

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Residential High Performance Walls and QII

Measure Number: 2016-RES-ENV2-F

Residential Envelope

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team

September 2014

Prepared by: Joshua Rasin (TRC)
Farhad Farahmand (TRC)

California Energy Commission

DOCKETED

15-BSTD-01

TN # 74350

JAN 22 2015



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

Copyright 2014 Pacific Gas and Electric Company, Southern California Edison, Southern California Gas Company, San Diego Gas & Electric Company, Los Angeles Department of Water and Power.

All rights reserved, except that this document may be used, copied, and distributed without modification.

Neither PG&E, SCE, SDG&E, SoCalGas, LADWP nor any of its employees makes any warranty, express or implied; or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any data, information, method, product, policy or process disclosed in this document; or represents that its use will not infringe any privately-owned rights including, but not limited to, patents, trademarks or copyrights.

TABLE OF CONTENTS

Executive Summary	vii
1. Introduction.....	1
2. Measure Description.....	2
2.1 Measure Overview.....	2
2.1.1 Measure Description.....	2
2.1.2 Measure History	3
2.1.3 Existing Standards	5
2.1.4 Alignment with Zero Net Energy Goals.....	5
2.1.5 Relationship to Other Title 24 Measures.....	5
2.2 Summary of Changes to Code Documents.....	5
2.2.1 Catalogue of Proposed Changes	5
2.2.2 Standards Change Summary.....	7
2.2.3 Standards Reference Appendices Change Summary	8
2.2.4 Residential Alternative Calculation Method (ACM) Reference Manual Change Summary	8
2.2.5 Compliance Forms Change Summary.....	8
2.2.6 Simulation Engine Adaptations.....	9
2.2.7 Other Areas Affected.....	9
2.3 Code Implementation.....	9
2.3.1 Verifying Code Compliance.....	9
2.3.2 Code Implementation	9
2.3.3 Field Verification and Diagnostic Testing	10
2.4 Issues Addressed During CASE Development Process	10
3. Market Analysis	10
3.1 Market Structure.....	10
3.2 Market Availability and Current Practices	11
3.3 Useful Life, Persistence, and Maintenance	13
3.4 Market Impacts and Economic Assessments.....	13
3.4.1 Impact on Builders	13
3.4.2 Impact on Building Designers	14
3.4.3 Impact on Occupational Safety and Health	14
3.4.4 Impact on Building Owners and Occupants.....	14

3.4.5	Impact on Retailers (including manufacturers and distributors)	14
3.4.6	Impact on Energy Consultants.....	14
3.4.7	Impact on Building Inspectors.....	14
3.4.8	Impact on Statewide Employment.....	15
3.5	Economic Impacts	15
3.5.1	Creation or Elimination of Jobs.....	15
3.5.2	Creation or Elimination of Businesses within California.....	16
3.5.3	Competitive Advantages or Disadvantages for Businesses within California	17
3.5.4	Increase or Decrease of Investments in the State of California.....	17
3.5.5	Incentives for Innovation in Products, Materials, or Processes.....	17
3.5.6	Effects on the State General Fund, State Special Funds and Local Governments	17
4.	Methodology	19
4.1	Existing Conditions	19
4.2	Proposed Conditions	20
4.3	Simulation Prototype Buildings	21
4.4	Climate Dependent.....	22
4.5	Time Dependent Valuation.....	22
4.6	Energy Impacts Methodology	22
4.6.1	Per Unit Energy Impacts Methodology	22
4.6.2	Statewide Energy Impacts Methodology.....	23
4.7	Cost-effectiveness Methodology	26
4.7.1	Incremental Cost Methodology	26
4.7.2	Cost Savings Methodology.....	28
4.7.3	Cost-effectiveness Methodology	28
4.8	Environmental Impacts Methodology	28
4.8.1	Greenhouse Gas Emissions Impacts Methodology	28
4.8.2	Material Impacts Methodology	29
5.	Analysis and Results	30
5.1	Energy Impacts Results	31
5.1.1	Per Unit Energy Impacts Results.....	31
5.1.2	Statewide Energy Impacts Results	35
5.2	Cost-effectiveness Results	39
5.2.1	Incremental Cost Results	39
5.2.2	Cost Savings Results	43
5.2.3	Cost-effectiveness Results.....	44

