Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

High Performance Walls – Final Report

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Residential Envelope

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EXECUTIVE SUMMARY

Introduction

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

Measure Description

The proposed residential high performance walls measure increases the prescriptive performance of the residential envelope in certain climates, reducing the amount of heat transfer through walls and subsequently reducing heating, ventilation, and air conditioning (HVAC) loads. This prescriptive measure applies to single family buildings, both new construction and additions. Specifically, the proposed measure reduces the prescriptive wall U-factor from 0.051 to 0.043 in Climate Zones 1 and 11 through 16. While the proposed measure was also found to be cost effective for low-rise multifamily buildings in Climate Zones 11, 15 and 16, because of unique challenges experienced in multifamily construction this building type has been excluded from the proposal. This prescriptive measure does not apply to alterations.

Under the 2016 Title 24, Part 6 code cycle, high performance walls were introduced as a residential prescriptive requirement. The work for the 2019 Title 24, Part 6 code cycle expands on that conducted for the previous code cycle as well as the market transformation activities that are currently underway to help transition California builders toward high performance walls.

Scope of Code Change Proposal

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

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Will Compliance Software Be Modified	Modified Compliance Document(s)
High Performance Walls	Prescriptive	150.1	None	Yes	None

Market Analysis and Regulatory Impact Assessment

The construction of high performance walls (U-factor of 0.051 or lower) is not currently a mainstream residential industry practice in California, although some early adopter builders have begun to experiment with them in preparation for the 2016 and 2019 code updates (Pacific Gas & Electric 2014) and (Southern California Edison 2014)). There are several market transformation activities currently underway which are targeted at the production home market; there is an expectation of some level of market shift between the time of writing (summer 2017) and the effective date of the 2019 Standards in January 2020. There are various product offerings for components of high performance walls that are readily available today from multiple providers in the marketplace. Many of these product offerings are commonly used throughout California's residential construction industry, just not necessarily in a combination that comprises the proposed measure (i.e., 2x6 walls combined with continuous exterior insulation).

This proposal is cost-effective in many climate zones over the period of analysis. Overall, this proposal increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure.

The proposed changes to Title 24, Part 6 Standards have a negligible impact on the complexity of the standards or the cost of enforcement. When developing this code change proposal, the Statewide CASE Team interviewed building officials, Title 24 energy analysts and others involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

Cost-Effectiveness

The proposed code change was found to be cost-effective for all climate zones where it is proposed to be required. The benefit-to-cost (B/C) ratio compares the lifecycle benefits (cost savings) to the lifecycle costs. Measures 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 savings. The B/C ratio for this measure ranged between 1.04 and 1.32 depending on climate zone. See Section 5 for a detailed description of the cost-effectiveness analysis.

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the proposed code change. See Section 6 for more details.

Table 2: Estimated Statewide First-Year[a] Energy and Water Savings

Measure	First-Year Electricity Savings (GWh/yr)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Water Savings (million gallons/yr)	First-Year Natural Gas Savings (million therms/yr)
New Construction	2.1	2.4	N/A	0.6
Additions	0.3	0.3	N/A	0.1
Alterations	N/A	N/A	N/A	N/A
TOTAL	**2.4**	**2.7**	**N/A**	**0.7**

a. First-year savings from all buildings completed statewide in 2020.

Compliance and Enforcement

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process will have on various market actors. The compliance process is described in Section 2.5. The impacts the proposed measure will have on various market actors is described in Section 3.3 and Appendix B. The key issues related to compliance and enforcement are summarized below:

- Training will be necessary to educate the construction industry on strategies for high performance wall installation. While cost-effective solutions exist, the industry generally is not familiar with nor has much experience with them.
- Builders may need to account for additional time for wall installation and coordinate this with the installers.
- Designers may need to develop new details for thicker walls. There are many examples available to the industry.

Although a needs analysis has been conducted with the affected market actors while developing the code change proposal, the code requirements may change between the time the final CASE Report is submitted and the time the 2019 Standards are adopted. The recommended compliance process and compliance documentation may also evolve with the code language. To effectively implement the adopted code requirements, a plan should be developed that identifies potential barriers to compliance when rolling-out the code change and approaches that should be deployed to minimize the barriers.

1. INTRODUCTION

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

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

The overall goal of this CASE Report is to propose a code change proposal for high performance walls. The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during two public stakeholder workshops that the Statewide CASE Team held on September 14, 2016 and March 14, 2017.

Section 2 of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.

Section 3 presents the market analysis, including a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards such as fire, seismic, and other safety standards and whether technical, compliance, or enforceability challenges exist.

Section 4 presents the per unit energy, demand, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate energy, demand, and energy cost savings.

Section 5 presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of additional materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs. That is, equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

Section 6 presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2019 Standards take effect. This includes the amount of energy that will be saved by California building owners and tenants, and impacts (increases or reductions) on material use with emphasis placed on any materials that are considered toxic. Statewide water consumption impacts are also considered.

Section 7 concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Reference Appendices, Alternative Calculation Manual (ACM) Reference Manual, Compliance Manual, and compliance documents.

2. Measure Description

2.1 Measure Overview

The proposed residential high performance walls measure would increase the prescriptive performance of the residential envelope in certain climates, which would reduce the amount of heat transfer through walls and subsequently reduce heating, ventilation, and air conditioning (HVAC) loads. This prescriptive measure would apply to single family new construction and additions. Specifically, the proposed measure would reduce the prescriptive wall U-factor from 0.051 to 0.043 in Climate Zones one and 11 through 16. While the proposed measure was also found to be cost effective for low-rise multifamily buildings in Climate Zones 11, 15 and 16, because of unique challenges experienced in multifamily construction this building type has been excluded from the proposal. This proposed prescriptive measure does not apply to alterations. This code change would modify existing code language, but would not create any new sections of code.

2.2 Measure History

High performance walls were introduced as a residential prescriptive requirement for the 2016 Title 24, Part 6 code cycle. The 2016 Statewide CASE Team (California Statewide Codes and Standards Team 2014) evaluated various wall assembly types with cavity insulation ranging from R-15 to R-23 and exterior rigid insulation ranging from R-4 to R-10. The analysis found that a high performance wall with a U-factor of 0.046 was cost-effective in all climate zones except for six through eight. Ultimately, a wall with a U-factor of 0.051 was adopted under the code for all climate zones except six and seven (coastal Southern California). The work for the 2019 Title 24, Part 6 code cycle expands on that conducted for the previous code cycle as well as the market transformation activities that are currently underway to help transition California builders toward high performance walls.

The 2019 Title 24, Part 6 code cycle is poised to require zero net energy in all residential buildings. The "loading order" defined in California's Energy Action Plan (State of California 2003) prescribes that cost-effective efficiency and conservation measures be prioritized prior to installing new generation. Considering this, it is important that this process investigate and support cost-effective envelope improvement opportunities prior to introducing photovoltaic (PV) generation. With high performance walls prescriptively required under the 2016 Title 24, Part 6 Standards, it is expected that the level of construction industry comfort with the approach would continue to increase between now and 2020. A description of current practices in California is provided in Section 3 this report.

The 2016 Title 24, Part 6 Standards allows a solar photovoltaic (PV) Compliance Credit (PV Credit)[1] that can be used when complying via the performance approach. The PV Credit can be used in the climate zones that prescriptively require high performance walls and/or high performance attics, which are all zones except for southern California coastal zones (Climate Zones 6 and 7). The PV Credit is capped at the magnitude of the benefit that high performance walls and attics provide in that climate

[1] The minimum PV capacity is 2kW-DC for single family homes with conditioned floor area 2,000 square feet or less and 1kW-DC for multifamily units with conditioned floor area 1,000 square feet or less. For larger homes the minimum capacity increases per the calculations presented in the Residential ACM Reference Manual (California Energy Commission 2015a).

zone. In addition, there is a minimum PV sizing requirements of 2 kW direct current (dc) for single family and 1 kWdc for multifamily units. The recognized compliance benefit of the PV Credit is intentionally less than its actual benefit in terms of annual electricity generation. Nevertheless, the PV Credit gives builders the opportunity to pursue solar instead of these advanced measures and provides flexibility as they work towards increased familiarity and level of comfort with new construction techniques. However, the Energy Commission has indicated that sufficient market transformation activities will have occurred by the effective date of the 2019 Title 24, Part 6 Standards, and therefore the current PV Credit will no longer be allowed.

There are no preemption concerns with this measure.

2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each Title 24, Part 6 documents will be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Standards Change Summary

This proposal will modify the sections of the Building Energy Efficiency Standards as shown below. See Section 7.1 of this report for the detailed proposed revisions to the code language.

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

TABLE 150.1-A COMPONENT PACKAGE-A STANDARD BUILDING DESIGN: The proposed code change reduces the above grade framed walls U-factor requirement in the prescriptive table for single family homes in certain climate zones. This would reduce the energy use of residential buildings. This requirement cost-effectively increases the stringency of the standards, thereby minimizing the energy use of residential buildings, which in turn improves the state's economic and environmental health. The proposal also clarifies the distinction between exterior walls and demising walls and adds a row to Table 150.1-A, which states the U-factor requirements for demising walls.

SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING LOW-RISE RESIDENTIAL BUILDINGS

The proposed code change slightly modifies the exception for additions that allows the extension of existing wood-framed wall to retain the dimensions of the existing walls. The required cavity insulation for 2x6 framing would increase from R-19 to R-21.

2.3.2 Reference Appendices Change Summary

The proposed code change does not modify the appendices of the standards. However, it is recommended that tables in Joint Appendices JA4.3 be reviewed and compared to the U-factor calculations within CBECC-Res (California Building Energy Code Compliance for Residential Buildings Software) to ensure consistency.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

This proposal modifies the sections of the Residential Alternative Calculation Method (ACM) Reference Manual as shown below. See Section 7.3 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

SECTION 2 – The Proposed Design and Standard Design

2.5.6.3 Exterior Walls: The proposed changes would reduce the above-grade framed wall U-factor requirement for single family homes and subsequently the description of the Standard Design in the ACM would be updated to reflect the wall assembly U-factors defined in Table 150.1-A.

2.10.3.2 Exterior Walls: The proposed changes would reduce the above-grade framed wall U-factor requirement for single family additions and subsequently the description of the Standard Design in Table 22 of the ACM would be updated to reflect the wall assembly U-factors defined in Table 150.1-A. Additionally, the proposal includes a revision to the Standard Design, which would implement the prescriptive provision that allows eliminating continuous insulation for walls in an addition that are being extended.

2.3.4 Compliance Manual Change Summary

The proposed code change will modify the following section of the Title 24, Part 6 Compliance Manual:

- Section 3.6.2.2 Walls
- Section 3.6.3.2 Wall Assembly
- Section 9.5 Additions

2.3.5 Compliance Documents Change Summary

The proposed code change will not modify the compliance documents.

2.4 Regulatory Context

2.4.1 Existing Title 24, Part 6 Standards

The 2016 Title 24, Part 6 Standards prescriptively requires framed walls to meet a maximum U-factor of 0.051 for all climate zones except six and seven, where a 0.065 U-factor wall is required. Using the performance approach the PV Credit can be used to trade-off the high performance wall and high performance attic requirement in those climate zones where they are prescriptively required.

There are no local ordinances that require high performance walls. However, some jurisdictions are adopting local ordinances that require above code performance, such as Title 24, Part 11 CALGreen Tier I or II.

2.4.2 Relationship to Other Title 24 Requirements

Title 24, Part 2, the California Building Code: Chapter 7A – Materials and Construction Methods for Exterior Wildfire Expose (CA BSC 2016a), requires that exterior walls in new buildings located in any Fire Hazard Severity Zone or any Wildland-Urban Interface (WUI) Fire Area are either non-combustible or fire resistant. One-hour fire resistive wall assemblies may also be required in all or a portion of walls in multifamily buildings. See Section 3.2.3 for further discussion.

2.4.3 Relationship to State or Federal Laws

There are no federal regulatory requirements that address the same topic as this proposed change.

2.4.4 Relationship to Industry Standards

The 2015 International Energy Conservation Code (IECC) prescriptively requires a wall with R-20 cavity insulation and R-5 continuous insulation, roughly equivalent to California's high performance wall under the 2016 Title 24, Part 6 Standards, in Department of Energy (DOE) cold Climate Zones six through eight. Only a small part of California in Alpine and Mono counties falls under this requirement in what is California Climate Zone 16. The 2015 IECC requirement in the remainder of California is less stringent.

Title 24, Part 2.5, the 2016 California Residential Code (CRC): Chapter 7 – Wall Covering (CA BSC 2016b), requires class I or II vapor retarders on the interior of framed walls in Climate Zones 14 and 16. Alternatively, it allows for a class III vapor retarder if either a vented cladding system or insulated sheathing with a minimum R-value of four is also applied. This is in contradiction to the 2015

International Residential Code (IRC) (International Code Council 2016) for Climate Zone 16, portions of which coincide with DOE Climate Zones five and six. As is shown in Figure 1, the IRC requirement is more stringent than that in the CRC for these two DOE climate zones. While this is out of the purview of this CASE Report, it is recommended that this be evaluated further.

TABLE R702.7.1 CLASS III VAPOR RETARDERS

CLIMATE ZONE	CLASS III VAPOR RETARDERS PERMITTED FOR:[a]
Marine 4	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 2.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 3.75 over 2 × 6 wall.
5	Vented cladding over wood structural panels. Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 7.5 over 2 × 6 wall.
6	Vented cladding over fiberboard. Vented cladding over gypsum. Continuous insulation with *R*-value ≥ 7.5 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 11.25 over 2 × 6 wall.
7 and 8	Continuous insulation with *R*-value ≥ 10 over 2 × 4 wall. Continuous insulation with *R*-value ≥ 15 over 2 × 6 wall.

Figure 1: Table R702.7.1 from the 2015 International Residential Code.

2.5 Compliance and Enforcement

The Statewide CASE Team collected input during the stakeholder outreach process on what compliance and enforcement issues may be associated with this measure. This section summarizes how the proposed code change will modify the code compliance process. Appendix B presents a detailed description of how the proposed code changes could impact various market actors. 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 code change proposal will affect single family new construction buildings and additions, regardless of the compliance approach applied (prescriptive or performance). The key steps and changes to the compliance process are summarized below: There are training programs currently underway, such as the Workforce Instruction for Standards and Efficiency (WISE) program and Energy Code Ace Title 24, Part 6 Essentials courses, which should be leveraged to provide support to the industry in preparation for the 2019 Title 24, Part 6 Standards. See Section 3 for details on training programs.

