underside of the roof deck and the permeable insulation is directly underneath the impermeable insulation.

[19] https://up.codes/viewer/california/ca-residential-code-2022/chapter/8/roof-ceiling-construction#8

- If insulation is placed above the roof deck, enough must be installed to maintain the monthly average temperature of the underside of the structural roof sheathing above 45°F (this assumes an interior air temperature of 68°F and an exterior air temperature equal to the average outside air temperature of the three coldest months in the year). Because the roof deck temperature is a function of the ratio of the above deck to below deck insulation levels, more insulation placed below the roof deck means that more insulation is needed above the roof deck to meet this requirement.

For simple roofs where each rafter bay is unobstructed from the bottom of the roof to the top of the ridgeline, a ventilated cathedral ceiling is feasible to construct. When the rafter bays are broken up by hip roofs, dormers, skylights etc., it is more feasible to construct unvented enclosed rafter assemblies.

In some cases, vented assemblies may not be able to meet the proposed prescriptive requirements with cavity insulation alone. An air gap of at least one inch is required between the insulation and the roof sheathing, which is equivalent to about R-3.5 for fiberglass batt insulation. In these instances, designers can either increase the depth of the framing to fit more cavity insulation or apply a small amount of continuous above roof deck insulation.

3.2.3 Market Impacts and Economic Assessments

The code change proposal introduces prescriptive alternative requirements that are equivalent to existing prescriptive requirements. As such, there are no direct energy, market, economic, or fiscal impacts.

3.2.4 Economic Impacts

The code change proposal introduces prescriptive alternative requirements that are equivalent to existing prescriptive requirements. As such, there are no direct energy, market, economic, or fiscal impacts.

3.2.5 Fiscal Impacts

The code change proposal introduces prescriptive alternative requirements that are equivalent to existing prescriptive requirements. As such, there are no direct energy, market, economic, or fiscal impacts.

3.3 Energy Savings

The cathedral ceiling alternative prescriptive path code change proposal would not modify the existing energy budget used to assess compliance with California Energy Code, so there would be no savings on a per-unit basis. As an optional compliance pathway, the goal was to design requirements so that savings were equivalent to – not above – the current standard. This section of the CASE Report, which typically presents the methodology, assumptions, and results of the per-unit energy impacts, has been truncated for this proposal.

The Statewide CASE Team estimated Long-term Systemwide Cost (LSC), source energy, electricity, natural gas, peak demand, and GHG impacts by simulating the proposed code change using prototypical buildings and rulesets from the 2025 Research Version of the California Building Energy Code Compliance (CBECC-Res) software (California Energy Commission n.d.).

The CEC 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 (California Energy Commission 2022). The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 40.

Energy impacts are calculated using three new construction prototypes, a 500 square foot small home, a single story 2,100 square foot home, and a two-story 2,700 square foot home. Results are presented for a weighted average of the 2,100 square foot and 2,700 square foot new construction prototypes since results for each of these two prototypes individually are similar. Results are weighted 43% for the 2100 square foot prototype and 57% for the 2700 square foot prototype. Results for the 500 square foot prototype are presented separately. See Appendix A for further details on how the weighting was derived.

Additional details on the 2,100 and 2,700 square foot single family prototypes can be found in the Single-Family Residential Alternative Calculation Method (ACM) Approval Manual (California Energy Commission 2022). The 500 square foot single family prototype is a new prototype being evaluated in this code cycle to reflect recent trends in California construction of a greater number of accessory dwelling units and small homes (UC Berkeley Center for Community Innovation 2021). Further detail on this can be found in Section 2.3.1.2. This measure proposal does not apply to alterations.

Table 41: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (Square Feet)	Description
One-Story Single Family (SF2100)	1	2100	Single story 3-bedroom house with attached garage, 9-ft ceilings, vented attic and steep-sloped roof.
Two-Story Single Family (SF2700)	2	2700	Two-story 4-bedroom house with attached garage, 9-ft ceilings, 1-ft between floors, vented attic and steep-sloped roof.
Small Single Family (SF500)	1	500	Detached single story 1-bedroom small home, 9-ft ceilings.

CBECC-Res generates two models based on user inputs: the Standard Design and the Proposed Design.20 The Standard Design represents the geometry of the prototypical building and a design that uses a set of features that result in a LSC budget and Source Energy budget that is minimally compliant with 2022 Title 24, Part 6 code requirements. Features used in the Standard Design are described in the 2022 Single-Family Residential ACM Reference Manual. The Proposed Design represents the same geometry as the Standard Design, but it assumes the energy features that the software user describes with user inputs.

To estimate energy use for the proposed code changes, the Statewide CASE Team created a Standard Design and Proposed Design for each prototypical building (described below) with the Standard Design representing compliance with 2022 code, Option B, and the Proposed Design representing compliance with the proposed cathedral ceiling requirements. Savings show the assemblies with thermal performance that provide equivalent or near equivalent energy savings to the existing Option B (see Table 150.1-A of the 2022 Title 24, Part 6 code). Equivalency with Option C of Table 150.1-A was also evaluated, but this option results in lower energy use than Option B in most climates and therefore is a higher bar against which to establish equivalency.

The base case and proposed code for cathedral ceilings is summarized in Table 42. The cathedral ceiling is evaluated with 2x12, 24 inches on-center framing. CBECC-Res does not distinguish between vented and unvented cathedral ceiling assemblies and evaluates all cathedral ceiling assemblies as unvented or sealed. The Statewide CASE Team does not expect that the required insulation as part of this proposal would vary

[20] 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.

substantially between vented and unvented assemblies. In the base case, insulation at the attic ceiling is either R-30 or R-38 and the roof may have R-19 deck insulation or a radiant barrier, all depending on climate zone. In the proposed case, R-38 roof cavity insulation is used with a 5:12 sloped cathedral ceiling for all climate zones. Ducts are simulated in conditioned space and using the Verified Low Leakage Ducts in Conditioned Space credit.

Table 42: Existing and Proposed Insulation Levels for Cathedral Ceilings.

Climate Zones	Base Case (Existing Prescriptive Option B)	Proposed Case
1	R-38 cavity insulation	5:12 Sloped cathedral ceiling with R-38 cavity insulation and verified low leakage ducts in conditioned space.
2	R-38 cavity insulation + radiant barrier	
3, 5-7	R-30 cavity insulation + radiant barrier	
4, 8-16	R-38 cavity insulation + R-19 roof deck insulation	

Reasonably equivalent energy savings in cathedral ceiling construction is achieved through R-38 cavity insulation for all climate zones. The Statewide CASE Team initially considered requirements ranging from R-30 to R-49 based on climate zone to better fine tune the equivalency but opted for a single statewide R-value for simplicity. R-38 is typically the maximum batt cavity insulation that can be accommodated in cathedral ceilings. Higher R-values can be met with batt in combination with spray foam or by adding above- or below-roof deck continuous insulation.

A comparison in energy performance between the proposed and base case is presented in Table 43 and Table 44 for all climate zones. Since the purpose is to develop an equivalent code for cathedral ceilings, differences in performance values aim to be close to zero. Thus, some values are positive, and some are negative.

Stakeholder feedback was collected through the Utility-Sponsored Stakeholder Meeting on Tuesday, February 14, 2023, and through one-on-one discussions with the Statewide CASE team. No direct input was provided on energy savings, and stakeholders were not asked to validate data as an energy savings analysis is not required for this proposal. See Appendix F for a summary of stakeholder engagement.

Table 43: Comparison of LSC Energy for Cathedral Ceilings vs. Prescriptive Option B – 2100/2700 Weighted New Construction

Climate Zone	Base Case LSC (2026 PV$)	Proposed LSC (2026 PV$)	Total LSC Difference (2026 PV$)
1	$59,062	$55,175	$3,887
2	$42,075	$39,877	$2,198
3	$28,499	$27,368	$1,131
4	$34,640	$34,281	$358
5	$25,196	$24,114	$1,082
6	$14,831	$14,326	$506
7	$14,556	$13,952	$603
8	$17,446	$17,525	($78)
9	$20,014	$19,980	$34
10	$21,758	$21,652	$107
11	$44,883	$43,863	$1,021
12	$39,489	$38,932	$557
13	$40,185	$40,001	$184
14	$41,326	$40,563	$763
15	$36,490	$36,437	$52
16	$54,879	$52,763	$2,116

Table 44: Comparison of LSC Energy for Cathedral Ceilings vs. Prescriptive Option B – Small Home New Construction

Climate Zone	Base Case LSC (2026 PV$)	Proposed LSC (2026 PV$)	Total LSC Difference (2026 PV$)
1	$13,270	$13,025	$245
2	$10,480	$10,380	$100
3	$12,720	$12,630	$90
4	$14,575	$14,655	($80)
5	$7,300	$7,300	$0
6	$6,275	$6,075	$200
7	$7,055	$6,625	$430
8	$7,990	$7,890	$100
9	$7,965	$7,915	$50
10	$8,550	$8,445	$105
11	$12,480	$12,505	($25)
12	$10,955	$11,090	($135)
13	$16,480	$16,440	$40
14	$16,090	$16,045	$45
15	$14,015	$13,750	$265
16	$12,745	$12,840	($95)

Stakeholder feedback was collected through the Utility-Sponsored Stakeholder Meeting on Tuesday, February 14, 2023, and through one-on-one discussions with the Statewide CASE team. No direct input was provided on energy savings, and stakeholders were not asked to validate data as an energy savings analysis is not required for this proposal. See **Appendix** F for a summary of stakeholder engagement.