5.3	Environmental Impacts Results.....	49
5.3.1	Greenhouse Gas Emissions Results.....	49
5.3.2	Water Use and Water Quality Impacts.....	51
5.3.3	Material Impacts Results	52
6.	Proposed Language.....	53
6.1	Standards	53
6.2	Reference Appendices	55
6.3	ACM Reference Manual.....	55
6.4	Compliance Manuals.....	56
6.5	Compliance Forms	57
6.5.1	B. OPAQUE SURFACE DETAILS – Framed	57
6.5.2	M. HERS MEASURES	57
7.	References and Other Research	58
	Appendix A: Environmental Impacts Methodology	61
	Appendix B: Job Creation by Industry	62
	Appendix C: CBECC-Res Simulation Results for Additional Wall Assemblies	63

List of Tables

Table 1: Scope of Code Change Proposal.....	vii
Table 2: Estimated First Year Energy Savings	xii
Table 3: Cost-effectiveness Summary for U-factor=0.046 and QII	xiii
Table 4: Estimated Statewide Greenhouse Gas Emissions Impacts	xiv
Table 5: Scope of Code Change Proposal.....	6
Table 6: Sections of Standards Impacted by Proposed Code Change	6
Table 7: Appendices Impacted by Proposed Code Change	6
Table 8: Sections of Residential ACM Impacted by Proposed Code Change	7
Table 9: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code.....	16
Table 10: 2013 Summary of Measures Requiring Field Verification and Diagnostic Testing, Table RA2-1 (partial)	20
Table 11: Overall wall assembly U-factors for various interior and exterior insulation levels	21
Table 12: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis	21
Table 13: Key assumptions for per unit Energy Impacts Analysis.....	23
Table 14: Translation from FCZ to BCZ	24
Table 15: CEC Residential New Construction Forecast Households Mid Case	25
Table 16: Key Assumptions for per unit Incremental Construction Cost.....	27
Table 17: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis	31
Table 18: U-factors of wall assemblies modeled.....	31
Table 19: Energy savings per weighted prototype for various wall assembly U-factors	32
Table 20: Energy Impacts per Weighted Prototype with Exterior Walls, U-factor=0.046 ¹	33
Table 21: Energy Impacts per Weighted Prototype with QII ¹	34
Table 22: Energy Impacts per Weighted Prototype ¹ with Exterior Walls, U-factor=0.046 and QII	35
Table 23: Statewide Energy Impacts of Exterior Walls, U-factor=0.046.....	36
Table 24: Statewide Energy Impacts of QII	37
Table 25: Statewide Energy Impacts of Exterior Walls, U-factor=0.046 and QII	38
Table 26: Incremental Cost of Proposed Measure 2016 Present Value Dollars ¹	39
Table 27: Incremental Cost per weighted prototype for various wall assemblies and U-factors .	39
Table 28: Cost basis for incremental cost calculation	41