- **Design Phase**: Some high performance wall designs would require that architects and designers develop new details to be provided in drawings. These may include but are not limited to the wall components and thicknesses, how the cladding is attached over the rigid insulation, connections between the wall and roof, and flashing details around windows and doors.
- **Permit Application Phase**: Generally, the changes to the existing permit application phase process are minimal. During this phase, the plans examiner reviews the permit application document package and verifies that the specifications called out in the Title-24, Part 6 report match the building plans. Specifically regarding walls, the plans examiner will verify that the architectural details properly account for the wall assembly identified in the Title 24, Part 6 compliance analysis. Some plans examiners have indicated that this may increase the time necessary for plan review.

- **Construction Phase**: The builder would continue to provide coordination between the subcontractors. There may be additional time for which to account in the project schedule for picture framing around the windows and fastening of exterior rigid insulation if hand nailing or screwing will be done. The builder must ensure that flashing details are adequate and are implemented properly.
- **Inspection Phase**: Generally, there are no changes to the existing inspection application phase process. If the quality insulation inspection (QII) credit is applied, then the HERS Rater will inspect project insulation and air barriers including all wall insulation. The building inspector will conduct final field inspections before issuing a certificate of occupancy.

Although there are market barriers that must be overcome for the successful and widespread implementation of high performance walls (see Section 3.2), there would be no significant challenges or significant burdens placed on any market actor as it relates to compliance and enforcement. High performance walls are currently accommodated in the code and compliance credit has always been allowed under the performance compliance approach. This being acknowledged, it is recommended that the training and incentive programs currently underway continue across the state, providing support to and preparing the industry for the 2019 Title 24, Part 6 Standards.

If this code change proposal is adopted, the Statewide CASE Team recommends that information presented in this section, Section 3 and Appendix B be used to develop a plan that identifies a process to develop compliance documentation and how to minimize barriers to compliance.

3. MARKET ANALYSIS

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry players who were invited to participate in utility-sponsored stakeholder meetings held on September 14, 2016 and March 14, 2017.

3.1 Market Structure

There are three primary components that comprise a high performance wood-framed wall, the predominant wall assembly type in California residential construction. These components are the wall framing, cavity insulation, and exterior rigid continuous insulation. There are various product offerings for these components that are readily available today from multiple providers in the marketplace. Many of these product offerings are commonly used throughout California's residential construction industry, just not necessarily in a combination that comprises the proposed measure (i.e. 2x6 walls combined with continuous exterior insulation). Other related wall components include structural sheathing, air control and vapor control layers, exterior cladding, and interior finish. While these are all important aspects of a durable wall assembly, they are independent of the characteristics that make a wall a high performance wall. The focus of this analysis is on walls with one-coat stucco as it represents the predominant cladding choice of California production builders and is used as the reference wall-cladding system in the ACM Reference Manual (California Energy Commission 2015a). While the proposed measure is applicable to walls with siding and other cladding systems, different implementation strategies may be necessary. The performance compliance path allows builders to install other efficiency measures to meet the energy budget and tradeoff high performance walls if they choose not to achieve the prescriptive U-value.

Following is a summary of the principal manufacturers of wall insulation products.

3.1.1 Cavity Insulation

Fiberglass batt insulation is the predominant insulation type applied in residential California walls (see Section 3.2). Standard-density batt insulation is rated at R-13 for 2x4 walls and R-19 for 2x6 walls; however, because of compression, R-19 batt performs closer to R-18. High-density fiberglass batt options are also available at R-15 and R-21 for 2x4 and 2x6 walls, respectively. Owens Corning, Johns Manville, Knauf Insulation, and CertainTeed are four major manufacturers of fiberglass batt insulation. Owens Corning also makes an R-24 batt product that fits in 2x6 walls, although this is not commonly available in the United States.

Other insulation materials include mineral-wool batts, blown-in cellulose or fiberglass, and open and closed cell spray foam. These options offer certain benefits over traditional batt fiberglass insulation, but are currently more expensive on a per-R-value basis.

3.1.2 Rigid Continuous Insulation

There are currently three major types of rigid board insulation that are typically applied in residential wall construction. These are expanded polystyrene (EPS), extruded polystyrene (XPS), and polyisocyanurate (polyiso). In addition, there is a variation on EPS that is a graphite-enhanced expanded polystyrene, or GPS, that is now becoming increasingly available. EPS provides an insulating value of roughly R-4 per inch and is the most common continuous insulation used in California residential homes. Current manufacturers include Insulfoam and Atlas EPS, among others. Both XPS and GPS provide R-5 per inch. XPS is produced by multiple manufacturers including Dow, Owens Corning, and Knauf Insulation. GPS is currently made with a resin (Neopor resin), which is manufactured exclusively by BASF. However, BASF’s patent on Neopor is expiring soon and other manufacturers are expected to enter the market with competitive products. Insulfoam and Atlas EPS currently manufacturer GPS using the Neopor product. Polyiso has an R-value of R-6 per inch and is made by Dow, Rmax, and Johns Manville.

3.1.3 Other Insulation Solutions

There is a lot of innovation in the marketplace currently, and manufacturers are developing alternative solutions that provide additional benefits to builders and installers. Panelized solutions are constructed in a manufacturing environment and typically are installed onsite, pre-assembled, resulting in labor cost savings, and potentially accelerating construction schedules. One such type of assembly is structural insulation panels, or SIPs. SIPs consist of an insulated foam core sandwiched between two structural layers, typically oriented strand board (OSB). Other solutions are Covestro’s PUReWall and Rmax’s ThermaBase. The PUReWall is a panelized 2x4 wood framed wall with 1-1/2-inches of closed cell spray foam in the cavity and one-inch to 1-1/2-inches of polyiso installed on the exterior. R-11 batt insulation is field applied to fill the remainder of the cavity for an assembly U-factor of 0.051 (one-inch polyiso) to 0.043 (1-1/2-inches polyiso). The ThermaBase is a composite exterior solution that combines up to 4-1/2-inches of polyiso insulation board bonded to a nailing surface, typically 7/16-inch OSB. The nailing surface allows for direct attachment of cladding systems weighing up to 30 pounds per square foot.

There are also alternative building strategies that can result in improved thermal performance as compared to a traditional wood framed wall. One such strategy is double stud walls where two layers of wood studs provide a thicker total wall assembly. An example of an assembly is two 2x4 stud layers on a 2x10 top and bottom plate; this results in a gap between the two stud layers providing a thermal break. Depending on the insulation used, assembly R-values can be as high as R-30. Advanced wall framing (AWF) techniques reduce the amount of wood in a framed wall optimizing the area available for insulation. These techniques include 24-inch on center (oc) stud spacing, double stud corner, and single top plates, among other criteria.

Table 3 demonstrates four different wood framed wall assemblies that meet the proposed 0.043 U-factor requirements.

Table 3: Examples of Wood-Framed Wall Assemblies and U-Factors

Stud	Cavity Insulation	Cavity Insulation Type	Exterior Insulation	U-Factor
2x6 16” oc	R21	Loose-fill cellulose or high density batt	R7.5	0.043
2x4 AWF	R15	High density batt	R10	0.043
2x6 16” oc	R19	Low density batt	R9	0.042
2x6 16” oc	R31	Closed-cell spray foam (ccSPF)	R5	0.041

3.1.4 Accessories

In addition to the insulation, there are other required components to provide a complete durable wall system. The components that are discussed in this report include stucco system fastening, window and door flashing, and weep screeds. Although this is by no means a complete list, these three components impact the costs moving from a 0.051 to a 0.043 U-factor wall.

Senco, Paslode, and Bostitch are three major manufacturers that provide staples, nails and associated pneumatic tools to the stucco industry. Based on current practice, staples are the most common choice for fastening stucco lath over rigid insulation to the structural framing beneath. Other fastener options include roofing nails, screws, and cap nails. Rodenhouse is a fastening company that has developed an automatic feed screw gun that coupled with their washer is designed for quick attachment of continuous insulation to wood or metal framing.

With thicker exterior continuous insulation layers, a thicker weep screed is necessary to ensure that moisture can adequately escape the bottom of the cladding system. There are many manufacturers of weed screeds including Amico, Brand X Metals, and Stockton Wire Products, among others.

Window and door flashing for wall systems with up to one-inch of continuous insulation is a standard product. Strategies for thicker levels of continuous insulation are discussed in the following section. There has been innovation in this product category by the company Thermal Buck, which has developed a high performance insulated wood buck that simplifies water and air sealing around window and doors while extending the continuous insulation all the way to the rough opening.

3.2 Technical Feasibility, Market Availability, and Current Practices

The construction of high performance walls (U-factor of 0.051 or lower) is not currently a mainstream residential industry practice in California, although some early adopter builders have begun to experiment with them in preparation for the 2016 and 2019 code updates ((Pacific Gas & Electric 2014) and (Southern California Edison 2014)). There are several market transformation activities currently underway and there is an expectation of some level of market shift between the adoption of the 2016 Title 24, Part 6 Standards and 2020. Under the current 2016 Title 24, Part 6 code builders can trade off high performance walls and high performance attics using the PV Credit; however, the Energy Commission has indicated that sufficient market transformation activities will have occurred by implementation of the 2019 Title 24, Part 6 Standards, and therefore the current PV Credit will no longer be allowed. The builder decision on what approaches to apply to meet code is impacted by a range of factors including cost, marketability, building design constraints, and their comfort level with advanced envelope construction techniques. The Statewide CASE Team has heard a variety of perspectives from builders, contractors, energy consultants, and HERS Raters suggesting that some builders are pursuing the PV Credit, some are exploring high performance wall (and high performance attic) options, and some are looking for alternative methods of compliance (i.e., using other measures to offset the impact).

A 2016 Energy Commission report (California Energy Commission 2016) assessed the market for high performance walls by reviewing single family homes from 50 subdivisions across California. Collectively the sampled projects were represented by builders that produced 39.6 percent of all California single family construction in 2014. These projects may have been built under either the 2008 or the 2013 Title 24, Part 6 Standards. The following are key points established in the assessment regarding construction characteristics.

- 2x4 walls construction was the framing type on 98 percent of projects. Some sections of these homes may include 2x6 framing to accommodate plumbing, but the occurrence of single family homes with predominant 2x6 construction is rare.
- R-13 batt insulation was the predominant insulation type in 94 percent of projects. High density batt insulation (R-15 for 2x4 framing and R-21+ for 2x6 framing) was not found to be common.
- The industry is fairly evenly split between one-coat and three-coat stucco each representing 52 percent and 46 percent, respectively, of the surveyed projects. Past research has indicated that Southern California builders have preferred three-coat stucco (PG&E 2014). However, the results of this study did not confirm this and demonstrated a similar percentage of one-coat stucco applications in both regions. More recently, other experts have also commented that there is a trend towards one-coat stucco throughout the state.

While batt insulation is the predominant choice for residential wall cavities, there are other builders implementing or experimenting with alternative systems. One major production builder has been applying open-cell spray foam in wall cavities and attics for years, providing both insulating and air sealing benefits. This is their standard construction practice throughout California.

There are several market transformation activities currently underway. The Workforce Instruction for Standards and Efficiency (WISE) is a training and education program funded by the Energy Commission's Electric Program Investment Charge (EPIC) Program. The WISE program engages builders, manufacturers, and contractors to provide an exchange of best practices and solutions for high performance wall and attic construction. Their website[2] provides production installation guides and builder case studies, among other resources. The WISE team is also providing training directly to participating builders.

The IOUs provide builder and contractor support through various outreach activities, including the Code Readiness[3] and Emerging Technology programs, training centers, and incentive programs. PG&E's California Advanced Homes Program (CAHP) Master Builder program offered $1,000 to $4,000 per home under the 2013 Title 24, Part 6 Standards to builders incorporating both high performance walls and high performance attics. Recognizing that even with adoption of the 2016 Title 24, Part 6 Standards ongoing training and support is necessary to continue the market transformation effort of high performance walls, the current PG&E CAHP continues to offer a $200 "kicker" for projects that incorporate walls that meet the 2016 Title 24, Part 6 prescriptive requirements.

There are no required technological advances necessary to construct high performance walls today. The technology already exists, although there is the potential for product advances that make its implementation more cost-effective. Constructability challenges do exist. While some builders have been constructing similar walls for a long time and there are many available solutions, the California

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[2] http://www.wisewarehouse.org/

[3] The purpose of the Code Readiness programs is to support market transformation and increase code compliance for building measures that are important for achieving Title 24, Part 6 code goals, particularly zero net energy.

residential construction industry in general has not embraced this construction strategy. This is at least partly due to the relative novelty of the 2016 Standards at the time of the writing of this report, as builders are still exploring options to achieve compliance under the new code.

Meeting the proposed measure may be more of a challenge for certain projects. As discussed in Section 2.4.2 projects that are in the WUI or are otherwise subject to fire rated wall assemblies may need thicker walls to meet the prescriptive U-factor. This can present additional challenges with fastening and lot setback requirements, and may result in incremental costs higher than what is predicted in this report. This likely will impact multifamily projects more than single family, since multifamily buildings often require fire rated walls. This is one reason why multifamily buildings are not included in the proposal. The Statewide CASE Team has also been made aware that, while uncommon, some insurance companies will not insure one-coat stucco; alternatively, other builders are so averse to it they do not consider one-coat stucco an option. Stucco industry stakeholders have indicated there is no practical reason why continuous insulation cannot be installed under three-coat stucco, and in fact there are multiple three coat stucco products which provide instructions for installing their systems in combination with continuous insulation. However, this practice is very uncommon and would also require a shift in typical builder practice. With certain types of siding, such as Hardie Board, continuous insulation is limited to one-inch before furring strips are required, the result of which would be much higher incremental costs.

3.2.1 Window & Door Waterproofing

The primary challenge related to increasing wall performance through thicker exterior insulation surrounds the waterproofing of windows and doors. In a traditional one-coat stucco system (with one-inch of continuous insulation) the total thickness of the assembly beyond the framing member (or wood sheathing) is 1-3/8-inch (see Figure 2), consisting of one-inch continuous insulation and 3/8-inch for the lath, stucco base coat and finish coat. The typical practice in California involves installation of the window directly in the rough opening with the window flush-mounted to the structural sheathing or open framing behind. Most window manufacturers make residential windows with a nailing flange with a 1-3/8-inch setback. This setback accommodates the thickness of the one-coat stucco system, resulting in a finished product where the edge of the window and the wall system are in the same plane. Based on interviews with multiple stucco contractors, this approach is preferred for ease of waterproofing as well as aesthetics.