In addition to the above comparison of cathedral ceilings to the current prescriptive and standard design (as reflected by Option B of Table 150.1-A of the 2022 Title 24, Part 6 code), savings were analyzed when comparing cathedral ceilings to the buried duct proposal, as detailed in Section 2. Both option B, and buried ducts would remain compliance options with similar LSCs; this analysis is presented to complement the above comparison to current standard design.

Table 45 summarizes the buried duct proposal which serves as the base case for this additional comparison. Note that the base case doesn’t change for climate zones 4 and 8 through 16 since they are not affected by the buried duct proposal.

Equivalency with Option C of Table 150.1-A was also evaluated, but this option is more stringent than Option B and will therefore require a higher level of insulation than R-38 for cathedral ceilings.

Table 45: Proposed Cathedral Ceiling Insulation Levels Compared to Proposed Option B Requirements

Climate Zones	Base Case (Proposed Option B), 2100/2700 Prototypes	Base Case (Proposed Option B), 500 Prototype	Proposed Case
1-3	R-6 ducts buried in R-49 attic insulation and radiant barrier	R-49 attic insulation and radiant barrier, R-8 ducts in attic (R-6 in CZ3)	Cathedral 5:12 ceiling with roof R-38 cavity insulation and verified low leakage ducts in conditioned space.
5-7	R-6 ducts buried in R-49 attic insulation and radiant barrier	R-38 attic insulation and radiant barrier, R-6 ducts in attic	
16	R-6 ducts buried in R-60 attic insulation and radiant barrier	R-60 attic insulation and radiant barrier, R-6 ducts in attic	
4, 8-15	No change to existing prescriptive Option B	No change to existing prescriptive Option B	No change to existing prescriptive Option B

The resulting LSC savings comparing the cathedral ceiling case to the proposed Option B code changes are presented in Table 46 and Table 47 for all climate zones and show both positive and negative savings. The reason for the negative savings in Table 46 and Table 47 compared to Table 43 and Table 44 is that the proposed buried duct measure is more stringent than current code.

Table 46: Comparison of LSC Energy Cathedral Ceilings vs. Buried Duct Proposal – 2100/2700 Weighted New Construction

Climate Zone	Base Case LSC (2026 PV$)	Proposed LSC (2026 PV$)	Total LSC Difference (2026 PV$)
1	$55,079	$55,175	($96)
2	$39,998	$39,877	$120
3	$27,259	$27,368	($109)
5	$23,355	$24,114	($758)
6	$14,067	$14,326	($259)
7	$13,756	$13,952	($196)
16	$53,475	$52,763	$712

Table 47: Comparison of LSC Energy for Cathedral Ceilings vs. Buried Duct Proposal – Small Home New Construction

Climate Zone	Base Case LSC (2026 PV$)	Proposed LSC (2026 PV$)	Total LSC Difference (2026 PV$)
1	$13,035	$13,025	$10
2	$10,360	$10,380	($20)
3	$12,605	$12,630	($25)
5	$7,260	$7,300	($40)
6	$6,240	$6,075	$165
7	$7,005	$6,625	$380
16	$13,050	$12,840	$210

3.4 Cost and Cost Effectiveness

The code change proposal would not modify the stringency of the existing California Energy Code, so the CEC does not need a complete cost-effectiveness analysis to approve the proposed change. This section 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.

Costs associated with this proposal are not expected to increase that of the standard design as prescriptively required by Option B, Section 150.1, Table 150.1-A. Climate Zones 4 and 8 through 15 require both attic insulation and roof deck insulation, while Climate Zones 1 through 3, 5 through 7, and 16 currently require R-30 or R-38 (R-49 to R-60 as proposed by buried ducts measure) attic insulation. Typically, insulation R-values of 38 can easily be installed as batt insulation. Alternatively, R-38 can be achieved from spray foam, rigid insulation, or in combination with batt insulation.

No direct input was received on costs from stakeholder outreach nor the Utility-Sponsored Stakeholder Meeting on Tuesday, February 14, 2023. Stakeholders were not asked to validate data as a cost effectiveness analysis is not required for this proposal.

The primary intent of this proposal is not to drive action in the construction industry, but rather to codify existing practices into the compliance structure via a prescriptive pathway. This simplification may help lower costs for builders, especially for smaller projects and perhaps construction companies that more often rely on the prescriptive performance pathway.

3.5 First-Year Statewide Impacts

The code change proposal would not modify the stringency of the existing California Energy Code, 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 this section of the CASE Report. As discussed in Section 3.3, although the energy savings are limited, the measure would provide a compliance option which would particularly support builders of small homes/ADUs to meet California’s growing housing demand, as informed through direct stakeholder engagement.

4. Addressing Energy Equity and Environmental Justice

The Statewide CASE Team recognizes, acknowledges, and accounts for a history of prejudice and inequality in disproportionately impacted populations (DIPs) and the role this history plays in the environmental justice issues that persist today. DIPs refer to the areas throughout California that most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes, as well as high incidence of asthma and heart disease. DIPs also incorporate race, class, and gender since these intersecting identity factors affect how people frame issues, interpret, and experience the world.[21] While the term disadvantaged communities (DACs) is often used in the energy industry and state agencies, the Statewide CASE Team chose to use terminology that is more acceptable to and less stigmatizing for those it seeks to describe (DC Fiscal Policy Institute 2017).

Including impacted communities in the decision-making process, ensuring that the benefits and burdens of the energy sector are evenly distributed, and grappling with the unjust legacies of the past all serve as critical steps to achieving energy equity. Code change proposals must be developed and adopted with intentional screening for unintended consequences, otherwise they risk perpetuating systemic injustices and oppression.

The Statewide CASE Team assessed the potential impacts of the proposed measure, and based on a preliminary review, the measure is unlikely to have significant impacts on energy equity or environmental justice, therefore reducing the impacts of disparities in DIPs. The Statewide CASE Team does not recommend further research or action at this time.

As detailed in Section 3.1.2.2, the cathedral ceiling proposal offers a streamlined prescriptive option for builders that may be particularly useful in the construction of small homes and Accessory Dwelling Units. Such homes are typically more affordable options that their standard single-family home counterparts, and if builders are able to pass the savings from this streamlined approach down to occupants, that could help alleviate housing concerns faced disproportionately by DIPs.

[21] Environmental disparities have been shown to be associated with unequal harmful environmental exposure correlated with race/ethnicity, gender, and socioeconomic status. For example, chronic diseases, such as respiratory diseases, cardiovascular disease, and cancer, associated with environmental exposure have been shown to occur in higher rates in the LGBTQ+ population than in the cisgender, heterosexual population (Goldsmith and Bell 2021). Socioeconomic inequities, climate, energy, and other inequities are inextricably linked and often mutually reinforcing.

Similarly, the buried ducts proposal offers flexibility through an additional prescriptive compliance option, and potentially significant cost savings by avoiding installation of above-deck roof insulation. It is possible these benefits can be passed to the homeowner or renter.

DIPs likely include many renters, a group that is subject to the split incentive, where the person who makes energy efficiency upgrade decisions is not the same person who pays the utility bills, which lowers or removes the motivation to invest in energy efficiency. Both proposals ensure a minimum level of energy savings and thermal comfort that preclude this issue.

5. Proposed Revisions to Code Language

5.1 Guide to Markup Language

The proposed changes to the Energy Code, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2022 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

5.2 Standards

SUBCHAPTER 2 – ALL OCCUPANCIES—GENERAL PROVISIONS

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

CATHEDRAL CEILING is an exterior partition with a slope less than 60 degrees from horizontal that is created by applying the ceiling directly to the underside of the roof framing members and applying structural roof sheathing directly to the top of the roof framing members/rafters. It may be flat or sloped and vented or unvented.

SUBCHAPTER 7 – SINGLE-FAMILY RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150.0 – Mandatory Features and Devices

(a) **Roof deck, ceiling and rafter roof insulation**. The opaque portions of roof decks separating attic spaces from ambient air, and ceilings or rafter roofs separating conditioned spaces from unconditioned spaces or ambient air, shall meet the requirements of Items 1 through 4 below:

1. In Climate Zones 4 and 8 through 15~~16~~, roof decks in newly constructed attic systems shall be insulated to achieve an area-weighted average U-factor not exceeding U-0.184.

Exception to Section 150.0(a)1:

i. The space-conditioning system air handler and ducts are located entirely in conditioned space below the ceiling separating the occupiable space from the attic; or

ii. The space-conditioning system air handler is located in unconditioned space and has 12 linear feet or less of supply duct, including the length of the air handler and the plenum, located in unconditioned space, with all other portions of the supply ducts located in conditioned space below the ceiling separating the occupiable space from the attic; or

iii. The space-conditioning system air handler is located in a vented attic with a radiant barrier that meets the requirements specified in Section 110.8(j), and shall meet the installation criteria specified in the Reference Residential Appendix RA4, air handler leakage shall be field verified in accordance with the procedures specified in Reference Residential Appendix RA3.1.4.3.9, and ducts shall be fully buried in loose fill ceiling insulation and confirmed by field verification to meet the criterion of Reference Residential Appendix Section RA3.1.4.1.5 or RA3.1.4.9.

SUBCHAPTER 8 – SINGLE-FAMILY RESIDENTIAL BUILDINGS - PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 150.1(c) – Prescriptive standards/component packages

1. **Insulation**.