Table 29: TDV Energy Cost Savings Over 30 Year Period of Analysis - Per Weighted prototype, 2016 PV \$.....	43
Table 30: Cost-effectiveness Summary for Exterior Walls, U-factor=0.046 ¹	44
Table 31: Cost-effectiveness Summary for QII ¹	45
Table 32: Cost-effectiveness Summary for U-factor=0.046 and QII ¹	46
Table 33: Statewide Greenhouse Gas Emissions Impacts for Exterior Walls, U-factor=0.046 ...	49
Table 34: Statewide Greenhouse Gas Emissions Impacts for QII.....	50
Table 35: Statewide Greenhouse Gas Emissions Impacts for Exterior Walls, U-factor=0.046 and QII	51
Table 36: Impacts of Water Use and Water Quality	52
Table 37: Impacts of Material Use.....	52
Table 38: Proposed changes to the 2013 Standards Table 150.1-A Component Package A.....	55
Table 39: Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing.....	55
Table 40: Job Creation by Industry.....	62
Table 41: Alternate Assembly U-Values	63
Table 42: Alternate Assembly TDV Savings.....	63
Table 43: Alternate Assembly First Costs	63
Table 44: Alternate Assembly PV of Energy Cost Savings	64
Table 45: Alternate Assembly Life Cycle Cost	64
Table 46: Energy Impacts per Weighted Prototype with Exterior Walls, U-factor=0.049 ¹	65
Table 47: Statewide Energy Impacts of Exterior Walls, U-factor=0.049	66
Table 48: Cost-effectiveness Summary for Exterior Walls, U-factor=0.049 ¹	67

List of Figures

Figure 1: Change in board feet from base case framing to proposed framing (2013 CASE report)	29
Figure 2: Incremental Cost Breakdown for various assemblies, U-factors 0.051 to 0.043	42
Figure 3: Energy Savings and Incremental Costs of Assemblies with U-factors 0.046 or less....	48

Document Information

Category: Codes and Standards

Keywords: Statewide CASE, Statewide Codes and Standards Team, Statewide C&S Team, Codes and Standards Enhancements, Title 24, 2016, efficiency, residential new construction, high-performance walls, quality insulation installation (QII), rigid foam, cavity insulation, continuous insulation, 2x6 framing.

EXECUTIVE SUMMARY

Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) 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 Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) 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 regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose a code change proposal for Residential High Performance Walls. The report contains pertinent information that justifies the code change including:

- Description of the code change proposal, the measure history, and existing standards (Section 2);
- Market analysis, including a description of the market structure for specific technologies, market availability, and how the proposed standard will impact building owners and occupants, builders, and equipment manufacturers, distributors, and sellers (Section 3);
- Methodology and assumption used in the analyses energy and electricity demand impacts, cost-effectiveness, and environmental impacts (Section 4);
- Results of energy and electricity demand impacts analysis, Cost-effectiveness Analysis, and environmental impacts analysis (Section 5); and
- Proposed code change language (Section 6).

Scope of Code Change Proposal

Residential High Performance Walls will affect the following code documents listed in Table 1

Table 1: Scope of Code Change Proposal

Standards Requirements (see note below)	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Forms
M, Ps	Yes	JA4	Yes	No	CF1R-NCB-01-E

Note: An (M) indicates mandatory requirements, (Ps) Prescriptive, (Pm) Performance.

Measure Description

The Residential High Performance Walls measure is intended to increase the performance of the residential envelope, reducing the amount of heat transfer through walls and thus reduce HVAC loads. The Statewide Codes and Standards Enhancement Team (Statewide CASE Team) investigated two changes to the Standards: lower prescriptive wall U-factor requirements via increased insulation; and mandatory Quality Insulation Installation (QII). This measure requires updating the language contained in Sections 150.0(c) and updating row two (2) of Table 150.1-A Component Package A and editing associated footnotes.

For the 2013 Title 24 update, the Statewide CASE Team investigated the feasibility of requiring 2x6 inch studs at 24-inch on-center framing with R-19 cavity insulation as the prescriptive requirement for residential buildings in California. According to market research at the time, most builders were only mildly familiar with this design practice, and the majority preferred 2x4 inch studs at 16 inches on center framing. The 2013 Standards based the prescriptive requirement on 2x4 inch framing with 1" (R-4) continuous exterior insulation, and provided look-up tables for equivalent insulation levels in 2x6 inch framing to meet the requirement. The 2013 Title 24 Standards are not the most stringent values that were found to be cost-effective during analysis for each climate zone. The CEC decided to adopt one value that applies to all climate zones to simplify requirements and encourage compliance.