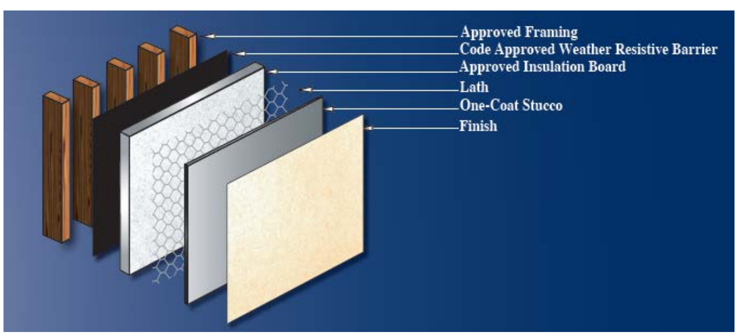

Figure 2: Typical one-coat stucco assembly detail.

Source: http://www.nocsa.org/pdf/onecoatstucco_fullpage.pdf

Walls with continuous insulation thicker than one-inch would require the window to be framed out with a wood buck[4] to maintain the window and the wall on the same plane. There are various approaches to this and the Fenestration Manufacturers Association (FAA), the American Architectural Manufacturers Association (AAMA), and the Window & Door Manufacturers Association (WDMA) came together to develop a set of best practices, which are presented in the FMA/AAMA/WDMA 500-16 standard practice document (FMA/AAMA/WDMA 2016).[5] Method C2 in the document reflects the current practice with one-inch of continuous insulation. Method B is the approach the Statewide CASE Team expects to be the preferred installer choice for walls with continuous insulation thicker than one-inch. In both cases the drainage plane is located behind the continuous insulation and the window and the wall remain in the same plane. This approach would require the installer to frame around the window with a wood buck that would be a half-inch thick for the case of 1-1/2-inches of continuous insulation, one-inch thick for the case of two inches of continuous insulation, and so on. Additional care would be necessary to ensure that this bump out is adequately weatherized. There is at least one alternative solution on the market – ThermalBuck[6] system, which is an insulated wood buck with integrated flashing. This type of solution provides an opportunity to reduce labor costs and improve overall wall performance by eliminating the thermal bridge underneath the wood buck.

There are other implementation strategies available, including the additional methods described in the FMA standard practice document. Builders can choose whichever approach they are most comfortable with while maintaining their internal cost and quality requirements. Training would be an important step in the process. While the new approaches are not novel or necessarily require unfamiliar materials or strategies, they do represent a new system and education is recommended.

3.2.2 Fastening

Stucco lath must be fastened directly to the wood studs just behind the insulation board according to requirements defined in manufacturers' code compliance reports, such as an ICC Evaluation Services Report, or according to an approved alternative method. Code compliance reports for one-coat stucco products typically cover installations with up to 1-1/2-inches continuous insulation and require the use of 16 gauge (GA) staples or 11GA roofing nails with a minimum penetration of one-inch into the wood studs. Fastening requirements for installations with greater than 1-1/2-inch insulation are governed by the 2016 California Residential Code (CRC): Chapter 7 Wall Covering (CA BSC 2016b). Figure 3 shows the table directly from the CRC, which describes the minimum fastener size and vertical spacing based on insulation thickness and cladding weight. One-coat stucco systems fall under the 11psf (pounds per square foot) cladding weight.

[4] A wood buck is a projection or extension to the structural wall framing around the rough opening of a window or door penetration.

[5] This document refers to the wood buck as a Rough Opening Extension Support Element (ROESE).

[6] https://thermalbuck.com/

TABLE R703.15.1
CLADDING MINIMUM FASTENING REQUIREMENTS FOR DIRECT ATTACHMENT OVER FOAM PLASTIC SHEATHING TO SUPPORT CLADDING WEIGHT[a]

CLADDING FASTENER THROUGH FOAD SHEATHING	CLADDING FASTENER TYPE AND MINIMUM SIZE[b]	CLADDING FASTENER VERTICAL SPACING (inches)	MAXIMUM THICKNESS OF FOAM SHEATHING[c] (inches)					
			16″ o.c. Fastener Horizontal Spacing			24″ o.c. Fastener Horizontal Spacing		
			Cladding Weight:			Cladding Weight:		
			3 psf	11 psf	25 psf	3 psf	11 psf	25 psf
Wood Framing (minimum 1 1/4-inch penetration)	0.113″ diameter nail	6	2	1	DR	2	0.75	DR
		8	2	1	DR	2	0.5	DR
		12	2	0.5	DR	2	DR	DR
	0.120″ diameter nail	6	3	1.5	0.5	3	0.75	DR
		8	3	1	DR	3	0.5	DR
		12	3	0.5	DR	2	DR	DR
	0.131″ diameter nail	6	4	2	0.75	4	1	DR
		8	4	1.5	0.5	4	0.75	DR
		12	4	0.75	DR	2	0.5	DR
	0.162″ diameter nail	6	4	4	1.5	4	2	1
		8	4	3	1	4	1.5	0.75
		12	4	2	0.75	4	1	DR

For SI: 1 inch = 25.4 mm, 1 pound per square foot = 0.0479 kPa, 1 pound per square inch = 6.895 kPa.
DR = Design required.
o.c. = on center
a. Wood framing shall be Spruce-pine-fir or any wood species with a specific gravity of 0.42 or greater in accordance with AWC NDS.
b. Nail fasteners shall comply with ASTM F1667, except nail length shall be permitted to exceed ASTM F1667 standard lengths.
c. Foam sheathing shall have a minimum compressive strength of 15 psi in accordance with ASTM C578 or ASTM C1289.

Figure 3: Table R703.15.1 from the 2016 California Residential Code.

Current typical construction practice is to attach the stucco lath over one-inch of continuous insulation using 2-inch or 2-1/2-inch staples and a staple gun. Following the minimum fastener penetration depth of one-inch (based on typical code compliance reports), and assuming ½-inch sheathing and 1-1/2-inches continuous insulation, a 3-inch staple is the minimum fastener length required. However, the industry currently does not manufacture staples at lengths greater than 2-1/2-inches. A survey of stucco contractors indicated that without staples, they would hand nail the lath over the foam, as standard nail guns could not be used, because they would compress the foam. Other solutions do exist, such as a cap nailer, which is a specialty nail gun that applies a large cap to the head of the nail resolving the issue of foam compression. However, similar to the staples, these are currently manufactured for nails only up to 2-1/2-inches in length. Alternatively, there are screw based options, such as the Rodenhouse system described in Section 3.1.4. However, the costs of screws versus nails or staples is high and does not offset the labor cost reduction relative to hand nailing.

Based on conversations with major fastener manufacturers, as well as other industry experts, the Statewide CASE Team does not expect there are any technical limitations to developing either a 3-inch stapler or a 3-inch cap nailer. There are ongoing discussions between the foam manufacturers and the fastener industry to develop a cost-effective solution for wall systems with 1-1/2-inches of continuous insulation. It's possible that based on expected demand, there may be available solutions in the next few years. However, to maintain a conservative cost analysis for this CASE Report labor costs for hand nailing have been assumed.

3.2.3 Fire Rated Assemblies

Some residential buildings are required to have either non-combustible or fire resistant wall assemblies. This includes buildings located in a WUI Fire Area as well many multifamily buildings. To determine the availability of fire resistant one-coat stucco walls, the Statewide CASE Team reviewed code compliance reports for several major one-coat stucco manufacturers, all of which had at least one wall assembly incorporating continuous foam insulation with a one-hour fire-resistive rating. Some of the approved assemblies accommodate continuous insulation thicker than one-inch; however most only allow an insulation thickness of one-inch. It's uncertain if these assemblies will need to be re-tested, which is very costly, to demonstrate compliance with the fire code using 1-1/2-inches of continuous insulation. A major one-coat stucco manufacturer discussed this issue with Intertek, the certification agency issuing code compliance reports for their products (Brown 2017). Their opinion was that adding ½-inch of continuous insulation would not have a significant impact on the assembly's fire resistance and that additional fire testing would likely not be required. In this case the manufacturer would need to submit engineering reports documenting the fastener requirements for walls with 1-1/2-inches of continuous insulation. However, this is feedback from one certification agency on a single product and to the Statewide CASE Team's knowledge no manufacturer has formally submitted a similar request to their code compliance agency.

An alternative compliance path per Title 24, Part 2 is to apply one layer of 5/8-inch Type X gypsum sheathing on the exterior side of the framing. This may require fasteners longer than three-inches. The impact of this on fastener cost is negligible provided that the difference in cost between three-inch and four-inch roofing nails is marginal. See Section 2.4.2 for further background on the fire code requirement.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

It is expected that builders will not be impacted significantly by any one proposed code change or the collective effect of all the proposed changes to Title 24, Part 6. Builders could be impacted for change in demand for new buildings and by construction costs. Demand for new buildings is driven more by factors such as the overall health of the economy and population growth than the cost of construction. The cost of complying with Title 24, Part 6 requirements represents a very small portion of the total building value. Increasing the building cost by a fraction of a percent is not expected to have a significant impact on demand for new buildings or the builders' profits. Even as shown in Figure 4, California home prices have increased by about $300,000 in the last 20 years. In the six years between the peak of the market bubble in 2006 and the bottom of the crashing in 2012, the median home price dropped by $250,000. The current median price is about $500,000 per single family home. The combination of all single family measures for the 2016 Title 24, Part 6 Standards was around $2,700 (California Energy Commission 2015b). This is a cost impact of approximately half of one percent of the home value. The cost impact is negligible as compared to other variables that impact the home value.

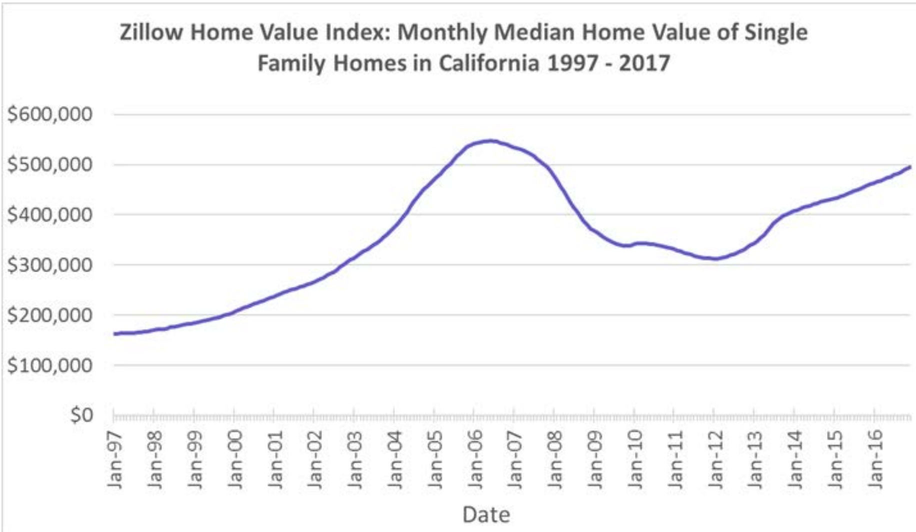

Figure 4: California median home values 1997 to 2017.

Source: (Zillow 2017)

Market actors will need to invest in training and education to ensure the workforce, including those working in construction trades, know how to comply with the proposed requirements. Workforce training is not unique to the building industry, and is common in many fields associated with the production of goods and services. Costs associated with workforce training are typically accounted for in long-term financial planning and spread out across the unit price of many units as to avoid price spikes when changes in designs and/or processes are implemented.

Builders would need to be aware of the lower wall U-factor prescriptive requirements and in which climate zones and building types they apply, and adjust their practices accordingly to comply. There are a variety of wall assemblies available to builders that would meet the new requirements. Builders can choose from different wall-framing depths (2x4, 2x6, 2x8, or double-stud walls), alternative wall assemblies such as Structural Insulated Panels (SIPs) or Insulated Concrete Forms (ICF), standard or high-density batts or blown-in cavity insulation, various types and thicknesses of continuous insulation, and advanced wall-framing strategies, which reduce the wood content of the wall assembly. All of these approaches are recognized by the ACM Reference Manual, providing a wide range of potential solutions.

The builder would be responsible for understanding the design requirements, ensuring that all subcontractors are aware of these requirements, and ultimately ensuring that all requirements are implemented per the design intent. Typical construction approaches practiced by subcontractors may need to be adjusted, as in the case of walls with continuous insulation thicker than one-inch where different methods for fastening the exterior cladding through the insulation and flashing around windows would be necessary. Additional time may be required for these processes, but it's not expected to have a significant impact on project schedule.

Some resources that are available to builders, installers, and other stakeholders include the following:

- WISE program: http://www.wisewarehouse.org/
- CAHP Master Builder program: http://cahp-pge.com/masterbuilder/
- Energy Code Ace: http://energycodeace.com/
- Building America Solution Center: https://basc.pnnl.gov/
- FMA/AAMA/WDMA 500-16 standard practice document (FMA/AAMA/WDMA 2016)

- AAMA InstallationMasters™ installer training program: http://www.installationmastersusa.com/
- Building Science Corporation website: https://buildingscience.com/
- Foam Sheathing Coalition technical resources: http://www.appliedbuildingtech.com/fsc

Refer to Appendix B for a description of how the compliance process would impact builders.

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Building code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials, and ASHRAE 90.1) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1, all market actors, including building designers and energy consultants, should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team is proposing for the 2019 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in requirements can be met.

Architects would be responsible for developing building details which indicate how the cladding is attached over the rigid insulation, connections between the wall and roof, and flashing details around windows and doors. In addition, floor plans would need to properly consider wall thicknesses when determining compliance with lot setback requirements. While designers may not be familiar with these strategies, there are many resources available to them, including those listed above under Section 3.3.1.

Energy consultants would not be significantly impacted regarding compliance by this measure. However, they could be impacted by dedicating more time to educating clients about code and specific project requirements. The energy consultant will continue to serve as the primary resource for designers and builders for Title 24, Part 6 compliance information. With their detailed knowledge of the Title 24, Part 6 compliance software, the energy consultant would work closely with the builder in determining the most cost-effective approach for demonstrating compliance based on builder design, project location, and construction team comfort level with alternative methods. Energy Code Ace is an important resource for the energy consultant.

Refer to Appendix B for a description of how the compliance process will impact building designers and energy consultants.

3.3.3 Impact on Occupational Safety and Health

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

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

Building owners and occupants will benefit from lower energy bills. For example, the Energy Commission estimates that on average the 2016 Title 24, Part 6 Standards will increase the construction cost by $2,700 per single family home, but the standards will also result in a savings of $7,400 in energy and maintenance cost savings over 30 years. This is roughly equivalent to an $11 per month increase in payments for a 30-year mortgage and a monthly energy cost savings of $31 per month. Overall, the 2016 Title 24, Part 6 Standards are expected to save homeowners about $240 per year relative to homeowners whose single family homes are minimally compliant with the 2013 Title 24, Part 6 requirements (California Energy Commission 2015b). As discussed in Section 3.4.1, when homeowners or building occupants save on energy bills, they tend to spend it elsewhere in the economy thereby creating jobs and economic growth for the California economy. 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 food or medical care to save money for energy bills (Association, National Energy Assistance Directors 2011).