A. Roof and ceiling insulation shall be installed in a ventilated attic with an R-value equal to or greater than or a U-factor equal to or less than that shown in Table 150.1-A meeting options ii, or iii, or iv below.

i. Option A: **RESERVED**.

ii. Option B: In Climate Zones 4 and 8 through 15 aA minimum R-value of insulation installed between the roof rafters in contact with the roof deck and an additional layer of ceiling insulation located between the attic and the conditioned space when meeting Section 150.1(c)9A. In Climate Zones 1 through 3, 5 through 7, and 16 a ventilated attic with a minimum R-value of ceiling insulation located between the attic and the conditioned space and space conditioning system complies with Section 150.1(c)9C; or

iii. Option C: A minimum R-value of ceiling insulation located between the attic and the conditioned space when meeting Section 150.1(c)9B Section 150.1(c)9B.; or

iv. Option D: A cathedral ceiling with a maximum U-factor or a minimum R-value of cavity insulation and space conditioning system complies with Section 150.1(c)9B.

Note: Low rise residential single- family buildings with the ducts and air handler located in the conditioned space, as specified by Section 150.1(c)9B, need only comply with insulation requirements of Option C.

9. **Space conditioning distribution systems**. All space conditioning systems shall meet all applicable requirements of A, B, or BC below:

A. High performance attics. Air handlers or ducts are allowed to be in ventilated attic spaces when the roof and ceiling insulation level meet Option B in Table 150.1-A. Duct insulation levels shall meet the requirements in Table 150.1-A.

B. Duct and air handlers, or ductless air handlers, located in conditioned space. Duct systems and air handlers of HVAC systems shall be located in conditioned space, and confirmed by field verification and diagnostic testing to meet the criterion of Reference Residential Appendix Section RA3.1.4.3.8. Duct insulation levels shall meet the requirements in Table 150.1-A.

C. Buried ducts. Air handlers and ducts are allowed to be in ventilated attic spaces when the following conditions are met.

i. All supply ducts are fully buried in loose fill ceiling insulation and confirmed by field verification and diagnostic testing to meet the criterion of Reference Residential Appendix Section RA3.1.4.9.

ii. Nominal duct R-values, ceiling insulation R-values, and radiant barriers shall meet the requirements in Table 150.1-A.

TABLE 150.1-A COMPONENT PACKAGE – Single- Family Standard Building Design

Single- Family				Climate Zone														
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Building Envelope	Roofs/Ceilings	Option B (meets § 150.1(c)9A or 150.1(c)9C)	Below Roof Deck Insulation[1,2] (With Air Space)	NR	NR	NR	R 19	NR	NR	NR	R 19	R 19	R 19	R 19	R 19	R 19	R 19	R 19
			Ceiling Insulation[3]	R ~~38~~49	R ~~38~~49	R ~~30~~49	R 38	R ~~30~~49	R ~~30~~49	R ~~30~~49	R 38	R 38	R 38	R 38	R 38	R 38	R 38	R 38
			Radiant Barrier	~~NR~~REQ	REQ	REQ	NR	REQ	REQ	REQ	NR	NR	NR	NR	NR	NR	NR	NR
		Option C (meets § 150.1(c)9B)	Ceiling Insulation	R 38	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 38	R 38	R 38	R 38	R 38
			Radiant Barrier	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ
		Option D (meets § 150.1(c)9B)	Roof Deck Insulation[1,4]	U 0.026 / R-38														

[Separator for formatting reasons]

Single- Family				Climate Zone															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HVAC System	Ducts~~[10]~~	Roof/Ceiling Option~~s~~ B	Duct Insulation	R-~~8~~6	R-~~8~~6	R- 6	R-8	R- 6	R- 6	R- 6	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-~~8~~6
			§150.1(c)9A	NA	NA	NA	REQ ~~NA~~	NA	NA	NA	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	REQ ~~NA~~	NA
			§150.1(c)9~~A~~C[12]	REQ	REQ	REQ	NA	REQ	REQ	REQ	NA	NA	NA	NA	NA	NA	NA	NA	REQ

		Roof/Ceiling Option C & D	Duct Insulation	R-6
			§150.1(c)9B	REQ

Footnote requirements to TABLE 150.1-A:

1. Install the specified R-value with an air space present between the roofing and the roof deck, such as standard installation of concrete or clay tile.
2. R-values shown for below roof deck insulation are for wood-frame construction with insulation installed between the framing members. Alternatives including insulation above rafters or above roof deck shall comply with the performance standards.
3. New dwelling units with a conditioned floor area of 500 square feet or less may comply using R-38 ceiling insulation in Climate Zones 5 and 6.
4. Assembly U-factors for roofs can be met with cavity insulation alone or with continuous insulation alone, or with both cavity and continuous insulation that results in an assembly U-factor equal to or less than the U-factor shown. Use Reference Joint Appendices JA4 Table 4.2.2 to determine alternative insulation products to be less than or equal to the required maximum U-factor. R-values shown represent the required insulation to meet the maximum U-factor with cavity insulation alone.

35. Assembly U-factors for exterior framed walls can be met with cavity insulation alone or with continuous insulation alone, or with both cavity and continuous insulation that results in an assembly U-factor equal to or less than the U-factor shown. Use Reference Joint Appendices JA4 Table 4.3.1, 4.3.1(a), or Table 4.3.4 to determine alternative insulation products to be less than or equal to the required maximum U-factor.

46. Mass wall has a heat capacity greater than or equal to 7.0 Btu/h-ft^2.

57. "Interior" denotes insulation installed on the inside surface of the wall. "Exterior" denotes insulation installed on the exterior surface of the wall.

68. Below grade "interior" denotes insulation installed on the inside surface of the wall, and below grade "exterior" denotes insulation installed on the outside surface of the wall.

79. HSPF means heating seasonal performance factor.

810. When whole-house fans are required (REQ), only those whole-house fans that are listed in the Home Ventilating Institute Certified Products Directory may be installed. Compliance requires installation of one or more WHFs whose total airflow cfm is capable of meeting or exceeding a minimum 1.5 cfm/square foot of conditioned floor area as specified by Section 150.1(c)12.

911. A supplemental heating unit may be installed in a space served directly or indirectly by a primary heating system, provided that the unit thermal capacity does not exceed 2 kilowatts or 7,000 Btu/hr and is controlled by a time-limiting device not exceeding 30 minutes.

~~10. For duct and air handler location: REQ denotes location in conditioned space. When the table indicates ducts and air handlers are in conditioned space, a HERS verification is required as specified by Reference Residential Appendix RA3.1.4.3.8.~~

12. New dwelling units with a conditioned floor area of 500 square feet or less shall not be required to comply with the duct burial requirements of 150.1(c)9C, but R-8 duct insulation is required in Climate Zones 1, 2, and 16.

SUBCHAPTER 9 – SINGLE-FAMILY RESIDENTIAL BUILDINGS - ADDITIONS AND ALTERATIONS TO EXISTING RESIDENTIAL BUILDINGS

SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING SINGLE-FAMILY RESIDENTIAL BUILDINGS

(a) **Additions.** Additions to existing single-family residential buildings shall meet the requirements of Sections
110.0 through 110.9, Sections 150.0(a) through (n), (p), (q), and either Section 150.2(a)1 or 2.

1. **Prescriptive approach.** Additions to existing buildings shall meet the following additional requirements:

   A. Additions that are 700 square feet or less shall meet the requirements of Section 150.1(c), with the following modifications:

      i. ~~Roof and c~~Ceiling insulation in a ventilated attic shall meet one of the following requirements~~:~~. The duct burial requirements of 150.1(c)9C and the roof deck insulation requirements of 150.1(c)1Aii do not apply.

         a. In Climate Zones 1~~, 2, 4, and 8~~ through 15~~16~~, achieve an overall assembly U-factor not exceeding 0.025. In wood framed assemblies, compliance with U-factors may be demonstrated by installing insulation with an R-value of R-38 or greater.

         b. In Climate Zone~~s~~ 16 ~~3, and 5 through 7~~, achieve an overall assembly U-factor not exceeding 0.019~~0.031~~. In wood framed assemblies, compliance with U-factors may be demonstrated by installing insulation with an R-value of R-49~~30~~ or greater.

      ii. Radiant barriers shall be installed in climate zones 2-15.

      iii. Extensions of existing wood-framed walls may retain the dimensions of the existing walls and shall install cavity insulation of R-15 in a 2×4 framing and R-21 in a 2×6 framing.

      iv. In Climate Zones 2, 4 and 6-15; the maximum allowed west-facing fenestration area shall not be greater than 60 square feet; and shall also comply with either a or b below:

         a. For additions that are 700 square feet or less but greater than 400 square feet, the maximum allowed fenestration area limit is the greater of 120 square feet or 25 percent of the conditioned floor area of the addition; or

         b. For additions that are 400 square feet or less, the maximum allowed fenestration area is the greater of 75 square feet or 30 percent of the conditioned floor area of the addition.

      v. Quality Insulation Installation (QII) requirements of Section 150.1(c)1E do not apply.

      vi. When existing siding of a wood-framed wall is not being removed or replaced, cavity insulation of R-15 in a 2×4 framing and R-21 in a 2×6 framing shall be installed and continuous insulation is not required.

      Exception to Section 150.2(a)1B: Insulation in an enclosed rafter ceiling shall meet the requirements of Section 150.0.