Detailed lifecycle cost analysis performed by the Statewide CASE Team for the 2016 Standards shows the cost-effectiveness of lowering the effective U-factor of residential walls. Also, recent interviews with the PG&E California Advanced Home Program (CAHP) implementer as part of the 2016 CASE effort reveal that 2x6" studs are now more common in the Central Valley (Climate Zones 11-13) for advanced homes because lower wall U-factors are necessary to be considered an advanced home and eligible for the program.

Section 2 of this report provides detailed information about the code change proposal including: Section 2.2 Summary of Changes to Code Documents (page 5) provides a section-by-section description of the proposed changes to the standards, appendices, alternative compliance manual and other documents that will be modified by the proposed code change. See the following tables for an inventory of sections of each document that will be modified:

- Table 5: Scope of Code Change Proposal (page 6)
- Table 6: Sections of Standards Impacted by Proposed Code Change (page 6)
- Table 7: Appendices Impacted by Proposed Code Change (page 6)
- Table 8: Sections of Residential ACM Impacted by Proposed Code Change (page 7)

Detailed proposed changes to the text of the building efficiency standards, the reference appendices, and are given in **Section 6 Proposed Language** of this report. This section proposes modifications to language with additions identified with underlined text and deletions identified with ~~struck-out~~ text.

The following documents will be modified by the proposed change:

- Title 24 Part 6 Sections 150.0(c), 150.1(c)1.B, and Table 150.1-A
- Joint Appendix 4 and Residential Appendix 2
- Residential ACM

- Compliance form CF1R

Market Analysis and Regulatory Impact Assessment

There are several components involved in constructing a high performance wall, and each was investigated for market structure, availability and useful life, persistence and maintenance. The following briefly provides the findings for this measure; further detail is provided in Section 3.

- **Exterior rigid and cavity insulations:** a variety of insulation types are available that provide varying levels of insulation per unit depth, and can meet the proposed requirement using either 2x4 or 2x6 studs. No additional maintenance is expected for these products if installed properly.
- **Framing:** The use of 2x6 studs in the California residential market has increased in advanced homes since the 2013 CASE analysis, and is expected to further increase with the 2013 Standards going into effect. A market shift towards greater use of 2x6 studs will only have a minor impact on the timber industry and negligible impact on lumber use due to optimal lumber sawing practices. Framing requirements are expected to have no additional maintenance if installed properly.
- **External finish:** Stucco is the predominant finishing for California residential new construction. It is expected that there will be labor and material increases when applying stucco over rigid insulation at depths greater than 1” due to the need for longer nails and wider door and window frames.
- **Window frames and flashing:** Window frames are directly affected by the thickness of the external finish; meaning adjustments must be made in the installation of windows when using thicker rigid exterior insulation.

This proposal is cost effective in Climate Zones 1-5 and 9-16 over the Lifecycle Cost (LCC) period of analysis of 30 years. 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. As a result this leaves more money available for discretionary and investment purposes.

The expected impacts of the proposed code change on various stakeholders are summarized below:

- **Impact on builders:** Builders will need to adjust to the lower U-factor requirements by changing one or more ‘typical’ building practices, including exterior rigid and cavity insulation, or framing size and spacing. Builders that have not commonly taken the QII compliance credit will need to adjust labor and schedules to receive HERS verification.
- **Impact on building designers:** The proposed code change is not expected to significantly impact building designers.
- **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 California Division of Occupational Safety and Health. All existing health and safety rules will remain in place. Complying with the proposed code changes is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