Additional benefits to the builder, owner, and occupants include increased interior comfort due to higher wall R-value, resulting in greater thermal envelope integrity.

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

The proposed measure is expected to increase demand for certain insulation products as well as products that target implementation of high performance walls, such as certain fasteners and insulating window bucks. Manufacturers, distributors, and retailers can expect to experience requests for these products from the industry. Increased demand is expected to increase the number of products that are available and subsequently decrease the cost of providing these products.

Refer to Appendix B for a description of how the compliance process would impact building designers and energy consultants.

3.3.6 Impact on Building Inspectors

Building inspectors would not be significantly impacted by this measure.

3.3.7 Impact on Statewide Employment

Section 3.4.1 discusses statewide job creation from the energy efficiency sector in general, including updates to Title 24, Part 6.

3.4 Economic Impacts

3.4.1 Creation or Elimination of Jobs

In 2015, California's building energy efficiency industry employed more than 321,000 workers who worked at least part time or a fraction of their time on activities related to building efficiency. Employment in the building energy efficiency industry grew six percent between 2014 and 2015 while the overall statewide employment grew three percent (BW Research Partnership 2016). Lawrence Berkeley National Laboratory's report titled *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth* (2010) provides details on the types of jobs in the energy efficiency sector that are likely to be supported by revisions to building codes (Goldman, et al. 2010).

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.[7] Title 24, Part 6 creates jobs in all three categories with a

[7] The definitions of direct, indirect, and induced jobs vary widely by study. Wei et al (2010) describes the definitions and usage of these categories as follows: "*Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. *Indirect employment* refers to the ''supplier effect'' of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers."

significant amount from induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. For example, as mentioned in Section 3.3.4, the 2016 Standards are expected to save single family homeowners about $240 per year. Money saved from hundreds of thousands of homeowners over the entire life of the building will be reinvested in local businesses. Wei, Patadia, and Kammen (2010) estimate that energy efficiency creates 0.17 to 0.59 net job-years[8] per GWh saved. By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced. Using the mid-point for the energy efficiency range (0.38 net job-years per GWh saved) and estimates that this proposed code change will result in a statewide first-year savings of 2.4 GWh, this measure will result in approximately 0.91 jobs created in the first year. See Section 6.1 for statewide savings estimates.

An alternative analysis of the potential for job creation within the installer industry was also conducted. Based on estimated incremental labor hours to install the proposed measure, there is an expected increase of 8.9 hours per "typical" single family home (based on the prototype buildings applied in this analysis). On a statewide basis, this corresponds to an increase in construction employment by 199 full time employees.

3.4.2 Creation or Elimination of Businesses in California

There are approximately 43,000 businesses that play a role in California's advanced energy economy (BW Research Partnership 2016). California's clean economy grew ten times more than the total state economy between 2002 and 2012 (20 percent compared to two percent). The energy efficiency industry, which is driven in part by recurrent updates to the building code, is the largest component of the core clean economy (Ettenson and Heavey 2015). Adopting cost-effective code changes for the 2019 Title 24, Part 6 code cycle will help maintain the energy efficiency industry.

Table 4 lists industries that will likely benefit from the proposed code change classified by their North American Industry Classification System (NAICS) Code. Builders, insulation contractors, and manufacturers would all be impacted, primary as it relates to the new construction residential industry. All insulation manufacturers mentioned in Section 3.1 conduct business within California and have the opportunity to increase sales revenue. The proposed code changes are not expected to have a significant impact on the retrofit market.

Table 4: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Residential Building Construction	2361
Insulation Contractors	23831
Manufacturing	32412

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the United States were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can be otherwise invested, which

8 One job-year (or ''full-time equivalent'' FTE job) is full time employment for one person for a duration of one year.

provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code changes that impact residential buildings.

3.4.4 Increase or Decrease of Investments in the State of California

The proposed changes to the building code are not expected to impact investments in California on a macroeconomic scale, nor are they expected to affect investments by individual firms. The allocation of resources for the production of goods in California is not expected to change as a result of this code change proposal.

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

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes. The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if homeowners spend their additional discretionary income on taxable items. Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes will increase construction costs. As discussed in Section 3.3.1, however, there is no statistical evidence that Title 24, Part 6 drives construction costs or that construction costs have a significant impact on home price. Since compliance with Title 24, Part 6 does not have a clear impact on purchase price, it can follow that Title 24, Part 6 cannot be shown to impact revenues from property taxes.

3.4.5.1 Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall cost savings and policy benefits associated with the code change proposals. The proposed residential changes will not impact state buildings.

Cost to Local Governments

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will 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 2019 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 Investor Owned Utility codes and standards program. As noted in Section 2.5 and Appendix B, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

3.4.6 *Impacts on Specific Persons*

The proposed changes to Title 24, Part 6 are not expected to have a differential impact on any groups relative to the state population as a whole, including migrant workers, commuters, or persons by age, race or religion. Given construction costs are not well correlated with home prices, the proposed code changes are not expected to have an impact on financing costs for business or home-buyers. Some financial institutions have progressive policies that recognize the financial implications associated with occupants of energy efficient homes saving on energy bills and therefore have more discretionary income.[9]

Renters will typically benefit from lower energy bills if they pay energy bills directly. These savings should more than offset any capital costs passed-through from landlords. Renters who do not pay directly for energy costs may see some of the net savings depending on if and how landlords account for energy cost when determining rent prices.

On average, low-income families spend less on energy than higher income families, however lower income families spend a much larger portion of their incomes on energy (Association, National Energy Assistance Directors 2011). Thus, low-income families are likely to disproportionately benefit from Title 24, Part 6 Standards that reduce residential energy costs.

4. ENERGY SAVINGS

4.1 Key Assumptions for Energy Savings Analysis

The energy savings analysis relied on the CBECC-Res software to estimate energy use for single family and multifamily prototype buildings. Various wall assembly scenarios were evaluated and compared to a mixed-fuel (natural gas used for space heating, water heating, cooking, and clothes drying) building that minimally complies with the 2016 Title 24, Part 6 Standards. All climates zones were evaluated except for Climate Zones six and seven, since the 2016 Statewide CASE Team found that the 2016 high performance wall (0.051 U-factor wall) was not cost-effective in these two climate zones.

4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, the Statewide CASE Team compared current design practices to design practices that will comply with the proposed requirements. There is an existing Title 24, Part 6 Standards that covers the building system in question, and applies to both new construction and additions, so the existing conditions assume a building minimally complies with the 2016 Title 24, Part 6 Standards. The 2016 Title 24 Part 6 prescriptive standards require a maximum wall U-factor of 0.051 for all climate zones except six and seven, where the maximum wall U-factor is 0.065. The baseline condition for the 0.051 U-factor wall for new construction buildings assumes minimal compliance with the 2016 Standards using a 2x6 wall with R-21 cavity insulation and one-inch of R-4 continuous rigid insulation. This wall assembly was selected as it best represents how a 0.051 U-factor would be built today based on current construction practices, as EPS is the rigid insulation of choice. See Section 5.1 for further details on the simulation assumptions.

The proposed conditions are defined as the design conditions that will comply with the proposed code change. Specifically, the proposed code change will reduce the prescriptive wall U-factor to 0.043 in climates zones one and 11 through 16 for single family construction. A 0.043 U-factor wall can be

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[9] For example, see United States (U.S) EPA's ENERGY STAR® website for examples: http://www.energystar.gov/index.cfm?fuseaction=new_homes_partners.showStateResults&s_code=CA.

achieved with various assembly configurations; for this analysis, a 2x6 wall with R-21 cavity insulation and 1.5inches of R-7.5 continuous rigid insulation was evaluated.

The Energy Commission provided guidance on the type of prototype buildings that must be modeled. Residential single family energy savings are calculated using two prototypes (a 2,100 square foot single story and a 2,700 square foot two story) available in CBECC-Res. Residential results are weighted 45 percent for the 2,100 square foot prototype and 55 percent for the 2,700 square foot prototype. Multifamily savings are calculated based on a multifamily prototype (an 8-unit, 6,960 square foot two-story building) available in CBECC-Res. Details on the prototypes are available in the ACM Approval Manual (California Energy Commission 2015c).

Table 5 presents the details of the prototype buildings used in the analysis. Additional details can be found in Appendix C.

Table 5: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype ID	Occupancy Type	Area (square feet)	Number of Stories	Statewide Area (million square feet)
New Construction Prototype 1	Residential single family	2,100	1	110.6
New Construction Prototype 2	Residential single family	2,700	2	173.8
New Construction Prototype 3	Residential low-rise multifamily	6,960	2	45.7

The energy savings from this measure varies by climate zone. As a result, the energy impacts and cost-effectiveness were evaluated by climate zone.

Energy savings, energy cost savings, and peak demand reductions were calculated using a TDV (Time Dependent Valuation) methodology. The 2019 TDV multipliers were applied.

4.3 Per-Unit Energy Impacts Results

All single family result tables in Sections 4 and 5 present results for the weighted 2,430 square foot prototype. Energy impacts for each prototype (a 2,100 square foot single story and a 2,700 square foot two story) are presented in Appendix D.

Energy savings and peak demand reductions per single family unit for new construction are presented in Table 6. See Section 6.1 of this report for estimated statewide savings from additions and alterations. The per-unit energy savings estimates do not take naturally occurring market adoption or compliance rates into account. Per-unit electricity savings for the first year are expected to save 150 kilowatt-hours per year (kWh/yr) on the high end to 10 kWh/yr on the low end, depending upon climate zone. Per unit gas savings are expected to range from a high of 28 therms/year to a low of 2.7 therms/year depending upon climate zone. Demand reductions/increases are expected to range between zero kilowatts (kW) and 0.11 kW depending on climate zone. The proposed measure does have expected demand reductions in most climates, however the impact would be marginal and the impact on demand response potential would be negligible.

Table 6: First-Year Energy Impacts per Dwelling Unit (Single Family) – New Construction

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	20	0.00	24.4	5,622
2	16	0.02	15.0	4,415
3	10	0.00	12.6	3,092
4	14	0.01	12.4	3,527
5	10	0.00	13.0	3,089
6	N/A			
7	N/A			
8	11	0.02	5.6	2,520
9	22	0.04	6.9	3,242
10	29	0.05	7.9	3,678
11	62	0.06	14.8	6,569
12	32	0.06	14.4	5,895
13	65	0.06	13.0	6,120
14	58	0.06	15.0	6,438
15	150	0.11	2.7	7,118
16	27	0.01	28.0	6,817

Table 7 presents energy savings and peak demand reductions per multifamily building for new construction. Per building electricity savings for the first year are expected to save 328 kWh/yr on the high end and to increase electricity use by 20 kWh/yr on the low end depending upon climate zone. Per building gas savings are expected to range from a high of 59 therms/year to a low of 1.3 therms/year depending upon climate zone. Demand reductions/increases are very marginal and are expected to range between negative 0.02 kW and 0.26 kW per unit depending on climate zone.

Table 7: First-Year Energy Impacts per Building (Multifamily) – New Construction

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	23	-0.02	44.4	10,162
2	24	0.02	29.3	8,178
3	-1	0.00	19.2	4,315
4	18	0.02	23.3	6,020
5	-20	-0.05	17.7	2,645
6	N/A			
7	N/A			
8	-5	0.05	5.1	3,062
9	24	0.11	9.3	5,812
10	41	0.11	11.4	6,682
11	127	0.14	29.0	13,955
12	56	0.10	28.6	11,101
13	130	0.14	25.8	12,841
14	118	0.13	29.1	13,085
15	328	0.26	1.3	14,964
16	44	0.01	59.0	14,198

5. LIFECYCLE COST AND COST-EFFECTIVENESS

5.1 Energy Cost Savings Methodology

Time Dependent Valuation (TDV) energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 30 years. The TDV cost impacts are presented in 2020 present value dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDV kBtu." Peak demand reductions are presented in peak power reductions (kW). The Energy Commission derived the 2020 TDV values that were used in the analyses for this report (Energy + Environmental Economics 2016).

To quantify energy savings and peak electricity demand reductions resulting from the proposed measure the 2016 CBECC-Res software was used. Simulations were conducted using the 2016.2.0+ (864) version of the software and the 2016.2.0+ (626) version of the BEM Compliance Manager with minor updates described below to the Standard Design to better reflect existing conditions.

1. The Energy Commission expects to adopt the ANSI/ASHRAE Standard 62.2-2016 (ASHRAE 2016), which requires higher mechanical ventilation airflows for single family homes than the 2010 version of the standard (the 2010 standard is the current requirement in California). The proposed 2016 airflows have been included in both the Standard Design and the Proposed Design for the single family analysis. There is no change in ventilation requirements for multifamily; therefore, no adjustments were made for ventilation rates in the multifamily prototype.
2. The 2016 California Plumbing Code (CA BSC 2016c) includes requirements that all hot water pipes be insulated. The next release of CBECC-Res is expected to incorporate this requirement, but the

current release does not. The Standard Design and the Proposed Design have been adjusted to include pipe insulation for both the single family and the multifamily analyses.

3. The next release of CBECC-Res is expected to automatically degrade all R-19 insulation to an installed value of R-18, due to compression of the batt in a 2x6 wall cavity. This affects the Standard Design because the 0.051 U-factor requirement is modeled as a wall with R-19 cavity insulation. The appropriate degradation to R-18 was applied to the Standard Design for the single family and multifamily analyses.

The proposed 0.043 U-factor wall is evaluated as a 2x6 framed wall with R-21 cavity insulation and 1.5-inches of continuous insulation rated at R-7.5. The version of CBECC-Res used for this analysis is not able to evaluate non-integer R-values. Therefore, cases with R-7 and R-8 continuous insulation were evaluated and the results were averaged to calculate the energy cost savings for the proposed R-7.5 measure. The latest release of the CBECC-Res 2019 research version does allow the user to input insulation levels to the tenth of an R-value.

The proposed code change applies to new construction and additions only and does not apply to alterations. The energy savings per square foot are assumed to be the same for additions as for new construction.

5.2 Energy Cost Savings Results

The per-unit TDV energy cost savings for newly constructed buildings over the 30-year period of analysis are presented in Table 8 for single family. These are presented as the discounted present value of the energy cost savings over the analysis period. Per unit savings over the 30-year period of analysis are expected to range from a high of $1,231 to a low of $436 depending upon climate zone. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. Energy cost savings results for each prototype are presented in Appendix D.