5.3 Reference Appendices

RA2.3.1.1 Whole-Building Compliance Approach for Multifamily Buildings

When the whole-building compliance approach is utilized for a multifamily building, some energy efficiency measures that require HERS field verification shall not be used for compliance credit in performance compliance calculations. These measures require *dwelling unit-specific* information input to the compliance software, and *dwelling unit-specific* information that must be shown on the Certificate of Compliance, thus these measures cannot be properly documented using a whole-building Certificate of Compliance (which is not a *dwelling unit-specific* document type). The HERS measures that shall not be utilized for the multifamily whole-building compliance approach are:

(a) Buried Ducts credit

~~(b) Deeply Buried Ducts credit~~

(~~c~~b) Reduced Duct Surface Area credit

(~~d~~c) Building Envelope Sealing credit for reduced outdoor air infiltration (blower door test)

Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing

Measure Title	Description	Procedure(s)
	Duct Measures	
Duct Sealing	Component Packages require that space conditioning ducts be sealed. If sealed and tested ducts are claimed for compliance, field verification and diagnostic testing is required to verify that approved duct system materials are utilized, and that duct leakage meets the specified criteria.	RA3.1.4.3
Duct Location, Surface Area and R-value	Compliance credit can be taken for improved duct location, surface area and R-value. Field verification is required to verify that the duct system was installed according to the design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.[1] For buried ducts measures, Duct Sealing and High Quality Insulation Installation (QII) is required.	RA3.1.4.1
Verification of Prescriptive Buried Duct Requirements	Compliance software recognizes buried ducts as a prescriptive measure in Climate Zones 1-3 and 5-7 for all new buildings 500 square feet and larger.	RA3.1.4.9
Verification of low leakage ducts located entirely in conditioned space	Duct system location shall be verified by visual inspection and diagnostic testing. Compliance credit can be taken for verified duct systems with low air leakage to the outside when measured in accordance with Reference Residential Appendix Section RA3.1.4.3.8. Field Verification for ducts in conditioned space is required. Duct sealing is required.	RA3.1.4.3.8
Low Leakage Air-handling Units	Compliance credit can be taken for installation of a factory sealed air handling unit tested by the manufacturer and certified to the Commission to have met the requirements for a Low Leakage Air-Handling Unit. Field verification of the air handler's model number is required. Duct Sealing is required.	RA3.1.4.3.9
Verification of Return Duct Design	Verification to confirm that the return duct design conform to the applicable criteria given in TABLE 150.0-B, TABLE 150.0-C, TABLE 160.3-A, or TABLE 160.3-B.	RA3.1.4.4

Table RA3.1-1 – Summary of Duct System Field Verification and Diagnostic Test Protocols

Verification/Diagnostic	**Description**	**Procedure**
Duct Location, Surface Area and R-Value	Verify duct system was installed according to the specifications on the Certificate of Compliance or in accordance with an approved duct system design layout.	RA3.1.4.3
Verified Duct System Design	Procedure for duct system design layout approval and field verification	RA3.1.4.1.1
Duct Leakage	Verify that duct leakage is less than or equal to the compliance criteria given in Table RA3.1-2	RA3.1.4.3
Return Duct Design	Verify compliance with the return duct and return grill sizing requirements of Table 150.0-B or Table 150.0-C	RA3.1.4.4
Air Filter Device Design	Verify compliance with the requirements in 150(m)12.	RA3.1.4.5
Verification of Prescriptive Bypass Duct and Zone Damper Requirements	Verification to confirm zonally controlled systems comply with the bypass duct requirements in 150.1(c)13 and that zone dampers are accessible.	RA3.1.4.6
Verification of Space-Conditioning System Airflow Supply to All Habitable Spaces	Verify that all habitable spaces in the dwelling unit receive space-conditioning system airflow.	RA3.1.4.1.7
Verification of Ductless Space-Conditioning System Indoor Units Located Entirely in Conditioned Space	Verify that ductless indoor units are located entirely in conditioned space.	RA3.1.4.1.8

RA3.1.4.1 Diagnostic Duct Location, Surface Area and R-value

The performance compliance calculations allow credit for duct systems that are designed to be in advantageous locations, that have reduced duct surface areas, and/or that provide higher R-values or portions of the system. This section specifies procedures for verification of duct systems for conformance with the requirements for the performance compliance credits. When indicated on the Certificate of Compliance, the Installer shall certify compliance with the applicable procedures in RA3.1.4.1 on a Certificate of Installation, and a HERS rater shall verify compliance on a Certificate of Verification.

RA3.1.4.1.5 Verification of Buried Ducts for Compliance Credit – Detailed Method ~~on The Ceiling R-Value~~

Compliance with Verified Duct System Design procedures specified in RA3.1.4.1.1 is prerequisite for compliance with the Buried Ducts ~~on the Ceiling~~ compliance credit (RA3.1.4.9 provides an alternative simplified compliance method for buried ducts). A visual inspection shall confirm the installed duct system layout conforms to the Duct Design Layout. This procedure shall be carried out prior to covering the ducts with insulation. **NOTE**: Refer to Section RA3.1.4.8 for prescriptive requirements for buried ducts for compliance with Standards Section 150.1(c)9C.

Ducts ~~designed to~~ shall be fully or partially buried and shall be insulated to R~~4.2~~6 or greater. In addition, ducts designed to be in contact with the ceiling shall be not more than 3.5 inches from the ceiling drywall. A sign shall be hung near the attic access that displays a warning: "Caution: Buried Ducts. Markers indicate location of buried ducts." All ducts ~~that will be completely buried~~ shall have vertical markers that are visible after insulation installation, placed at least every 8 feet of duct length and at the beginning and end of each duct run.

~~**RA3.1.4.1.6 Verification of Deeply Buried Ducts R-Value**~~

~~Compliance with Verified Duct System Design procedures specified in RA3.1.4.1.1 is prerequisite for compliance with the Deeply Buried Ducts compliance credit. A visual inspection shall confirm the installed duct system layout conforms to the Duct Design Layout. This procedure shall be carried out prior to covering the ducts with insulation. Ducts designed to be buried shall be insulated to R4.2 or greater. In addition, ducts designed to be in contact with the ceiling shall be not more than 3.5 inches from the ceiling drywall. A sign shall be hung near the attic access that displays a warning: "Caution: Buried Ducts. Markers indicate location of buried ducts." All ducts that will be completely buried shall have vertical markers that are visible after insulation installation, placed at least every 8 feet of duct length and at the beginning and end of each duct run.~~

RA3.1.4.6 Verification of Bypass Ducts <u>and Zone Dampers</u> for Zonally Controlled Forced Air Systems

When a zonally controlled forced air system is installed, a visual inspection shall confirm:

(a) That bypass ducts are not used to deliver conditioned supply air directly to the space conditioning system return duct airflow; or

(b) That the Certificate of Compliance indicates an allowance for use of bypass ducts.

<u>(c) If ducts are to be buried in accordance with either RA3.1.4.1.5 or RA3.1.4.8, a visual inspection shall verify that all zone dampers will be fully accessible after installation of ceiling insulation by locating them at or near the air handler supply plenum or will be accessible from a platform in conformance with RA3.5.3.3.3.</u>

<u>RA3.1.4.9 Verification of Buried Ducts for Prescriptive and Performance Compliance – Simplified Method</u>

<u>This section specifies procedures for compliance and verification of buried duct systems for meeting the requirements of Standards Section 150.1(c)9C and is a simplified alternative to RA3.1.4.1.5 that may be used for compliance credit in climate zones where buried ducts are not prescriptively required. The Installer shall certify compliance with the procedures of this section and a HERS Rater shall verify compliance on a Certificate of Verification.</u>

<u>RA3.1.4.9.1 Duct System Design Layout</u>

<u>The duct system design shall be documented on the Duct Design Layout, a scaled drawing that identifies the location of the space conditioning equipment, all supply and return registers/grilles, and the size and location of each duct segment. The Duct</u>

Design Layout shall be included with the building design plans and the registered Certificate of Compliance submitted to the enforcement agency in conjunction with the application for a building permit.

A copy of the Duct Design Layout and shall be posted or made available to the enforcement agency, installing contractor, and HERS Rater for use during installation work and all applicable inspections. All ducts shall have a nominal insulation rating of R-6. The Duct Design Layout shall show the outside diameter (including insulation) of the largest duct, the R-value and depth of attic insulation, and all other duct design details reported on the registered Certificate of Compliance.

RA3.1.4.9.2 Buried Duct Design Method

The duct system design shall be based on an industry standard design methodology such as ACCA Manual D or an equivalent and shall take into account: the available external static pressure from the air handler, the equivalent length or pressure drop of external devices, and the pressure drop of the duct runs accounting for size, type and configuration of the ducts and fittings. The duct system shall be designed to meet the required system airflow rate with the manufacturer-specified available external static pressure for the specified system air handler at that airflow. The duct system design shall include calculations that indicate the duct system will operate at equal to or greater than 0.0292 cfm/Btu (350 cfm/12000 Btu) in cooling speed (350 cfm per nominal ton of condensing unit cooling capacity specified by the manufacturer).

RA3.1.4.9.3 Duct Installation and Field Verification at Rough-In

Installed duct systems shall be field verified at rough-in to be consistent with the Duct Design Layout. Insulated supply ducts shall be installed over trusses with their undersides not more than 3.5 inches above ceiling drywall, except where connected to plenums, such that they will be fully covered by ceiling insulation. Not more than 3 feet of any single duct shall above the level of ceiling insulation. Where flexible ducts run in between trusses they shall be supported by strapping at not more than 4 feet intervals in accordance with 2022 CMC Section 603.4.

Ducts shall be tested and verified for leakage at rough-in stage with the air handling unit connected and shall meet leakage rates specified in Standards Section 150.0(m)11 using the methods of RA3.1.4.3.1, and RA3.1.4.3.2.1. Nominal air handler airflow shall be calculated using methods (b) or (d) of RA3.1.4.2.2 or the measured airflow method of RA3.1.4.2.3.