- **Impact on building owners and occupants:** For building owners and occupants who pay energy bills, the energy cost savings are higher than the cost of the measure over the buildings expected life of 30 years, so both owners and renters are expected to experience net cost savings over the life of the building.
- **Impact on equipment retailers (including manufacturers and distributors):** Retailers, manufacturers, and distributors will see different lines of products being requested; over time it is expected that the costs of these products will reduce and cost savings will improve.
- **Impact on energy consultants:** The proposed code change is not expected to significantly impact energy consultants.
- **Impact on building inspectors:** As compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.
- **Statewide Employment Impacts:** The proposed changes to Title 24 are expected to result in positive job growth as noted below in Section 3.5. The biggest impact from this particular measure is likely to be an increase in the number of HERS raters available in the state to conduct verification of QII.
- **Impacts on the creation or elimination of businesses in California:** The updates to Title 24 as a whole are expected to drive additional business creation in California. This is discussed in greater detail below in Section 3.5.
- **Impacts on the potential advantages or disadvantages to California businesses:** California businesses would benefit from an overall reduction in energy costs. This could help California businesses gain competitive advantage over businesses operating in other states or countries and an increase in investment in California, as noted below.
- **Impacts on the potential increase or decrease of investments in California:** As described in Section 3.5 of this report, the California Air Resources Board (CARB) economic analysis of greenhouse gas reduction strategies for the State of California indicates that higher levels of energy efficiency and 33% Renewable Portfolio Standard (RPS) will increase investment in California by about 3% in 2020 compared to 20% RPS and lower levels of energy efficiency. After reviewing the CARB analysis, the Statewide CASE Team concluded that the majority of the increased investment of the more aggressive strategy is attributed to the benefits of efficiency (CARB 2010b Figures 7a and 10a). The specific code change proposal presented in this report is not expected to have an appreciable impact on investments in California.
- **Impacts on incentives for innovations in products, materials or processes:** Updating Title 24 standards will encourage innovation through the adoption of new technologies to better manage energy usage and achieve energy savings. There are no projected impediments to, or incentives for, innovation that would result from the proposed measures.
- **Impacts on the State General Fund, Special Funds and local government:** The proposed measure is not expected to have an appreciable impact on the State General Fund, Special Funds, or local government funds.

- **Cost of enforcement to State Government and local governments:** Building inspection requirements remain the same. Likewise, training or additional time spent on enforcement, which may lead to increased enforcement costs for the state or local government, are very minimal.
 - State government already has budgeted for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 standards, including updating education and compliance materials and responding to questions about the revised standards, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.
 - 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. Although retraining is a cost of the revised standards, Title 24 energy efficiency standards are expected to increase economic growth and income with positive impacts on local revenue.
 - These proposed changes would revise an existing measure without significantly affecting the complexity of this measure. Therefore, on-going costs are not expected to change significantly.
- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by the CEC into Title 24, part 6 do not disadvantage or discriminate in regards to race, religion or age group.
- **Impact on Homeowners (including potential first time home owners):** This proposal is cost-effective for the homeowner. As a result the combined mortgage costs and utility bill payment for the homeowner are less if the measure is incorporated into all new homes.
- **Impact on Renters:** This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid by renters. Since the measures adopted were shown to have net negative lifecycle costs, the societal impact will be to save more energy costs than the incremental cost of the adopted measures during construction, resulting in energy cost savings experienced by renters as a whole.
- **Impact on Commuters:** This proposal and all measures adopted by the CEC into Title 24, part 6 are not expected to have an impact on commuters.

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the Residential High Performance Walls. Demand reductions estimates are not available at this time. The statewide TDV savings estimate the energy cost savings over the lifetime of the measure (30 years) for the first year of construction when the new code is in effect.

Table 2: Estimated First Year Energy Savings

	First Year Statewide Savings			Statewide TDV Savings	
	Electricity Savings (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	TDV Energy Savings (Million kBTU)	TDV Dollar Savings (Million \$)
U-factor=0.046	8.3	10.7	2.2	844	\$145
QII	6.9	7.7	2.5	817	\$141
U-factor=0.046 and QII	14.2	16.8	4.5	1,552	\$268

The savings calculated in Table 2 include all Single Family New Construction the first year the new Standards are in effect. The forecasted new construction is presented in Table 15. The total statewide savings for these combined measures uses the savings from a model of the proposed U-factor (0.046) with QII for 90% of the population, and the savings from the U=0.046 simulations without QII for the remaining 10% of the population. This produces savings between 4% and 9% less than the sum of the savings from the independently modeled measures. Section 4.6.1 discusses the methodology and Section 5.1.1 shows the results for the per unit energy impact analysis.