Table 8: TDV Energy Cost Savings Over 30-Year Period of Analysis – per Dwelling Unit (Single Family) – New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	$103	$870	$973
2	$201	$563	$764
3	$58	$477	$535
4	$143	$468	$610
5	$51	$483	$534
6	N/A		
7	N/A		
8	$221	$215	$436
9	$295	$266	$561
10	$334	$302	$636
11	$579	$558	$1,136
12	$475	$545	$1,020
13	$565	$494	$1,059
14	$540	$574	$1,114
15	$1,125	$106	$1,231
16	$144	$1,035	$1,179

Table 9 presents the per-building TDV energy cost savings over the 30-year period of analysis for multifamily. Per building savings over the 30-year period of analysis are expected to range from a high of $2,589 to a low of $458 depending upon climate zone.

Table 9: TDV Energy Cost Savings Over 30-Year Period of Analysis – per Building (Multifamily) – New Construction

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	$144	$1,613	$1,758
2	$307	$1,108	$1,415
3	$12	$734	$747
4	$163	$879	$1,042
5	-$205	$662	$458
6		N/A	
7		N/A	
8	$325	$205	$530
9	$656	$349	$1,005
10	$716	$439	$1,156
11	$1,306	$1,108	$2,414
12	$837	$1,084	$1,921
13	$1,234	$987	$2,222
14	$1,144	$1,120	$2,264
15	$2,541	$48	$2,589
16	$271	$2,185	$2,456

5.3 Incremental First Cost

Incremental first costs were estimated from interviews with contractors, builders, distributors, and manufacturers; previous research including the 2016 Residential High Performance Wall and Quality Insulation Inspection (QII) CASE Report (California Statewide Codes and Standards Team 2014); cost databases such as RSMeans and NREL's BEopt software; and internet research. During this process the Statewide CASE Team endeavored to consider all aspects of the proposed measure that may result in additional cost. Additionally, where costs were uncertain or the data provided spanned a broad range, the Statewide CASE Team attempted to estimate conservatively so as not to underestimate the first-cost impact. Cost estimates were made to reflect costs expected in the year 2020 when the 2019 Title 24, Part 6 Standards will be implemented. All costs were based on one-coat stucco as the cladding material, as it represents the predominant cladding choice of California production builders and is used as the reference wall-cladding system in the ACM Reference Manual.

Table 10 presents the incremental costs for each of the wall components in the proposed measure as well as the base case. Costs are broken out by material and labor. Labor costs are only included when there would be an incremental labor activity for the proposed measure. For example, the labor associated with installing one-inch of rigid insulation is assumed to be the same regardless of product type or R-value, therefore there would be no incremental labor cost for the two continuous insulation products.

Total costs are presented as costs to the builder. A 30 percent overhead and profit markup was applied to all material costs. Labor costs were based on a fully loaded labor rate from RSMeans of $44/hour after applying an average California regional labor multiplier of 1.1.

Costs for GPS continuous insulation were applied to the proposed measure based on conversations with manufacturers that indicated this material is becoming more common in the marketplace and costs are declining. Currently the product is sold at a cost premium of about 30 percent higher than its counterpart, EPS. There is only one manufacturer, BASF, currently that makes the graphite resin for the United States market. Their patent is expiring in 2017 and it is likely that this will bring competition to the market. Today the resin is manufactured in Europe, resulting in freight costs that would be eliminated with domestic production. Considering all of these aspects the Statewide CASE Team expects the cost of GPS to decline by January 2020 when the 2019 Title 24, Part 6 Standards take effect. The estimate applied in this analysis is a 25 percent cost premium over EPS.

Costs for hand nailing were applied to the proposed measure. While currently there is not a cost-effective fastening solution that uses a pneumatic tool, there are several opportunities for manufacturers to expand currently-available strategies to accommodate longer fasteners. It is likely that additional options will become available over the next couple of years. Therefore, this cost may be high and the Statewide CASE Team is confident it is a conservative estimate. The construction industry has a long history of finding cost-effective solutions as the market transforms.

Incremental window framing costs are based on the 2016 CASE Report (California Statewide Codes and Standards Team 2014). Values have been adjusted to account for a wood buck thickness of one-half inch for the 1-1/2-inch continuous insulation case. Total adjusted costs were disaggregated into labor and material costs. Adjusted costs are $12.24 for a 3-foot x 5-foot window, which includes roughly 12 minutes of labor at $44/hour and materials valued at $3.50. The Statewide CASE Team compared this to costs provided by Thermal Buck[10] on their website for a wood buck installation. While they were not directly comparable, after further analysis the costs seem fairly consistent. A rough cost estimate of $10-$20 for a 3-foot x 5-foot window was also provided by a California builder who builds with two inches of continuous insulation as part of their standard wall construction. Linear feet of window perimeter for the single family prototypes was based on an assumption of twenty-one windows with a realistic mix of window sizes (predominately 4ft x 6ft and 5ft x 5ft) for the blended 2,430 square foot prototype. This was revised from the original default CBECC-Res assumption of thirty-two windows. With this change the total window area remained at 20-percent of the conditioned floor area. The multifamily assumption was based on the original CBECC-Res assumption of 70 3ft x 5ft windows (15-percent of the total conditioned floor area). Entry door perimeter was also included for costing purposes. Additional details can be found in Appendix C.

1-3/8-inch (or 1-1/2-inch) weep screed has become a standard product available from most manufacturers to accommodate one-coat stucco with one-inch of continuous insulation. Currently, 1-7/8-inch (or 2-inch) weep screed is not typically available in standard product catalogs. However, the Statewide CASE Team spoke with at least one manufacturer who had no issue obtaining the deeper product for a marginal additional cost. The incremental costs applied in this analysis are based on actual current costs provided by manufacturers.

The incremental cost and energy impact analysis is based on upgrading all walls between conditioned space and the exterior. It does not assume continuous insulation on demising walls between conditioned and unconditioned spaces, for example walls between the house and the garage. It also doesn't include any changes to other exterior walls, such as garage exterior walls or gable end walls. Some builders may choose to continue the same level of continuous insulation on these surfaces so that the surface plane is not interrupted. It's acknowledged that this would result in higher total incremental costs; however, this scenario is not directly evaluated in this analysis.

[10] https://thermalbuck.com/uncategorized/installation-challenge/

Table 10: Summary of Incremental Costs Applied in the Analysis (CI = Continuous Insulation)

Product Type	Description	Material Cost / Unit (2020 $)	Additional Labor Cost / Unit[a] (2020 $)	Total Cost / Unit Including Markup[b] (2020 $)	Unit
Rigid continuous insulation	1” EPS - expanded polystyrene	$0.22	$0.00	$0.29	square foot exterior wall - inch foam
	1” GPS - graphite enhanced EPS	$0.28	$0.00	$0.36	
Weep screed	1-3/8" weep screed - 1" CI	$0.77	$0.00	$1.00	linear foot foundation perimeter
	1-7/8" weep screed - 1.5" CI	$0.87	$0.00	$1.13	
Fasteners	2-1/2" staples, staple gun - 1" CI	$2.15	$0.00	$2.79	100 square foot exterior wall
	3" nail, hand nail - 1.5" CI	$2.04	$9.52	$12.18	
Window picture framing & additional flashing	0.5" window buck - 1.5" CI	$0.22	$0.55	$0.83	linear foot window perimeter

a. **Additional Labor Cost / Unit:** This cost only includes incremental labor relative to the base case of a 2x6 wall with 1” of continuous insulation. For example, the labor associated with installing 1” of rigid insulation is assumed to be same regardless of product type or R-value and therefore there is no labor cost for the rigid insulation product.

b. **Total Cost / Unit Including Markup:** Total costs are presented as costs to the builder. A 30 percent overhead and profit markup was applied to all material costs presented. Labor costs were based on a fully loaded labor rate from RSMeans of $44/hour after applying an average California regional multiplier of 1.1.

Incremental costs for the proposed measure are presented relative to a 0.051 U-factor wall with R-21 cavity insulation and one-inch of R-4 EPS continuous insulation. This wall assembly was selected as it best represents how a 0.051 U-factor would be built today based on current construction practices, as EPS is the rigid insulation of choice. Table 11 presents incremental costs for the proposed measure relative to this base case for the three residential prototypes.

Table 11: Incremental Costs for the Proposed Measure for Each New Construction Prototype

Measure	2,100 Square Foot Single Family Prototype	2,700 Square Foot Single Family Prototype	8-unit, 6,960 Square Foot Multifamily Prototype
0.043 U-factor wall R-21 + R7.5	$680	$1,142	$2,384

Incremental costs for additions are expected to be somewhat higher that those estimated for new construction. The economies of scale available in new construction are not present in alteration work and therefore volume purchasing discounts are less and labor costs can be higher.

Per the Energy Commission’s guidance, design costs are not included in the incremental first cost.

5.4 Lifetime Incremental Maintenance Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the period of analysis. The present value of equipment and maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2019 TDV. The present value of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate of three percent):

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

The useful life of the proposed measure is expected to be the lifetime of the home. There are no maintenance requirements for high performance walls beyond those which are normal for any residential wall assembly. There would be no net increase in the maintenance cost for the proposed measures relative to existing conditions.

5.5 Lifecycle Cost-Effectiveness

This measure proposes a prescriptive requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 30-year period of analysis.

The Energy Commission establishes the procedures for calculating lifecycle cost-effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. In this case, incremental first cost and incremental maintenance costs over the 30-year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were also included in the evaluation.

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

According to the Energy Commission’s definitions, a measure is cost-effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the total present lifecycle cost benefits by the present value of the total incremental costs.

Results of the per unit lifecycle cost-effectiveness analyses are presented in Table 12 for single family and Table 13 for multifamily for new construction. Energy impacts for each singly family prototype are presented in Appendix D.

For single family, the proposed measure demonstrates a favorable B/C ratio over the thirty-year period of analysis relative to the existing conditions in Climate Zones one and 11 through 16. For multifamily only Climate Zones 11, 15, and 16 demonstrate a favorable B/C ratio. Due to some of the challenges unique to multifamily construction, including fire rated assembly requirements and affordability, there is no recommendation to change the prescriptive wall U-value for multifamily buildings in any climate.

Table 12: Lifecycle Cost-effectiveness Summary per Dwelling Unit (Single Family) – New Construction

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	$973	$934	1.04
2	$764	$934	0.82
3	$535	$934	0.57
4	$610	$934	0.65
5	$534	$934	0.57
6	N/A		
7	N/A		
8	$436	$934	0.47
9	$561	$934	0.60
10	$636	$934	0.68
11	$1,136	$934	1.22
12	$1,020	$934	1.09
13	$1,059	$934	1.13
14	$1,114	$934	1.19
15	$1,231	$934	1.32
16	$1,179	$934	1.26

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three-percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

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

Table 13: Lifecycle Cost-effectiveness Summary per Building (Multifamily) – New Construction

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	$1,758	$2,384	0.74
2	$1,415	$2,384	0.59
3	$747	$2,384	0.31
4	$1,042	$2,384	0.44
5	$458	$2,384	0.19
6	N/A		
7	N/A		
8	$530	$2,384	0.22
9	$1,005	$2,384	0.42
10	$1,156	$2,384	0.48
11	$2,414	$2,384	1.01
12	$1,921	$2,384	0.81
13	$2,222	$2,384	0.93
14	$2,264	$2,384	0.95
15	$2,589	$2,384	1.09
16	$2,456	$2,384	1.03

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three-percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

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

Lifecycle cost-effectiveness will differ for additions relative to new construction. While incremental costs are expected to be higher than for new construction, energy cost savings may also be slightly higher provided the exceptions to meeting the prescriptive requirements for additions per Section 150.2(a)1. For the purposes of this analysis the cases which are demonstrated to be cost effective for new construction are also assumed to be cost effective for additions.

6. First-year Statewide Impacts

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per unit savings, which are presented in Section 4.3, by the statewide new construction forecast for 2020, which is presented in more detail in Appendix A.

The approach to estimate energy savings for additions and alterations is based on the methodology applied in the impact analysis report for the 2016 Title 24, Part 6 updates (Noresco and Nittler 2015). In the impact analysis, the projected savings for new construction buildings were increased by 43 percent to account for additions and alterations. The 43 percent factor was based on the dollars spent on new construction compared to that spent on additions and alterations according to 2011 data from the

Construction Industry Research Board. For this proposal, the 43 percent is revised to reflect that the proposed code change does not apply to alterations, nor does it apply to extensions of existing walls for additions. In the absence of better information, it is assumed that additions represent half of the total dollars spent on additions and alterations. It is also assumed that two-thirds of walls in additions are not extensions of existing walls and therefore would be subject to the new proposed prescriptive requirements. Taking all of this into account the projected savings for new construction have been increased by 14.3 percent[11] to account for additions. Note that this approach does not consider differences in incremental costs or energy savings for additions relative to new construction.

The first-year energy impacts represent the first-year annual savings from all buildings that would be completed in 2020, for the climate zones and cases where the measure is cost-effective. Therefore, the impacts only include single family and Climates Zones one and 11 through 16. The lifecycle energy cost savings represent the energy cost savings over the entire 30-year analysis period. Results are presented in Table 14. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Results from new construction by climate zone are presented in Table 14. Table 15 presents first-year statewide savings from new construction, additions and alterations. Given data regarding the new construction forecast and expected additions in 2020, the Statewide CASE Team estimates that the proposed code change will reduce annual statewide electricity use by 2.4 GWh/yr with an associated demand reduction of 2.7 MW. Natural gas use is expected to be reduced by 0.7 million therms/year. The energy savings for buildings constructed in 2020 are associated with a present value energy cost savings of approximately present value $50 million in (discounted) energy costs over the 30-year period of analysis.

[11] 43% * 50% * 66.6% = 14.3%

Table 14: Statewide Energy and Energy Cost Impacts (Single Family) – New Construction

Climate Zone	Statewide New Construction in 2020 (units)	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Natural Gas Savings (million therms)	Lifecycle[b] Present Value Energy Cost Savings (Present Value $ million)
1	465	0.009	0.000	0.011	$0
2	N/A				
3	N/A				
4	N/A				
5	N/A				
6	N/A				
7	N/A				
8	N/A				
9	N/A				
10	N/A				
11	3,947	0.245	0.238	0.058	$4
12	19,414	0.617	1.125	0.280	$20
13	7,034	0.458	0.427	0.091	$7
14	3,484	0.203	0.206	0.052	$4
15	3,203	0.481	0.350	0.009	$4
16	3,188	0.085	0.027	0.089	$4
TOTAL	**40,735**	**2.1**	**2.4**	**0.6**	**$44**

a. First-year savings from all new buildings completed statewide in 2020.

b. Energy cost savings from all new buildings completed statewide in 2020 accrued during 30-year period of analysis.