A sign shall be hung near the attic access that displays a warning: “Caution: Buried Ducts. Markers indicate location of buried ducts.” All ducts shall have vertical markers that are visible after insulation installation, placed at least every 8 feet of duct length and at the beginning and end of each duct run.

RA3.1.4.9.4 Visual Field Verification at Final Construction Stage

Following the installation of ceiling insulation, duct and register sealing and complete duct coverage by insulation shall be verified by visual inspection.

RA3.1.4.9.4.1 Final Verification of Duct Sealing

After installing the ceiling drywall and verifying that the air leakage test was completed at rough-in, the following procedure shall be used:

(a) Remove at least one supply and one return register and verify that the spaces between the register boot and the interior finishing wall are properly sealed.

(b) Inspect all joints to ensure that no cloth backed rubber adhesive duct tape is used.

RA3.1.4.9.4.2 Verification of Duct Coverage by Ceiling Insulation

The maximum duct diameters that can be covered by ceiling insulation is provided in Table 3.1-3. The Insulation Installer shall certify compliance with Table 3.1-3 and a HERS Rater shall verify that all ducts are fully covered by ceiling insulation on a Certificate of Installation.

Table 3.1-3 – Attic Insulation Depth and Maximum Duct Diameters for R-6 Ducts

Attic Insulation R-Value	Attic Insulation Depth[1] (inches)		Maximum Duct Diameter (inches)	
	Fiberglass	Cellulose	Fiberglass	Cellulose
30	12.0	8.8	4	
31	12.4	9.1	4	
32	12.8	9.4	5	
33	13.2	9.7	5	
34	13.6	10.0	6	
35	14.0	10.3	6	
36	14.4	10.6	6	3
37	14.8	10.9	7	3
38	15.2	11.2	7	3
39	15.6	11.5	8	4
40	16.0	11.8	8	4
41	16.4	12.1	8	4
42	16.8	12.4	9	4
43	17.2	12.6	9	5
44	17.6	12.9	10	5
45	18.0	13.2	10	5
46	18.4	13.5	10	6
47	18.8	13.8	10	6
48	19.2	14.1	10	6
49	19.6	14.4	12	6

50	20.0	14.7	12	7
51	20.4	15.0	12	7
52	20.8	15.3	12	7
53	21.2	15.6	12	8
54	21.6	15.9	14	8
55	22.0	16.2	14	8
56	22.4	16.5	14	9
57	22.8	16.8	14	9
58	23.2	17.1	14	9
59	23.6	17.4	16	9
60	24.0	17.6	16	10

[1]Based on R-values of 2.5 per inch for fiberglass and 3.4 per inch for settled cellulose

5.4 Single-Family Residential ACM Reference Manual

Section 2.4.7 Distribution Subsystems

Distribution Type

Standard Design

The standard heating and cooling system for central systems is modeled with nondesigned air-distribution ducts located as described in Table 13: Summary of Standard Design Duct Location, with duct leakage as specified in Table 21: Duct/Air Handler Leakage. The standard design duct insulation is determined by Table 150.1-A (assuming attic Option B) as R-6 in Climate Zones 1-3, ~~and~~ 5–7, and 16 and R-8 in Climate Zones ~~1, 2,~~ 4, and 8–15~~6~~. Buildings 500 square feet and under will have duct insulation of R-6 in Climate Zones 3 and 5–7, and R-8 in Climate Zones 1, 2, 4, and 8–16. The standard design building is assumed to have the same number of stories as the proposed design for determining the duct efficiency.

Table 13: Summary of Standard Design Duct Location

Configuration of the Proposed Design	Standard Design Duct Location	Detailed Specifications
Buildings with no attic	Ducts and air handler located indoors	Ducts tested to meet verified low leakage ducts in conditioned space requirements.
Attic over all or a portion of the dwelling unit	Ducts and air handler located in the attic	Ducts sealed (mandatory requirement) No credit for verified R-value, location, or duct design. In CZs 1-3, 5-7, & 16 in buildings greater than 500 square feet ducts are buried in attic insulation.
~~No attic but crawl space or basement~~	~~Ducts and air handler located in the crawl space or basement~~	~~Ducts sealed (mandatory requirement)~~ ~~No credit for verified R-value, location, or duct design~~
~~Buildings with no attic, crawl space or basement~~	~~Ducts and air handler located indoors~~	~~Ducts sealed (mandatory requirement)~~ ~~No credit for verified R-value, location or duct design~~

This table is applicable only when the standard design system has air-distribution ducts

Buried Attic Ducts

The Statewide CASE Team is developing proposed revisions for this subsection that will be provided in the Final CASE Report.

Section 2.5.6 Exterior Surfaces

2.5.6.1 Ceilings Below Attics

Ceilings below attics are horizontal surfaces between conditioned zones and attics. The area of the attic floor is determined by the total area of ceilings below attics defined in conditioned zones.

PROPOSED DESIGN

The software allows the user to define ceilings below attic, enter the area, and select a construction assembly for each.

STANDARD DESIGN

The standard design for newly constructed buildings has the same ceiling-below-attic area as the proposed design modeled with the features of Option B from Section 150.1(c) and Table 150.1-A for the applicable climate zone. In Climate Zones 4 and 8–15, tThe standard design is a ventilated high-performance attic with a ceiling constructed with 2x4 framed trusses and insulated with R-38 and below-roof deck insulation of R-19the R-values specified in Section150.1(c) and Table 150.1-A for the applicable climate zone, assuming Option B. The roof surface is a 10 lbs/ft^2 tile roof with an air space when the proposed roof is steep slope or a lightweight roof when the proposed roof is low slope. Climate Zones 1-3, 5-7, and 16 the standard design is a ventilated attic with a ceiling constructed with 2x4 framed trusses and insulated with R-49. It has a radiant barrier, no roof deck insulation, and the ducts are fully buried in the attic insulation.

Single-family dwelling units: Below-roof-deck insulation has R-0 in Climate Zones 1–3 and 5–7 and R-19 in Climate Zones 4 and 8–16. Insulation on the ceiling has R-38 in Climate Zones 1, 2, 4, and 8–16 and R-30 insulation in Climate Zones 3 and 5–7. Climate Zones 2, 3, and 5–7 have a radiant barrier, and Climate Zones 1, 4, and 8–16 have no radiant barrier.

VERIFICATION AND REPORTING

Ceiling below attic area and constructions are reported on the CF1R. SIP assemblies are reported as a special feature on the CF1R.

2.5.6.2 Non-Attic (Cathedral) Ceiling and Roof

Non-attic ceilings, also known as cathedral ceilings, are surfaces with roofing on the outside and finished ceiling on the inside but without an attic space.

PROPOSED DESIGN

The software allows the user to define cathedral ceilings, enter the area, and select a construction assembly for each. The user also enters the roof characteristics of the surface.

STANDARD DESIGN

The standard design has the same area as the proposed design cathedral ceiling modeled as a cathedral ceiling below attic with the features of Option DB from Section150.1(c) and Table 150.1-A or for the applicable climate zone. The total cathedral ceiling area is equally divided among the four main compass points – north, east, south, and west.

~~The standard design building has an area of ceiling below attic equal to the non-attic ceiling/roof areas of the proposed design.~~ The standard design roof ~~and ceiling~~ surfaces are modeled with the same ~~construction assembly and~~ aged solar reflectance and thermal emittance characteristics~~, aged reflectance, and emittance~~ as Section150.1(c), Table 150.1-A for the applicable roof slope and climate zone.

VERIFICATION AND REPORTING

Non-attic ceiling/roof area and constructions are reported on the CF1R. SIP assemblies are reported as a special feature on the CF1R.

5.5 Compliance Documents

The following compliance documents would need to be revised. These revisions are necessary to accommodate new prescriptive requirements for the buried ducts proposal.

- CF1R-NCB-01: Prescriptive Newly Constructed Buildings and Additions Equal to or Greater than 1,000 ft^2
- CF1R-PRF-01-E: Performance Compliance Method
- CF2R-MCH-21-H: Mechanical-HERS Duct Location Verification
- CR2R-MCH-29-H: Mechanical-HERS Duct Surface Area Reduction; R-Value; Buried Ducts Compliance Credit
- CF3R-MCH-21-H: Mechanical-HERS Duct Location Verification
- CF3R-MCH-29-H: Mechanical-HERS Duct Surface Area Reduction; R-Value; Buried Ducts Compliance Credit

For the cathedral ceiling proposal, the following compliance documents would also need to be revised to add this prescriptive compliance option and/or to clarify the U-factor requirements thereof.

- CF2R-ENV-03-E: Insulation Installation
- CF1R-NCB-01: Prescriptive Newly Constructed Buildings
- CF1R-ADD-01-E: Prescriptive Additions 1000 Ft2 or Less
- CF1R-ADD-02-E: Prescriptive Residential Additions That Do Not Require HERS Field Verification
- CF2R-ADD-02-E: Prescriptive Residential Additions That Do Not Require HERS Field Verification

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Appendix A: Statewide Savings Methodology

The Statewide CASE Team estimated statewide impacts for the first year by multiplying per-unit savings estimates by statewide construction forecasts that the CEC provided (California Energy Commission Housing and Commercial Construction Data - Excel 2022 California Energy Commission 2022). The CEC provided the construction estimates on March 27, 2023.