Cost-effectiveness

Cost-effectiveness Analyses Results are presented in Table 3 below. The TDV Energy Costs Savings are the present valued energy cost savings over the 30 year period of analysis using CEC's TDV methodology. The Total Incremental Cost represents the incremental initial construction and maintenance costs of the proposed measure relative to existing conditions (current minimally compliant construction practice when there are existing Title 24 Standards). The Planning Benefit to Cost (B/C) Ratio is the incremental TDV Energy Costs Savings divided by the Total Incremental Costs. When the B/C ratio is 1.0 or greater, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is deemed to be cost effective. For a detailed description of the Cost-effectiveness Methodology see Section 4.7 of this report.

The Change in Lifecycle Cost values are negative in all climate zones except 6, 7 and 8 (the southern California coast). This means that the proposed code change has a B/C ratio greater than one and is cost effective in climate zones 1-5 and 9-16, and the code change will result in cost savings relative to the existing conditions in those climate zones.

Table 3: Cost-effectiveness Summary for U-factor=0.046 and QII

Climate Zone	Benefit: TDV Energy Cost Savings (2016 PV\$)	Cost: Total Incremental First Cost and Maintenance Cost (2016 PV\$)	Change in Lifecycle Cost (2016 PV\$)	Benefit to Cost (B/C) Ratio
Climate Zone 1	\$3,337	\$1,626	(\$1,711)	2.1
Climate Zone 2	\$2,384	\$1,626	(\$758)	1.5
Climate Zone 3	\$1,785	\$1,626	(\$159)	1.1
Climate Zone 4	\$2,171	\$1,626	(\$545)	1.3
Climate Zone 5	\$1,670	\$1,626	(\$45)	1.0
Climate Zone 6	\$1,191	\$1,626	\$434	0.7
Climate Zone 7	\$577	\$1,626	\$1,049	0.4
Climate Zone 8	\$1,342	\$1,626	\$284	0.8
Climate Zone 9	\$2,141	\$1,626	(\$516)	1.3
Climate Zone 10	\$2,300	\$1,626	(\$674)	1.4
Climate Zone 11	\$4,183	\$1,626	(\$2,558)	2.6
Climate Zone 12	\$3,558	\$1,626	(\$1,932)	2.2
Climate Zone 13	\$4,095	\$1,626	(\$2,470)	2.5
Climate Zone 14	\$4,040	\$1,626	(\$2,414)	2.5
Climate Zone 15	\$3,784	\$1,626	(\$2,158)	2.3
Climate Zone 16	\$4,453	\$1,626	(\$2,827)	2.7

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates a 30 year lifecycle cost savings of \$114 million for all single family houses built with a U-factor of 0.046 and Quality Insulation Installation during the first year the 2016 Standards are in effect.

Section 4 discusses the methodology and section 5.2 shows the results of the Cost Effectiveness Analysis.

Greenhouse Gas and Water Related Impacts

For more a detailed and extensive analysis of the possible environmental impacts from the implementation of the proposed measure(s), please refer to Section 5.3 of this report.

Greenhouse Gas Impacts

Table 4 presents the estimated avoided greenhouse gas (GHG) emissions of the proposed code change for the first year the standards are in effect. Assumptions used in developing the GHG savings are provided in Section 4.8.1 on page 28 of this report.

The monetary value of avoided GHG emissions is included in TDV cost factors (TDV \$) and is thus included in the Cost-effectiveness Analysis prepared for this report.

Table 4: Estimated Statewide Greenhouse Gas Emissions Impacts

	First Year Statewide Avoided GHG Emissions (MTCO₂e/yr)
U-factor=0.046	14,788
QII	15,844
U-factor=0.046 and QII	28,852

Section 4.8.1 discusses the methodology and Section 5.3.1 shows the results of the greenhouse gas emission impacts analysis.