Table 15: Statewide Energy and Energy Cost Impacts – New Construction, Alterations and Additions

Construction Type	First-Year[a] Electricity Savings (GWh)	First-Year Peak Electrical Demand Reduction (MW)	First -Year Natural Gas Savings (million therms)	Lifecycle[b] Present Value Energy Cost Savings (Preset Value $ million)
New Construction	2.1	2.4	0.6	$44
Additions	0.3	0.3	0.1	$6
Alterations	N/A	N/A	N/A	N/A
TOTAL	**2.4**	**2.7**	**0.7**	**$50**

a. First-year savings from all buildings completed statewide in 2020.

b. Energy cost savings from all buildings completed statewide in 2020 accrued during 30-year period

6.2 Statewide Water Use Impacts

The proposed code change would not result in water savings.

6.3 Statewide Material Impacts

The proposed code change would not result in impacts to toxic materials or materials which require significant energy inputs.

6.4 Other Non-Energy Impacts

Non-energy benefits of the proposed measures include improved occupancy comfort and increased property valuation.

7. PROPOSED REVISIONS TO CODE LANGUAGE

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

7.1 Standards

The proposed measure would require updating the walls section of Table 150.1-A Component Package-A as well as the associated language regarding prescriptive wall requirements in Section 150.1. Table 150.1-A will now have two sections, one for single family requirements and another for multifamily.

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

Section 150.1(c)1.B:

B. i. Framed exterior w~~W~~alls ~~(including heated basements and crawl spaces)~~ shall be insulated such that the opaque wall has an assembly U-factor equal to or less than that shown in Table 150.1-A~~, or walls shall be insulated between wood framing with an R-value equal to or greater than shown in TABLE 150.1-A~~. The U-factors shown are maximum U-factors for the opaque wall assembly.

ii. ~~Alternatively, for m~~Mass walls above grade and ~~for~~ below grade shall be insulated such that the wall has an assembly U-factor equal to or less than that shown in Table 150.1-A, or walls shall be insulated with continuous insulation that has an R-value equal to or greater than that shown in TABLE 150.1-A. ~~walls with insulation installed on the interior, the R-values shown are the minimum R-values for insulation installed between wood-framing members; and for below grade with exterior insulation, the R-values shown are the minimum R-values for continuous insulation.~~ "Interior" denotes continuous insulation installed on the inside surface of the wall and "exterior" denotes continuous insulation installed on the outside surface of the wall

iii. Framed demising walls, such as walls between the house and garage and knee walls, shall be insulated such that the opaque wall has an assembly U-factor equal to or less than that shown in Table 150.1-A. Demising walls do not need to include continuous insulation if the wall meets the U-factor requirements without it.

iv. Other unframed walls, which are not mass walls, shall meet the requirements for framed walls shown in Table 150.1-A.

Table 150.1-A COMPONENT PACKAGE-A STANDARD BUILDING DESIGN

SINGLE FAMILY

				Climate Zone															
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Building Envelope Insulation	**Walls**	**Above Grade**	**Framed Exterior**[4]	~~U 0.051~~ U 0.043	U 0.051	U 0.051	U 0.051	U 0.051	U 0.065	U 0.065	U 0.051	U 0.051	U 0.051	~~U 0.051~~ U 0.043	~~U 0.051~~ U 0.043	~~U 0.051~~ U 0.043	~~U 0.051~~ U 0.043	~~U 0.051~~ U 0.043	~~U 0.051~~ U 0.043
			Framed Demising[5]	0.064	0.064	0.064	0.064	0.064	0.086	0.086	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
			Mass Wall Interior[~~5~~6]	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.059 R 17
			Mass Wall Exterior[6]	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.070 R 13
		Below Grade	**Mass Wall ~~Below Grade~~ Interior**[7]	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.066 R 15
			Mass Wall ~~Below Grade~~ Exterior[~~8~~7]	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.100 R 10	U 0.100 R 10	U 0.053 R 19

MULTIFAMILY

				Climate Zone															
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Building Envelope Insulation	**Walls**	**Above Grade**	**Framed Exterior**[4]	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051	U 0.065	U 0.065	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051	U 0.051
			Framed Demising[5]	0.064	0.064	0.064	0.064	0.064	0.086	0.086	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
			Mass Wall Interior[~~5~~6]	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.059 R 17
			Mass Wall Exterior[6]	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.070 R 13
		Below Grade	**Mass Wall Interior**[7]	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.066 R 15
			Mass Wall Exterior[~~8~~7]	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.100 R 10	U 0.100 R 10	U 0.053 R 19

Footnote requirements to TABLE 150.1-A:

4. 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 meet the required maximum U-factor.

5. Assembly U-factors for demising 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.

6~~5~~. Mass walls have ~~has~~ a thermal heat capacity greater than or equal to 7.0 Btu/h-ft2. "Interior" denotes continuous insulation installed on the inside surface of the wall. "Exterior" denotes continuous insulation installed on the exterior surface of the wall.

~~6. Mass wall has a thermal heat capacity greater than or equal to 7.0 Btu/h-ft2. "Exterior" denotes insulation installed on the exterior surface of the wall.~~

7. Below grade "interior" denotes continuous insulation installed on the inside surface of the wall. "Exterior" denotes continuous insulation installed on the outside surface of the wall.

~~8. Below grade "exterior" denotes insulation installed on the outside surface of the wall.~~

SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING LOW-RISE RESIDENTIAL BUILDINGS

Section 150.2(a)1:

1. **Prescriptive approach**. Additions to existing buildings shall meet the following additional requirements:
   - A. Additions that are greater than 700 square feet shall meet the prescriptive requirements of Section 150.1(c), except:
     - i. Extensions of existing wood-framed walls may retain the dimensions of the existing walls and shall install cavity insulation of R-15 in a 2x4 framing and R-21~~19~~ in a 2x6 framing.
     - ii. The maximum allowed fenestration area shall be the greater of 175 square feet or 20 percent of the addition floor area, and the maximum allowed west-facing fenestration area shall be the greater of 70 square feet or the requirements of Section 150.1(c).
   - B. Additions that are 700 square feet or less shall meet all the requirements of Section 150.1(c) except:
     - i. Roof and Ceiling insulation shall meet the requirement of Section 150.0; and
     - ii. Extensions of existing wood-framed walls may retain the dimensions of the existing walls and shall install cavity insulation of R-15 in a 2x4 framing and R-21~~19~~ in a 2x6 framing; and

7.2 Reference Appendices

There are no proposed changes to the Reference Appendices, but rather a recommendation for further investigation. As CBECC-Res has been further developed over the past two code cycles, the tables in Joint Appendices JA4.3 do not always match the options available as well as the calculated U-factors in CBECC-Res. It's recommended that this be examined and revised to provide consistency between the software and the Reference Appendices.

7.3 ACM Reference Manual

This proposed measure would require modification to the description of the exterior walls in the Standard Design in Section 2 of the Residential ACM Reference Manual.

The CBECC-Res software will need to be modified to reflect the revisions described below.

SECTION 2 – The Proposed Design and Standard Design

2.5.6.3 Exterior Walls:

STANDARD DESIGN

The standard design building has high performance walls modeled with the same gross area of framed walls as is in the proposed design separating conditioned space and the exterior~~ or unconditioned space~~, with a U-factor equivalent to that as specified in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone. For single family homes walls in Climate Zones 1 and 11-16 have 2”x6” wood framing 16-inch on center with R-21 insulation between framing and R-7.5 continuous insulation. Walls in Climate Zones 2-5 and 8-10 have 2”x6” wood framing 16-inch on center with ~~R-19~~ R-21 insulation between framing and R-4~~5~~ continuous insulation~~ in Climate Zones 1-5, 8-16 or~~. Walls in Climate Zones 6-7 have 2”x4” wood framing 16-inch on center with R-15 insulation between framing and R-4 continuous insulation~~ in Climate Zones 6-7~~. For multifamily buildings walls in Climate Zones 1-5 and 8-16 have 2”x6” wood framing 16-inch on center with ~~R-19~~ R-21 insulation between framing and R-4~~5~~ continuous insulation~~ in Climate Zones 1-5, 8-16 or~~. Walls in Climate Zones 6-7 have 2”x4” wood framing 16-inch on center with R-15 insulation between framing and R-4 continuous insulation~~ in Climate Zones 6-7~~.

The standard design building is modeled with the same gross area of demising walls, such as walls between the house and garage and knee walls, as is in the proposed design separating conditioned space and unconditioned space. Framed demising walls are modeled with a U-factor equivalent to that as specified in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone. Walls in Climate Zones 1-5 and 8-16 have 2”x6” wood framing 16-inch on center with R-21 insulation between framing. Walls in Climate Zones 6 and 7 have 2”x4” wood framing 16-inch on center with R-15 insulation between framing. Mass demising walls are treated as other mass walls as described below.

The standard design building is modeled with the same gross area of above grade mass walls as is in the proposed design with interior ~~and exterior~~ insulation equivalent to the requirements in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone.

The standard design building is modeled with the same gross area of below grade mass walls as is in the proposed design with interior insulation equivalent to the requirements in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone.

Other types of walls modeled in the proposed design building (e.g. SIP, straw bale) are evaluated as framed walls in the standard design with a U-factor equivalent to that as specified in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone.

The total gross exterior wall area in the standard design is equal to the total gross exterior wall area of the proposed design for each wall type. ~~If the proposed wall area is framed wall,~~ T~~t~~he gross exterior wall area of framed walls in the standard design (excluding demising ~~knee~~ walls) ~~contains wood framing and~~ is equally divided between the four main compass points, north, east, south, and west. The gross exterior wall area of mass walls in the standard design (excluding demising walls and below grade walls) is equally divided between the four main compass points, north, east, south, and west.~~ Wall construction shall match wall construction and thermal characteristics of Section 150.1(c), Table 150.1-A.~~ Window and door areas are subtracted from the gross wall area to determine the net wall area in each orientation.

~~Walls adjacent to unconditioned space (garage walls) for all climate zones are wood framed, 2”x4”, 16-in. on center, Walls have 2”x6” wood R-15 cavity insulation.~~

2.10.3.2 Exterior Walls:

STANDARD DESIGN

The total net area~~s~~, orientation and tilt of existing~~, new~~ and altered ~~net~~ exterior wall areas (with windows and doors subtracted) are the same in the existing portion of the building ~~and addition portions~~ of the standard design as the proposed design.

The wall area rules for additions follows the same approach as that for new construction as defined in Section 5.6.3.

The standard design exterior wall construction assembly is based on the proposed design assembly type as shown in Table 22. Framed walls are modeled as 16-inch on center wood framing. Insulation levels for mass walls refer to continuous insulation. The standard design for unaltered walls is the existing condition. ~~The software does not implement the prescriptive provision that allows eliminating continuous insulation for walls being extended to an addition.~~

The software allows the user to indicate whether a new wall in an addition is an extension of an existing wood-framed wall, and if so, what is the dimension of the existing wall. For these instances, the standard design exterior wall construction assembly is based on a wood-framed wall with R-15 cavity insulation for existing 2x4 walls or R-21 cavity insulation for existing 2x6 walls.

Table 22: Addition Standard Design for ~~Exterior~~ Walls

Proposed Design Exterior Wall Assembly Type	**Standard Design Values Based on Proposed Wall Status**		
	Addition	**Altered**	**Verified Altered**
Framed ~~Exterior Walls~~ & Non-Mass Exterior Wall[1,2] – Single Family	~~CZ 1-5, 8-16 = R19+R5 in 2x6 (U0.051)~~ CZ 1,11-16 = R21+R7.5 in 2x6 (U-0.043) CZ 2-5,8-10 = R21+R4 in 2x6 (U-0.051) CZ 6-7 = R15+R4 in 2x4 (U-0.065)	R-13 in 2x4 R-19 in 2x6	Existing
Framed ~~Exterior~~ & Non-Mass Exterior Wall[1,2] – Multifamily	CZ 1-5,8-16 = R21+R4 in 2x6 (U-0.051) CZ 6-7 = R15+R4 in 2x4 (U-0.065)	R-13 in 2x4 R-19 in 2x6	Existing
Framed Demising Wall ~~Adjacent to Unconditioned~~[1,3] (e.g. Garage Wall)	R-15 in 2x4 (U-0.086) R-21~~19~~ in 2x6 (U-0.064)	R-13 in 2x4 R-19 in 2x6	Existing
Above Grade Mass Wall - Interior Insulation[4]	CZ 1-15 = R-13 (U-0.070) CZ 16 = R-17 (U-0.059)	Mandatory requirements have no insulation for mass walls	Existing
Above Grade Mass Wall - Exterior Insulation[4]	CZ 1-15 = R-8 (U-0.125) CZ 16 = R-13 (U-0.070)		Existing
Below Grade Mass Wall - Interior Insulation[4]	CZ 1-15 = R-13 (U-0.070) CZ 16 = R-15 (U-0.066)		Existing

Footnotes to Table 22:

1. All framed walls are modeled as 16-inch on center with wood framing.

2. For additions where the wall is an extension of an existing wood-framed wall, continuous insulation is not required and removed from the standard design wall construction.

3. Demising walls are those walls between conditioned and unconditioned spaces.

4. Mass wall insulation is modeled as continuous insulation. “Interior” denotes continuous insulation installed on the inside surface of the wall. “Exterior” denotes continuous insulation installed on the

exterior surface of the wall. For above grade mass walls the insulation is applied based on the location in the proposed design. For below grade mass walls the insulation is always applied on the inside surface.

7.4 Compliance Manuals

Chapter 3 and 9 of the Residential Compliance Manual would need to be revised as follows. In addition, it is recommended that **Section 3.6.3.2 Wall Assembly** be expanded to include guidance on best practices when constructing walls with exterior continuous insulation.

Section 3.2 What's New for ~~2016~~ 2019

1. The prescriptive requirements for framed walls in single family in Climate Zones 1 and 11-16 have been reduced from a U-factor of 0.051 to 0.043. This prescriptive requirement does not apply to multifamily buildings.

Section 3.6.2.2 Walls

A. Wall Insulation

1. Framed Walls

The Package A prescriptive requirements for framed walls in single family homes (Table 150.1-A) call for a U-factor of 0.043 in Climate Zones 1 and 11-16, a U-factor of 0.051 in Climate Zones ~~1~~2-5, and 8-10~~6~~, and a U-factor of 0.065 in Climate Zones 6 and 7. For multifamily buildings the requirements are a U-factor of 0.051 in Climate Zones 1-5 and 8-16, and a U-factor of 0.065 in Climate Zones 6 and 7.