The Statewide CASE Team followed guidance provided in the CEC's New Measure Proposal Template (developed by the Energy Commission) to calculate statewide energy savings using the CEC's construction forecasts and assuming statewide weighting of 2 percent for the 500 square foot prototype, 42 percent for the 2,100 square foot prototype, and 56 percent for the 2,700 square foot prototype. In Sections 2.3, 0, and 3.3 results are presented for a weighted average of the 2,100 square foot and 2,700 square foot new construction prototypes since results for each of these two prototypes individually are similar. With the exclusion of the 500 square foot prototype, savings results are weighted 43 percent for the 2100 square foot prototype and 57 percent for the 2700 square foot prototype (Section 4.2 of the CEC's New Measure Proposal Template) (California Energy Commission 2022).

The Statewide CASE Team did not make any changes to the CEC's construction estimates.

The Statewide CASE Team estimated statewide impacts for the first year by multiplying per-unit savings estimates by the Energy Commission's statewide construction forecasts. The Statewide CASE Team made assumptions about the percentage of buildings in each climate zone that would be impacted by the proposed code change. Table 48 presents the number of homes, both newly constructed and existing, that the Statewide CASE Team assumed will be impacted by the proposed code change during the first year the 2025 code is in effect.

The buried ducts code change proposal is the only measure that has statewide energy impacts to quantify. For new construction the measure will impact 100 percent of all new homes in Climate Zones 1 through 3, 5 through 7, and 16. Even if a project does not meet the new prescriptive requirements, they will need to trade this off in the performance approach with another energy efficiency measure that would provide the same level of savings.

The buried duct prescriptive proposal does not impact existing buildings, as is shown in Table 48.

Table 48: Estimated New Construction and Existing Building Stock for Single Family Buildings by Climate Zone

Building Climate Zone	Total Homes Completed in 2026 (New Construction) [A]	Percent of New Buildings Impacted by Proposal [B]	New Buildings Impacted by Proposal in 2026 C = A x B	Total Existing Homes in 2026 [D]	Percent of Existing Buildings Impacted by Proposal [E]	Buildings Impacted by Proposal in 2026 F = D x E
1	359	100%	359	43,798	0%	0
2	1,861	100%	1,861	260,224	0%	0
3	3,035	100%	3,035	963,408	0%	0
4	2,689	0%	0	489,254	0%	0
5	616	100%	616	95,423	0%	0
6	1,719	100%	1,719	589,387	0%	0
7	1,869	100%	1,869	488,748	0%	0
8	4,163	0%	0	913,789	0%	0
9	4,286	0%	0	1,237,621	0%	0
10	7,950	0%	0	1,043,549	0%	0
11	5,840	0%	0	317,948	0%	0
12	14,542	0%	0	1,275,153	0%	0
13	7,257	0%	0	612,938	0%	0
14	3,739	0%	0	236,635	0%	0
15	3,160	0%	0	168,190	0%	0
16	1,937	100%	1,937	92,126	0%	0
TOTAL	**65,022**	**-**	**11,396**	**8,828,191**	**-**	**0**

Source: (California Energy Commission 2022)

Appendix B: Embedded Electricity in Water Methodology

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

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

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

Appendix C is still under development and will be completed in the Final CASE Report.

Appendix D: Environmental Analysis

Potential Significant Environmental Effect of Proposal

The CEC is the lead agency under the California Environmental Quality Act (CEQA) for the 2025 Energy Code and must evaluate any potential significant environmental effects resulting from the proposed standards. A “significant effect on the environment” is “a substantial adverse change in the physical conditions which exist in the area affected by the proposed project.” (Cal. Code Regs., tit. 14, § 15002(g).)

The Statewide CASE Team has considered the environmental benefits and adverse impacts of its proposal including, but not limited to, an evaluation of factors contained in the California Code of Regulations, Title 14, section 15064 and determined that the proposal will not result in a significant effect on the environment.

Direct Environmental Impacts

Direct Environmental Benefits

Direct environmental benefits from the highly insulated attics code change proposal are energy savings, peak demand savings, and GHG emission reductions.

Direct Adverse Environmental Impacts

There are no direct adverse environmental impacts from the code change proposals.

Indirect Environmental Impacts

Indirect Environmental Benefits

An indirect environmental benefit from the highly insulated attics code change proposal is the installation of smaller HVAC equipment due to lower heating and cooling loads. Less material including refrigerant are required to manufacture and install smaller equipment.

Indirect Adverse Environmental Impacts

There are no indirect adverse environmental impacts from the code change proposals.

Mitigation Measures

The Statewide CASE Team has considered opportunities to minimize the environmental impact of the proposal, including an evaluation of “specific economic, environmental, legal, social, and technological factors.” (Cal. Code Regs., tit. 14, § 15021.) The

Statewide CASE Team did not determine this measure would result in significant direct or indirect adverse environmental impacts and therefore, did not develop any mitigation measures.

Reasonable Alternatives to Proposal

If an EIR is developed, CEQA requires a lead agency to evaluate reasonable alternatives to proposals that would have a significant adverse effect on the environment, including a “no project” alternative. (Cal. Code Regs. Tit. 14, §§ 15002(h)(4) and 15126.6.)

The Statewide CASE Team has considered alternatives to the proposal and believes that no alternative achieves the purpose of the proposal with less environmental effect.

Water Use and Water Quality Impacts Methodology

The proposed code change produces no impacts to water quality or water use.

Embodied Carbon in Materials

Accounting for embodied carbon emissions is important for understanding the full picture of a proposed code change’s environmental impacts. The embodied carbon in materials analysis accounts specifically for emissions produced during the “cradle-to-gate” phase: emissions produced from material extraction, manufacturing, and transportation. Understanding these emissions ensures the proposed measure considers these early stages of materials production and manufacturing instead of emissions reductions from energy efficiency alone.

The Statewide CASE Team calculated emissions impacts associated with embodied carbon from the change in materials as a result of the proposed buried duct measure. The calculation builds off the materials impacts outlined in Section 2.5.4, see section for more details on the materials impact analysis.

After calculating the materials impacts, the Statewide CASE Team applied average embodied carbon emissions for each material. The embodied carbon emissions are based on industry-wide environmental product declarations (EPDs).[22, 23] These industry-wide EPDs provide global warming potential (GWP) values per weight of specific materials.[24] The Statewide CASE Team chose the industry-wide average for GWP values in the EPDs because the materials accounted for in the statewide calculation will have a range of embodied carbon; i.e. some materials like concrete have a wide range of embodied carbon depending on the manufacturer's processes, source of the materials, etc. The Statewide CASE Team assumes that most building projects will not specify low embodied carbon products. Therefore, an average is appropriate for a statewide estimate.

First year statewide impacts per material (in pounds) were multiplied by the GWP impacts for each material. This provides the total statewide embodied carbon impact for each material. If a material's use is increased, then there is an increase in embodied carbon impacts (additional emissions). If a material's use is decreased, then there is a decrease in embodied carbon impacts (emissions reduced). The total emissions reductions from this measure are the total GHG emissions reductions from Section 2.5.2 combined with emissions reductions (or additional emissions) from embodied carbon in Section 2.5.4.

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[22] EPDs are documents which disclose a variety of environmental impacts, including embodied carbon emissions. These documents are based on lifecycle assessments on specific products and materials. Industry-wide EPDs disclose environmental impacts for one product for all (or most) manufacturers in a specified area and are often developed through the coordination of multiple manufacturers and/or associations. A manufacturer specific EPD only examines one product from one manufacturer. Therefore, an industry-wide EPD discloses all the environmental impacts from the entire industry (for a specific product/material) but a manufacturer specific EPD only factors one manufacturer.

[23] An industry wide EPD was not used for mercury, lead, copper, plastics, and refrigerants. Global warming potential values of mercury, lead and copper are based on data provided in a lifecycle assessment (LCA) conducted by Yale University in 2014. The GWP value for plastic is based on a LCA conducted by Franklin Associates, which capture roughly 59% of the U.S.' total production of PVC and HDPE production. The GWP values for refrigerants are based on data provided by the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.

[24] GWP values for concrete and wood were in units of kg CO2 equivalent by volume of the material rather than by weight. An average density of each material was used to convert volume to weight.

Appendix E: Discussion of Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in sections 2.1.4 and 3.1.5, impact various market actors. Table 49 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they are responsible, how the proposed code change could impact their existing workflow, and ways negative impacts could be mitigated. The information contained in Table 49 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes. Appendix F summarizes the stakeholder engagement that the Statewide CASE Team conducted when developing and refining the code change proposal, including gathering information on the compliance process.

Table 49 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 workflow, and ways negative impacts could be mitigated.