The designer may choose any wall construction from Reference Joint Appendix JA4 (Tables 4.3.1 and 4.3.4) that has a U-factor equal to or less than that required prescriptively~~0.051 or 0.065, depending on the climate zone~~. U-factors can also be calculated by building the construction assembly in Commission-approved compliance software, including the inside finish, sheathing, cavity insulation, and exterior finish. For example, JA4 Table 4.3.4 shows that a 2x6 wood-framed wall at 16-inch on center can achieve a U-factor of 0.051 with R-19 batt insulation in the cavity and R-5 exterior insulation. Some examples of various wood-framed wall assemblies, associated construction, and U-factors are provided in Figure 3-30.

Figure 3-30: Examples of Wood-Framed Wall Assemblies and U-Factors, Assuming Gypsum Board Interior, Stucco Exterior, and 16-inch on center Framing

Stud	Cavity Insulation	Cavity Insulation Type	Exterior Insulation	U-Factor
2x4	R15	High density batt	R4	0.065
2x6	R21	Loose-fill cellulose or high density batt	R4	0.051
2x6	R19	Low density batt	R5	0.051
2x4	R15	High density batt	R8	0.050
2x6	R21	Loose-fill cellulose or high density batt	R7.5	0.043
2x6	R19	Low density batt	R9	0.042
2x6	R31	Closed-cell spray foam (ccSPF)	R5 ~~R2~~	0.041 ~~0.050~~
2x4	R15	High density batt	R12 ~~R4~~	0.041 ~~0.049~~

Metal-framed assemblies will also require rigid insulation to meet the maximum U-factor criteria. U-factors for metal-framed walls are given in Reference Joint Appendix JA4 Table 4.3.4 and can also be calculated in compliance software.

Demising partitions and knee walls, other than mass demising walls, are ~~not~~ required to meet the prescriptive Package A U-factor requirements for framed demising walls. For wood-framed walls, this will not require continuous insulation if a minimum R-21 insulation is installed in a 2x6 wall for Climate Zones 1-5 and 8-16, and if R-15 in installed in a 2x4 wall for Climate Zones 6 and 7.

~~Demising partitions and knee walls shall meet the mandatory minimum wall insulation requirements from §150.0(c)1 and §150.0(c)1 requires a minimum of R-13 cavity insulation in 2x4 wood framing, or a U-factor less than or equal to, U-0.102. §150.0(c)2 requires a minimum of R-19 cavity insulation for 2x6 inch or greater wood framing, or a U-factor less than or equal to 0.074.~~

3. Other Walls Types

All other types of walls that are not framed or mass walls which are recognized in the Reference Joint Appendix JA4, for example, SIP panels and straw bale walls, must meet the U-factor requirements for framed walls in Table 150.1-A.

Section 9.5 Additions

A. Additions <= 400 ft^2:

…

3. Extensions of existing wood-framed walls may retain the dimensions of the existing walls and require the following cavity insulation:

a. In 2x4 wood-framed walls, insulation shall be R-15.

b. In 2x6 or greater wood-framed walls, insulation shall be R-21~~19~~.

…

B. Additions > 400 ft^2 and <= 700 ft^2:

…

3. Extensions of existing wood-framed walls may retain the dimensions of the existing walls and require the following cavity insulation:

a. In 2x4 wood-framed walls, insulation shall be R-15.

b. In 2x6 or greater wood-framed walls, insulation shall be R-21~~19~~.

…

C. Additions > 700 ft^2:

…

4. ~~To provide consistency with existing wall alignment, e~~Extensions of existing wood-framed walls may retain the dimensions of the existing walls and require the following cavity insulation:

a. In 2x4 wood-framed walls, insulation shall be R-15.

b. In 2x6 or greater wood-framed walls, insulation shall be R-21~~19~~.

…

Table 9-3D: Envelope Insulation Requirements for Prescriptive Additions

Component	**Requirements of Additions <= 400 ft^2**	**Requirements of Additions > 400 ft^2 and <= 700 ft^2**	**Requirements of Additions > 700 ft^2**
Exterior Framed Wall[1,2] Insulation – Single Family	Package A: CZ 1, 11-16: U=0.043 CZ ~~1~~2-5, 8-10~~16~~: U=0.051 CZ 6 & 7: U=0.065	Package A: CZ 1, 11-16: U=0.043 CZ ~~1~~2-5, 8-10~~16~~: U=0.051 CZ 6 & 7: U=0.065	Package A: CZ 1, 11-16: U=0.043 CZ ~~1~~2-5, 8-10~~16~~: U=0.051 CZ 6 & 7: U=0.065

Exterior Framed Wall[1,2] Insulation - Multifamily	Package A: CZ 1-5, 8-16: U=0.051 CZ 6 & 7: U=0.065	Package A: CZ 1-5, 8-16: U=0.051 CZ 6 & 7: U=0.065	Package A: CZ 1-5, 8-16: U=0.051 CZ 6 & 7: U=0.065
1. R-values refer to wood framing, and U-factors refer to both wood and metal framing. 2. There is an exception for walls that are an extension of an existing wall.			

7.5 Compliance Documents

There are no proposed changes to the compliance documents.

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Appendix A: Statewide Savings Methodology

The projected residential new construction forecast that will be impacted by the proposed code change in 2020 is presented in Table 16.

The Statewide CASE Team estimated statewide impacts for the first year that new single family and multifamily buildings comply with the 2019 Title 24, Part 6 Standards by multiplying per-unit savings estimates by statewide construction forecasts that the California Energy Commission Demand Analysis Office provided. The construction forecast from the Energy Commission presented annual new construction estimates for single family and multifamily dwelling units by forecast climate zones (FCZ). The Statewide CASE Team converted estimates from FCZ, which are not used for Title 24, Part 6, to building standards climate zones (BSCZ) using a conversion factors that the Energy Commission provided. The conversion factors, which are presented in Table 17, represent the percentage of dwelling units in a FCZ that are also in a BSCZ. For example, looking at the first column of conversion factors in see Table 17, 22.5 percent of the homes in FCZ 1 are also in BSCZ 1 and 0.1 percent of homes in FCZ 4 are in BSCZ 1. To convert from FCZ to BSCZ, the total forecasted construction in each FCZ was multiplied by the conversion factors for BSCZ 1, then all homes from all FCZs that are found to be in BSCZ 1 are summed to arrive at the total construction in BSCZ 1. This process was repeated for every climate zone. See Table 18 for an example calculation to convert from FCZ to BSCZ. In this example, BSCZ 1 is made up of homes from FCZs 1, 4, and 14.

After converting the statewide construction forecast to BSCZs, the Statewide CASE Team made assumptions about the percentage of buildings in each climate zone that will be impacted by the proposed code change. Assumptions are presented in Table 16.

Table 16: Projected New Residential Construction Completed in 2020 by Climate Zone[a]

Building Climate Zone	Single Family Buildings					Multifamily Dwelling Units[b]				
	Total Buildings Completed in 2020	Percent of Total Construction in Climate Zone	Percent of New Buildings Impacted by Proposal	Buildings Impacted by Proposal	Percent of Total Impacted by Proposal in Climate Zone	Total Dwelling Units Completed in 2020	Percent of Total Construction in Climate Zone	Percent of New Dwelling Units Impacted by Proposal	Dwelling Units Impacted by Proposal	Percent of Total Impacted by Proposal in Climate Zone
1	465	0.4%	100%	465	1.1%	111	0.2%	0%	0	0.0%
2	3,090	2.6%	0%	0	0.0%	1,582	3.0%	0%	0	0.0%
3	11,496	9.8%	0%	0	0.0%	8,432	16.1%	0%	0	0.0%
4	7,435	6.4%	0%	0	0.0%	3,848	7.3%	0%	0	0.0%
5	1,444	1.2%	0%	0	0.0%	747	1.4%	0%	0	0.0%
6	6,450	5.5%	0%	0	0.0%	3,379	6.4%	0%	0	0.0%
7	5,779	4.9%	0%	0	0.0%	3,939	7.5%	0%	0	0.0%
8	9,948	8.5%	0%	0	0.0%	5,153	9.8%	0%	0	0.0%
9	12,293	10.5%	0%	0	0.0%	10,350	19.7%	0%	0	0.0%
10	18,399	15.7%	0%	0	0.0%	4,191	8.0%	0%	0	0.0%
11	3,947	3.4%	100%	3,947	9.7%	747	1.4%	0%	0	0.0%
12	19,414	16.6%	100%	19,414	47.7%	6,023	11.5%	0%	0	0.0%
13	7,034	6.0%	100%	7,034	17.3%	1,375	2.6%	0%	0	0.0%
14	3,484	3.0%	100%	3,484	8.6%	756	1.4%	0%	0	0.0%
15	3,203	2.7%	100%	3,203	7.9%	454	0.9%	0%	0	0.0%
16	3,188	2.7%	100%	3,188	7.8%	1,441	2.7%	0%	0	0.0%
Total	**117,069**	**100%**		**40,735**	**100%**	**52,528**	**100%**		**0**	**0%**

Source: Energy Commission Demand Analysis Office

a. Statewide savings estimates do not include savings from mobile homes.

b. Includes low-rise multifamily construction.

Table 17: Translation from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ)

		Building Standards Climate Zone (BSCZ)																
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**
Forecast Climate Zone (FCZ)	**1**	22.5%	20.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.8%	33.1%	0.2%	0.0%	0.0%	13.8%	100%
	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.0%	75.7%	0.0%	0.0%	0.0%	2.3%	100%
	3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	20.9%	22.8%	54.5%	0.0%	0.0%	1.8%	100%
	4	0.1%	13.7%	8.4%	46.0%	8.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.8%	0.0%	0.0%	0.0%	0.0%	100%
	5	0.0%	4.2%	89.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.6%	0.0%	0.0%	0.0%	0.0%	100%
	6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100%
	7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	75.8%	7.1%	0.0%	17.1%	100%
	8	0.0%	0.0%	0.0%	0.0%	0.0%	40.1%	0.0%	50.8%	8.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	100%
	9	0.0%	0.0%	0.0%	0.0%	0.0%	6.4%	0.0%	26.9%	54.8%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	5.8%	100%
	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	74.9%	0.0%	0.0%	0.0%	12.3%	7.9%	4.9%	100%
	11	0.0%	0.0%	0.0%	0.0%	0.0%	27.0%	0.0%	30.6%	42.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
	12	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	4.2%	95.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	100%
	13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	69.6%	0.0%	0.0%	28.8%	0.0%	0.0%	0.0%	1.6%	0.1%	0.0%	100%
	14	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	97.1%	100%
	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	99.9%	0.0%	100%
	16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

Table 18: Converting from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ) – Example Calculation

Climate Zone	Total Statewide Single Family Homes by FCZ [A]	Conversion Factor FCZ to BSCZ 1 [B]	Single Family Homes in BSCZ 1 [C] = A x B
1	1,898	22.5%	427
2	8,148	0.0%	0
3	9,396	0.0%	0
4	16,153	0.1%	23
5	11,385	0.0%	0
6	6,040	0.0%	0
7	2,520	0.0%	0
8	12,132	0.0%	0
9	9,045	0.0%	0
10	21,372	0.0%	0
11	3,741	0.0%	0
12	4,746	0.0%	0
13	8,309	0.0%	0
14	518	2.9%	15
15	1,509	0.0%	0
16	159	0.0%	0
Total	117,069		**465**

Appendix B: DISCUSSION OF IMPACTS OF COMPLIANCE PROCESS ON MARKET ACTORS

This section discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. The Statewide CASE Team asked stakeholders for feedback on how the measure will impact various market actors during public stakeholder meetings that were held on September 14, 2016 and March 14, 2017 (Statewide CASE Team 2016). The key results from feedback received during stakeholder meetings and other target outreach efforts are detailed below.

Table 19 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated.

The proposed measure would not present any significant challenges to compliance and enforcement. The compliance process generally fits within the current work flow of market actors, although some new tasks would be required (see Table 19). Market actors would continue to coordinate and collaborate with the same actors with whom they currently engage. There would not be any new documentation practices required, such as new compliance documents.

The proposed measure would require some level of training to ensure that implementers acquire knowledge and familiarity with revised installation procedures. However, the new procedures utilize materials and skills with which installers would already be familiar and any required training is expected to be minimal. The new procedures would require a small amount of additional labor time during installation.

Table 19: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Manufacturers & Distributors	• Develop products that meet code requirements	• Balance cost objectives and customer needs with code requirements	• Provides opportunities for expanding product offering	• N/A
Architect / Designer	• Product specification • Develop building details & sections	• Balances form/function to satisfy owner desires • Documentation prepared for permit submittal with minimal clarifications • Meet project budgets	• Include proper flashing details in drawings	• Provide resources to designers on typical details for one-inch CI and > one-inch CI.
Title-24 Consultant	• Provide feedback on the impact of energy measures on compliance • Ensure builder is aware of code requirements • Complete forms & upload to HERS registry	• Project team is aware of requirements with no surprises • Energy goals are met • Minimal plan check comments	• No change to work flow	• N/A
Owner	• Develop project goals including programming, schedules, & budget • Little direct involvement	• Project completed to expected standards and within budget & schedule	• No change to work flow	• N/A
Builder	• Coordinate with design team & trades • Ensure trades are aware of all requirements • Ensure proper product installation • Schedule inspections & post forms onsite	• Owner satisfied and no warranty issues • Meet project budgets & schedule • Minimal inspection failures • Minimal paperwork required • Owner satisfied and no warranty issues	• Account for extra time to hand nail insulation >=1-1/2-inch if staple option not available • Account for time to frame around windows • Determine who is framing around windows	• Training for builders/installers on process & proper installation techniques

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Subcontractors (framer, stucco contractor, window installer)	• Install product to meet requirements • Ensure air barrier and flashing around window is installed properly	• Meet builder's schedule • Finish within budget • Minimal inspection failures • Minimal paperwork required	• Account for extra time to hand nail insulation >=1-1/2-inch if staple option not available • Account for time to frame around windows • May require some additional coordination across subs	• Training for builders/installers on process & proper installation techniques
Plans examiner	• Verify that CF-1R is consistent with building plans and meets compliance criteria for local jurisdiction	• Minimize amount of paperwork needed to review	• No change to work flow	• N/A
Building inspector	• Verify code requirements are met • Verify that paperwork is complete & CF forms are signed and certified • Sign occupancy permit	• Issue permit with minimal re-inspections • Minimal paperwork	• No change to work flow	• N/A

Appendix C: PROTOTYPE DETAILS

Following are details on the residential prototypes applied in this analysis. Table 20 is a re-creation of the table in Section 4.2. Table 21 and Table 22 provides details on the multipliers that were applied to estimate incremental costs for each prototype. The total demising wall area is the sum of items #5 and #6 in Table 21. Continuous insulation was not applied to demising partition for either the proposed measure or the base case.

The total perimeter of the window and door openings used in calculating the incremental cost for window buck framing is the sum of items #8 and #11 in Table 21. Linear feet of window perimeter for the single family prototypes was based on a mix of window sizes for the blended 2,430 square foot prototype as described in Table 22. This was revised from the original default CBECC-Res assumption of thirty-two windows to prepare a more realistic estimate of incremental costs. The window perimeter for the 2,100 square foot and 2,700 square foot prototypes was estimates based on scaling the value for the blended prototype based on total window area. The multifamily assumption was based on the original CBECC-Res assumption of 70 3ft x 5ft windows. One entry door per unit was assumed across all prototypes.

Table 20: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype ID	Occupancy Type	Area (square feet)	Number of Stories	Statewide Area (million square feet)
New Construction Prototype 1	Residential single family	2,100	1	110.6
New Construction Prototype 2	Residential single family	2,700	2	173.8
New Construction Prototype 3	Residential low-rise multifamily	6,960	2	45.7

Table 21: Prototype Multiplier Details

Item	Description	Unit	New Construction Prototype 1	New Construction Prototype 2	New Construction Prototype 3
1	Number of Dwelling Units		1	1	8
2	Floor Area	Square feet	2,100	2,700	6,960
3	Slab Perimeter	Linear feet	162	128	292
4	Wall Area	Square feet	1,018	2,130	3,760
5	Wall Area between house and garage	Square feet	250	250	0
6	Wall Area between house and attic	Square feet	0	42	0
7	Window Area	Square feet	420	540	1044
8	Window Perimeter	Linear feet	351	457	1,114
9	Door Area	Square feet	20	20	160
10	Door Area between house and garage	Square feet	20	20	0
11	Door Perimeter	Linear feet	19	19	155

Table 22: Window Schedule for 2,430 Blended Single Family Prototype

Window #	Width (ft)	Height (ft)	Area (ft^2)	Perimeter (ft)	Multiplier
1	4	6	24	20	8
2	5	5	25	20	7
3	3	5	15	16	4
4	6	6.7	40	25.3	1
5	3	6.7	20	19.3	1
		Totals:	**487**	**409**	**21**

Appendix D: ENERGY AND COST-EFFECTIVENESS RESULTS BY PROTOTYPE

This section presents energy and cost-effectiveness results for the individual prototypes.

Per-unit Energy Impacts Results

Energy savings and peak demand reductions for the three residential new construction prototypes are presented in Table 23, Table 24, and Table 25.

Table 23: First -Year Energy Impacts per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	14	0.00	16.3	3,749
2	9	0.01	9.7	2,698
3	7	0.00	8.4	2,037
4	9	0.01	7.9	2,310
5	7	0.00	8.8	2,079
6	N/A			
7	N/A			
8	8	0.02	3.7	1,722
9	14	0.03	4.4	2,205
10	18	0.03	5.1	2,415
11	41	0.04	9.5	4,137
12	19	0.04	9.2	3,612
13	43	0.04	8.3	4,064
14	38	0.04	9.7	4,242
15	98	0.08	1.5	4,746
16	17	0.01	17.8	4,358

Table 24: First-Year Energy Impacts per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	26	0.00	31.0	7,155
2	21	0.02	19.3	5,819
3	13	0.00	16.0	3,956
4	18	0.01	16.0	4,522
5	13	0.00	16.4	3,915
6	N/A			
7	N/A			
8	14	0.03	7.2	3,172
9	29	0.05	9.0	4,090
10	37	0.06	10.2	4,711
11	80	0.08	19.2	8,559
12	42	0.07	18.6	7,763
13	83	0.08	16.8	7,803
14	75	0.07	19.3	8,235
15	193	0.14	3.7	9,059
16	34	0.01	36.3	8,829

Table 25: First-Year Energy Impacts per Building – Multifamily Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	23	-0.02	44.4	10,162
2	24	0.02	29.3	8,178
3	-1	0.00	19.2	4,315
4	18	0.02	23.3	6,020
5	-20	-0.05	17.7	2,645
6	N/A			
7	N/A			
8	-5	0.05	5.1	3,062
9	24	0.11	9.3	5,812
10	41	0.11	11.4	6,682
11	127	0.14	29.0	13,955
12	56	0.10	28.6	11,101
13	130	0.14	25.8	12,841
14	118	0.13	29.1	13,085
15	328	0.26	1.3	14,964
16	44	0.01	59.0	14,198

Energy Cost Savings Results

Per unit energy cost savings over the 30-year period of analysis are presented in Table 26, Table 27, and Table 28 for the three residential new construction prototypes.

Table 26: TDV Energy Cost Savings over 30-Year Period of Analysis – per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	$69	$579	$648
2	$104	$363	$467
3	$33	$320	$352
4	$100	$300	$400
5	$36	$323	$360
6		N/A	
7		N/A	
8	$156	$142	$298
9	$213	$169	$381
10	$223	$194	$418
11	$358	$358	$716
12	$276	$349	$625
13	$391	$312	$703
14	$363	$371	$734
15	$759	$62	$821
16	$94	$659	$754

Table 27: TDV Energy Cost Savings over 30-Year Period of Analysis – per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	$131	$1,107	$1,238
2	$280	$726	$1,007
3	$79	$605	$684
4	$177	$605	$782
5	$63	$614	$677
6		N/A	
7		N/A	
8	$273	$276	$549
9	$362	$346	$708
10	$425	$390	$815
11	$759	$722	$1,481
12	$638	$705	$1,343
13	$708	$642	$1,350
14	$684	$740	$1,425
15	$1,425	$142	$1,567
16	$185	$1,343	$1,527

Table 28: TDV Energy Cost Savings over 30-Year Period of Analysis – per Building – Multifamily Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	$144	$1,613	$1,758
2	$307	$1,108	$1,415
3	$12	$734	$747
4	$163	$879	$1,042
5	-$205	$662	$458
6	N/A		
7	N/A		
8	$325	$205	$530
9	$656	$349	$1,005
10	$716	$439	$1,156
11	$1,306	$1,108	$2,414
12	$837	$1,084	$1,921
13	$1,234	$987	$2,222
14	$1,144	$1,120	$2,264
15	$2,541	$48	$2,589
16	$271	$2,185	$2,456

Lifecycle Cost-Effectiveness

Lifecycle cost-effectives results per unit are presented in Table 29, Table 30, and Table 31 for the three residential new construction prototypes.

Table 29: Lifecycle Cost-effectiveness Summary per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	$648	$680	0.95
2	$467	$680	0.69
3	$352	$680	0.52
4	$400	$680	0.59
5	$360	$680	0.53
6	N/A		
7	N/A		
8	$298	$680	0.44
9	$381	$680	0.56
10	$418	$680	0.61
11	$716	$680	1.05
12	$625	$680	0.92
13	$703	$680	1.03
14	$734	$680	1.08
15	$821	$680	1.21
16	$754	$680	1.11

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

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

Table 30: Lifecycle Cost-effectiveness Summary per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	$1,238	$1,142	1.08
2	$1,007	$1,142	0.88
3	$684	$1,142	0.60
4	$782	$1,142	0.68
5	$677	$1,142	0.59
6	N/A		
7	N/A		
8	$549	$1,142	0.48
9	$708	$1,142	0.62
10	$815	$1,142	0.71
11	$1,481	$1,142	1.30
12	$1,343	$1,142	1.18
13	$1,350	$1,142	1.18
14	$1,425	$1,142	1.25
15	$1,567	$1,142	1.37
16	$1,527	$1,142	1.34

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

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

Table 31: Lifecycle Cost-effectiveness Summary per Building – Multifamily Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	$1,758	$2,384	0.74
2	$1,415	$2,384	0.59
3	$747	$2,384	0.31
4	$1,042	$2,384	0.44
5	$458	$2,384	0.19
6	N/A		
7	N/A		
8	$530	$2,384	0.22
9	$1,005	$2,384	0.42
10	$1,156	$2,384	0.48
11	$2,414	$2,384	1.01
12	$1,921	$2,384	0.81
13	$2,222	$2,384	0.93
14	$2,264	$2,384	0.95
15	$2,589	$2,384	1.09
16	$2,456	$2,384	1.03

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

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

Appendix E: ALTERNATIVE MEASURE ANALYSIS

The results presented in Sections 4 and 5 only cover the proposed 0.043 U-factor measure. Various additional assemblies were evaluated during the process of determining the recommended measure. Table 32 presents costs for wall components that were evaluated.

Results for three alternative assemblies compared with the proposed measures are demonstrated in Figure 5.

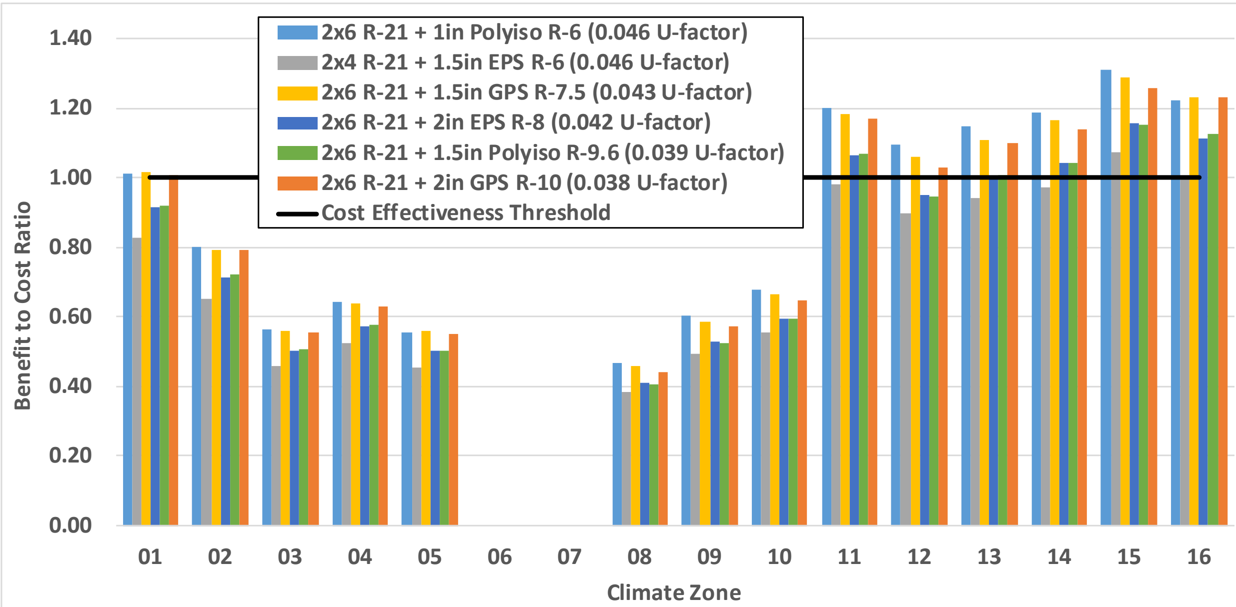

Figure 5: Lifecycle cost-effectiveness results for alternative evaluated assemblies for the 2,430 square foot blended single family prototype.

Table 32: Expanded Summary of Incremental Costs (CI = Continuous Insulation)

Product Type	Description	Material Cost / Unit	Additional Labor Cost / Unit[a]	Total Cost / Unit Including Markup[b]	Unit
Cavity insulation	R-21 vs R-19 fiberglass batt	$0.15	$0.00	$0.20	square feet exterior wall[c]
	R-23 blown-batt vs R-19 batt	$0.29	$0.14	$0.52	
	R-21 vs R-15 fiberglass batt	$0.13	$0.00	$0.17	
	2x6 wall vs 2x4 wall	$0.11	$0.03	$0.17	
Rigid insulation[d]	EPS 1" R-4	$0.22	$0.00	$0.29	square feet exterior wall
	EPS 1.5" R-6	$0.33	$0.00	$0.43	
	EPS 2" R-8	$0.44	$0.00	$0.57	
	GPS 1" R-5	$0.28	$0.00	$0.36	
	GPS 1.5" R-7.5	$0.41	$0.00	$0.54	
	GPS 2" R-10	$0.55	$0.00	$0.72	
	XPS 1" R-5	$0.55	$0.00	$0.72	
	XPS 1.5" R-7.5	$0.83	$0.00	$1.08	
	XPS 2" R-10	$1.10	$0.00	$1.43	
	Polyiso 1" R-6 [e]	$0.51	$0.00	$0.67	
	Polyiso 1.5" R-9.6 [e]	$0.65	$0.00	$0.84	
	Polyiso 2" R-13.1 [e]	$0.87	$0.00	$1.13	
Weed screed	1-3/8" weep screed - 1" CI	$0.77	$0.00	$1.00	linear feet foundation perimeter
	1-7/8" weep screed - 1.5" CI	$0.87	$0.00	$1.13	
	2-3/8" weep screed	$0.98	$0.00	$1.27	
Fasteners	2-1/2" staples, staple gun - 1" CI	$2.15	$0.00	$2.79	100 square feet exterior wall
	3" nail, hand nail - 1.5" CI	$2.04	$9.52	$12.18	
	4" nail, hand nail - 2" CI	$4.86	$9.52	$15.84	
Window picture framing & additional flashing	0.5" window buck - 1.5" CI	$0.22	$0.55	$0.83	linear feet window perimeter
	1" window buck - 2" CI	$0.34	$0.55	$1.00	
	1.5" window buck - 2.5"CI	$0.48	$0.55	$1.17	

a. **Additional Labor Cost / Unit:** This cost only includes incremental labor relative to the base case of a 2x6 wall with 1" of continuous insulation. The labor associated with installing 1" of rigid insulation (not including fasteners and window framing/flashing) is assumed to be same regardless of product type or R-value and therefore there is no labor cost for the rigid insulation product.

b. **Total Cost / Unit Including Markup:** Total costs are presented as costs to the builder. A 30 percent overhead and profit markup was applied to all material costs presented. Labor costs were based on a fully loaded labor rate from RSMeans of $44/hour after applying an average California regional multiplier of 1.1.

c. Costs converted from square foot of material to square foot of exterior wall based on a 25 percent framing factor.

d. EPS = expanded polystyrene; GPS = graphite enhanced expanded polystyrene; XPS = extruded polystyrene; Polyiso = polyisocyanurate.

e. Costs obtained from multiple sources indicated a difference in cost per inch between the one-inch product and thicker products.