Table 49: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) in current compliance process relating to the CASE measure	How will the proposed measure impact the current task(s) or workflow?	How will the proposed code change impact compliance and enforcement?	Opportunities to minimize negative impacts of compliance requirement
Architect	• Designs house to accommodate buried ducts and cathedral attic requirements as appropriate • Engages structural, electrical, and mechanical engineers/designers • Makes adjustments to meet all code requirements • Submits plan set to the builder	• Must consider structural design elements that facilitate installation of buried ducts and/or construction of cathedralized attic • Additional coordination with the HVAC designer and energy modeler may be necessary	Building design must accommodate code requirements	Clearly communicate needs to the structural engineer (e.g. on truss design and ceiling framing) and HVAC designer
Builder/ Developer	• Develops general specifications that form the basis for the house design • Coordinates with the architect and energy modeler to arrive at a design that meets energy code requirements • Contracts with the HVAC designer, framing, mechanical, and insulation contractors, and HERS rating organization • Submits plans to the enforcement agency for approval • Provides the HERS rater with the Certificates of Compliance and Installation	• Must coordinate with the architect and trades to ensure structural and mechanical needs are met, for example in the case of buried ducts, air handler locations, ceiling design, insulation depth, and other considerations that will facilitate proper installation	May require additional coordination between the HVAC designer and insulation and HVAC installers	Clearly communicate needs to the framing, HVAC, and insulation contractors
Energy Modeler	• Completes preliminary compliance evaluation • Coordinates modifications with architect and builder to achieve desired energy compliance margins • Creates Certificate of Compliance and initiates registry process	No change in workflow required	Modeler not responsible for compliance and enforcement	Communicate modeling assumptions to builder

Market Actor	Task(s) in current compliance process relating to the CASE measure	How will the proposed measure impact the current task(s) or workflow?	How will the proposed code change impact compliance and enforcement?	Opportunities to minimize negative impacts of compliance requirement
Building Official/ Enforcement Agency	• Receives Certificate of Compliance and plan set • Reviews plan set for general code compliance • Completes inspections to ensure compliance with all building (structural, and energy codes	Will require familiarity with prescriptive code changes relating to buried ducts and cathedral attics	The building official may have to take a more active role in compliance	Arrange meeting to review prescriptive requirements for the new measures
HVAC Designer	• Completes required equipment sizing calculations • Develops equipment specifications and provides plans and specifications	• Significant attention must be paid to the buried duct design to ensure full coverage • Must complete *required* Manual D and duct layouts if not standard practice • Initially need more coordination with the builder than typical	Minimal to no change	• Provide clear drawings calling out duct diameters, zone damper locations, insulation depth, allowable duct exposure, and noting any locations where insulation dams may be needed • Utilize advanced design tools such as Kwik Model to facilitate duct sizing and layouts. • Include radial duct design approaches where needed
HERS Rater	• Receives registered certificates of compliance and installation • Verifies registration of applicable certificates of installation • Confirm HVAC and insulation contractor diagnostic test results and perform applicable field verification and diagnostic testing including insulation levels; HVAC equipment specifications, duct design, airflow, and duct leakage as required • Complete and submit Certificate of Verification to the registry	• Verification of duct sealing and leakage tests must occur during rough-in • Verification of full duct burial is an added inspection completed in lieu of or in addition to QII (if needed for compliance)	• HERS role is key to compliance and enforcement as with all measures • Compliance will be easier to verify than for the existing detailed buried duct performance path	Ensure that raters are familiar with the new prescriptive requirements

Market Actor	Task(s) in current compliance process relating to the CASE measure	How will the proposed measure impact the current task(s) or workflow?	How will the proposed code change impact compliance and enforcement?	Opportunities to minimize negative impacts of compliance requirement
HVAC Contractor	• Receives HVAC plans and specifications • Installs equipment including air handlers and ducting in accordance with plans and specifications • Completes necessary diagnostic testing • Signs certificate of installation	• The contractor must become acquainted with buried duct installation practices and have an understanding of the maximum distance that ducts can be above the lower truss cords. • Coordination with the insulation contractor may be necessary; duct markers must be installed. • Suspending ducts with strapping must not be done except where ducts are installed parallel to trusses and are unsupported.	Careful observance of design drawings is critical to compliance	Educating the uninformed on buried duct practices and requirements, radial duct designs, how to avoid cross-overs, etc. would be time well spent.
Insulation Contractor	• Receives structural plans and relevant compliance forms from the builder • Installs insulation in accordance with manufacturer specified density to achieve full R-value per building specifications and to meet QII requirements as applicable • Signs certificate of installation	• Insulators must be careful to avoid damaging ducts during the application process • May increase time required to blow insulation	The necessity to cover all ducts may enhance compliance with attic R-value requirements.	Oversight of insulators on initial installs would help avoid damage to ducts.
Site Superintendent	Schedules and coordinates activities of subcontractors, the building inspector, and the HERS rater	The site superintendent can play a key role in coordinating work between HVAC installers and insulation contractors until a level of familiarity is established.	Minimal to no change	Ensure site superintendent is aware of role in coordinating work.

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 CEC in this Draft CASE Report are generally supported. Public stakeholders provide valuable feedback on draft analyses and help identify and address challenges to adoption including cost effectiveness, market barriers, technical barriers, compliance and enforcement challenges, or potential impacts on human health or the environment. Some stakeholders also provide data that the Statewide CASE Team uses to support analyses.

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

Utility-Sponsored Stakeholder Meetings

Utility-sponsored stakeholder meetings provide an opportunity to learn about the Statewide CASE Team's role in the advocacy effort and to hear about specific code change proposals that the Statewide CASE Team is pursuing for the 2025 code cycle. The goal of stakeholder meetings is to solicit input on proposals from stakeholders early enough to ensure the proposals and the supporting analyses are vetted and have as few outstanding issues as possible. To provide transparency in what the Statewide CASE Team is considering for code change proposals, during these meetings the Statewide CASE Team asks for feedback on:

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

The Statewide CASE Team hosted one stakeholder meeting for the proposed measures via the webinar described in Table 50. Please see below for dates and links to event pages on Title24Stakeholders.com. Materials from each meeting, such as slide presentations, proposal summaries with code language, and meeting notes, are included in the bibliography (Section 6) of this report [(Statewide CASE Team 2023a), (Statewide CASE Team 2023b), (Statewide CASE Team 2023c), (Statewide CASE

Team 2023d)]. A second stakeholder meeting is planned for May 17th and will present updates on the buried duct measure.

Table 50: Utility-Sponsored Stakeholder Meetings

Meeting Name	Meeting Date	Event Page from Title24stakeholders.com
First Round of Utility-Sponsored Stakeholder Meeting: Nonresidential, Multifamily, Single Family Envelope Utility-Sponsored Stakeholder Meeting	Tuesday, February 14, 2023	https://title24stakeholders.com/event/nonresidential-multifamily-and-single-family-envelope-utility-sponsored-stakeholder-meeting/
Second Round of Utility-Sponsored Stakeholder Meeting: Single Family Buried Ducts & High Performance Windows, Multifamily Envelope, and Indoor Air Quality Utility-Sponsored Stakeholder Meeting	Wednesday, May 17, 2023	https://title24stakeholders.com/event/single-family-buried-ducts-high-performance-windows-and-multifamily-envelope-utility-sponsored-stakeholder-meeting/

The first round of utility-sponsored stakeholder meetings occurred in January and February 2023 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 2025 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 is planned for May 2023 and will provide updated details on proposed code changes. The second round of meetings will introduce early results of energy, cost-effectiveness, and incremental cost analyses, and solicit 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 3,000 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 (and cross-promoted on the CEC LinkedIn page) two weeks before each meeting to reach out to individuals and larger organizations and channels outside of the listserv. The Statewide CASE Team conducted extensive personal outreach to stakeholders identified in initial work plans who had not yet opted into the listserv. Exported webinar meeting data captured attendance numbers and individual comments, and recorded outcomes of live attendee polls to evaluate stakeholder participation and support.

Statewide CASE Team Communications

The Statewide CASE Team held personal communications over email and phone with numerous stakeholders when developing this report. Those contacted for the Buried Ducts proposal are listed in Table 51.

Table 51: Engaged Stakeholders

Organization/Individual Name	Market Role	Mentioned in CASE Report Sections
Advocacy Groups	Beyond Efficiency	Buried Ducts
Builders/Developers & Industry Associations	CBIA	Buried Ducts/ Cathedral Ceilings
Builders/Developers & Industry Associations	KB Homes	Buried Ducts/ Cathedral Ceilings
Builders/Developers & Industry Associations	Lennar Homes	Buried Ducts
Building Officials, Industry Association and Consultant	City of Davis (former), CALBO	Buried Ducts
HERS Rater	CalCERTS, Inc.	Buried Ducts
HVAC Contractor - New Homes & Retrofit	Villara	Buried Ducts
HVAC Designer	Harris & Sloan	Buried Ducts/ Cathedral Ceilings
Industry Association / Consultant	CONSOL	Buried Ducts
Industry Association / Consultant	Bright Green Strategies	Buried Ducts
Industry Association / Consultant	SPRI	Cathedral Ceilings
Insulation Manufacturers	Owens Corning	Buried Ducts/ Cathedral Ceilings
Manufacturers	Sika Corporation/Rmax	Cathedral Ceilings
National Laboratories	Oak National Laboratory	Buried Ducts

Builder Survey

As part of the stakeholder outreach conducted by the Statewide CASE Team, a survey is underway to gather feedback from the building sector on numerous proposals. The survey is currently in development by the Statewide CASE Team with input from Evergreen Economics, who will administer the survey. The survey will be sent to members of the California Building Industry Association (CBIA) and results will be published in the final version of this CASE Report.

Appendix G: Energy Cost Savings in Nominal Dollars

The CEC requested energy cost savings over the 30-year period of analysis in both 2026 present value dollars (2026 PV$) and nominal dollars. The cost effectiveness analysis uses energy cost values in 2026 PV$. Costs and cost effectiveness using and 2026 PV$ are presented in sections 0 and 3.4 of this report. This appendix presents energy cost savings in nominal dollars.

Table 52: Nominal LSC Savings Over 30-Year Period of Analysis – Per Home – New Construction – 2100/2700 Weighted

Climate Zone	30-Year LSC Electricity Savings (Nominal $)	30-Year LSC Natural Gas Savings (Nominal $)	Total 30-Year LSC Savings (Nominal $)
1	$347	$10,204	$10,551
2	$182	$5,321	$5,502
3	$2,802	$0	$2,802
4	N/A	N/A	N/A
5	$182	$4,688	$4,870
6	$237	$1,758	$1,995
7	$529	$1,506	$2,035
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	($182)	$3,952	$3,771

Table 53: Nominal LSC Savings Over 30-Year Period of Analysis – Per Home – New Construction – Small Home

Climate Zone	30-Year LSC Electricity Savings (Nominal $)	30-Year LSC Natural Gas Savings (Nominal $)	Total 30-Year LSC Savings (Nominal $)
1	$23	$600	$622
2	$68	$240	$308
3	$260	$0	$260
4	N/A	N/A	N/A
5	$11	$93	$105
6	$79	$0	$79
7	$113	$0	$113
8	N/A	N/A	N/A
9	N/A	N/A	N/A
10	N/A	N/A	N/A
11	N/A	N/A	N/A
12	N/A	N/A	N/A
13	N/A	N/A	N/A
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	($351)	($400)	($751)

Appendix H: Effective R-values of Buried Ducts

Figure 6 illustrates a heat transfer network of ducts partially or fully buried in attic insulation. From this network, the effective R-value can be found in various ways, though using the heat flow at the upper attic insulation surface is typically the most convenient. As seen in Figure 6, there are two simulation scenarios presented. One for which conditioned air flows through the ducts, one for which the ducts are not conditioned. Both simulation scenarios are needed to calculate the effective R-value.

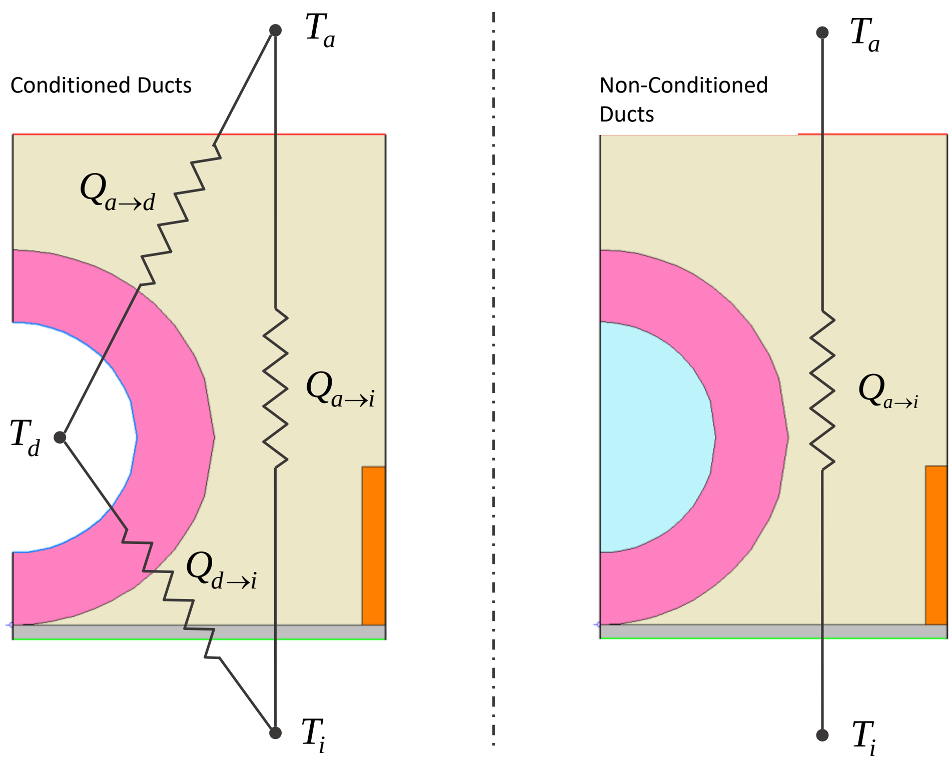

Figure 6: Left-hand picture depicts a heat transfer network representing a buried duct inside attic blown-in insulation and resting on top of the ceiling drywall. Right-hand picture represents the same case but with no conditioned air running through the ducts.

Left-hand illustration of Figure 6 depicts a buried duct inside blown-in attic insulation. Due to the symmetrical nature of a duct cross section and the surroundings, a simulation model can be setup only to simulate one side of the duct. For the case of a buried duct, the total heat flow at the upper surface of the blown-in insulation, Q_a is the sum of the heat flow between the attic and the duct, $Q_{a\to d}$ and the heat flow between the attic and the interior, $Q_{a\to i}$.

$$Q_{a \to d} + Q_{a \to i} = Q_a \quad (1)$$

Likewise, the total heat flow at the interior surface of the duct, Q_d is the sum of the heat flow between the attic and the duct, $Q_{a \to d}$ and the heat flow between the duct and the interior, $Q_{d \to i}$.

$$Q_{a \to d} + Q_{d \to i} = Q_d \quad (2)$$

Finally, the total heat flow at the interior ceiling plane, Q_c is the sum of the heat flow between the attic and the interior, $Q_{a \to i}$ and the heat flow between the duct and the interior, $Q_{d \to i}$.

$$Q_{a \to i} + Q_{d \to i} = Q_i \quad (3)$$

The effective R-value for the duct can be found using the heat flows defined in Eq.1 The heat flow between the ducts and the attic, $Q_{a \to d}$ is given by subtracting the heat flow between attic and the interior, $Q_{a \to i}$ from the total heat flow at the attic surface, Q_a.

$$Q_{a \to d} = Q_a - Q_{a \to i} \quad (4)$$

The simulation scenario with no conditioned air present inside the ducts provides $Q_{a \to i}$, as depicted in right-hand illustration of Figure 6. The simulation scenario with conditioned air running through the ducts generates Q_a, as shown by the left-hand illustration of Figure 6.

Finally, $Q_{a \to d}$ allows to determine the effective R-value of the ducts using the inner duct surface area, $A_{d,i}$ and the temperature difference between the attic and the air inside the ducts, ΔT.

$$R_{eff} = \frac{A_{d,i} \cdot \Delta T}{Q_{a \to d}} \quad (5)$$

Appendix I: Attic Temperature Simulation Inputs

As seen in Appendix H, the effective R-value of ducts is found using three boundary conditions; the temperatures in the attic, the air inside ducts, and that of the indoor space. Due to the dynamic nature of three boundary conditions, the direction and magnitude of heat flow is a function of the three temperature gradients for which the three temperature conditions contribute to. With that said, it's of great importance to determine which attic temperature to assume during heating and cooling demand to calculate realistic effective R-values for buried ducts.

Figure 7 depicts average attic temperature during heating and cooling season for traditional vented attic (simulated as Option C according to Table 150.1-A). Here, the average temperature is weighted against demand. Meaning, the average attic temperature represents the most common condition which calls for either a heating or cooling demand. Figure 7 shows the weighted average for all California Climate Zones. The overall average temperature is 107°F during cooling, and 47°F during heating across all climates.

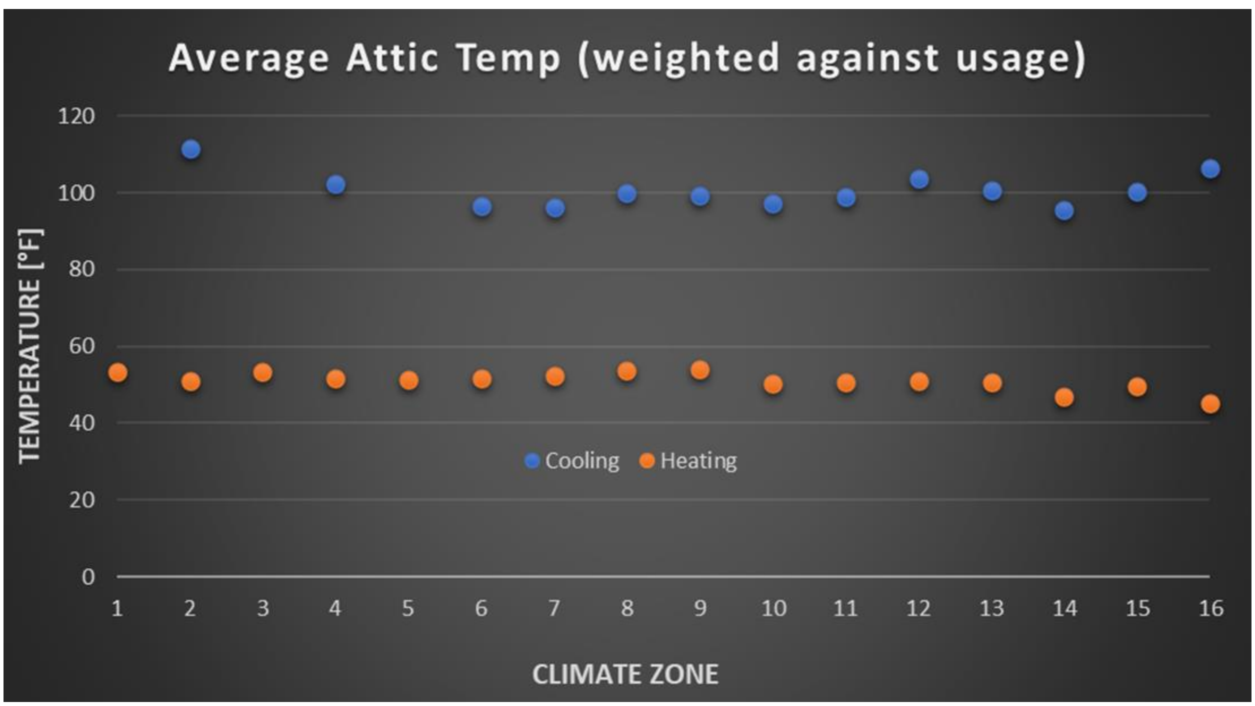

Figure 7: Average attic temperature used to calculate effective R-values of buried ducts.