Water Use and Water Quality Impacts

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

Field Verification and Diagnostic Testing

The proposed measure will entail the mandatory enforcement of existing requirements for field verification of QII. The requirements for the actual verification of QII will not be modified by this code change proposal (see Section 2.3.3).

1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) 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 Southern California Gas Company – and Los Angeles Department of Water and Power (LADWP) 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 regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to propose a lower prescriptive U-factor requirement for residential exterior walls and require Quality Insulation Installation (QII) as a mandatory requirement. The report contains pertinent information that justifies the code change.

Section 2 of this CASE Report provides a description of the measure, how the measure came about, and how the measure helps achieve the state's zero net energy (ZNE) goals. This section presents how the Statewide CASE Team envisions the proposed code change would be enforced and the expected compliance rates. This section also summarized key issues that were addressed during the CASE development process, including issues discussed during a public stakeholder meeting that the Statewide CASE Team hosted in May 2014.

Section 3 presents the market analysis, including a review of the current market structure, a discussion of product availability, and the useful life and persistence of the proposed measure. This section offers an overview of how the proposed standard will impact various stakeholders including builders, building designers, building occupants, equipment retailers (including manufacturers and distributors), energy consultants, and building inspectors. Finally, this section presents estimates of how the proposed change will impact statewide employment.

Section 4 describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. Key assumptions used in the analyses can be also found in Section 4.

Results from the energy, demand, costs, and environmental impacts analysis are presented in Section 5. The Statewide CASE Team calculated energy, demand, and environmental impacts using two metrics: (1) per unit, and (2) statewide impacts during the first year buildings complying with the 2016 Title 24 Standards are in operation. Time Dependent Valuation (TDV) energy impacts, which accounts for the higher value of peak savings, are presented for the first year both per unit and statewide. The incremental costs, relative to existing conditions are presented as are present value of year TDV energy cost savings and the overall cost impacts over the year period of analysis.

The report concludes with specific recommendations for language for the Standards, Appendices, Alternate Calculation Method (ACM) Reference Manual, and Compliance Forms.

2. MEASURE DESCRIPTION

2.1 Measure Overview

2.1.1 Measure Description

The Residential High Performance Walls measure is intended to increase the performance of the residential envelope, reducing the amount of heat transfer through walls and thus reduce HVAC loads. The Statewide Codes and Standards Enhancement Team (Statewide CASE Team) investigated two changes to the Standards: lower prescriptive wall U-factor requirements via increased insulation; and mandatory Quality Insulation Installation (QII). This measure requires updating the language contained in Sections 150.0(a) and (c), 150.1(c).B and updating row two (2) of Table 150.1-A Component Package A and associated footnotes.

The list below provides a summary of how each Title 24 document will be modified by the proposed change:

- **Standards:** The proposed language will lower the prescriptive U-factor requirements for walls and make QII mandatory for batt, blanket and loose-fill insulation for walls, roofs, and floors. The proposed code change will modify the following Sections:
 - 150.0(a) Mandatory Features and Devices – Ceiling and Rafter Roof Insulation QII
 - 150.0(c) Mandatory Features and Devices – Wall Insulation
 - 150.0(d) Mandatory Features and Devices – Raised-floor Insulation
 - 150.1(c).1 Performance and Prescriptive Compliance Approaches for Newly Constructed Residential Buildings - Insulation: Walls.
 - TABLE 150.1-A COMPONENT PACKAGE-A Standard Building Design – row 2.
- **Appendices:** The proposed code change will modify Sections JA4, RA2, and RA3.5 of the appendices to the Standards. The proposal will modify existing language by altering prescriptive wall insulation and QII requirements.
- **Residential Alternative Calculation Method (ACM) Reference Manual:** The proposed code change will modify sections 2.2.6 (Insulation Construction Quality), 2.3 (Building Materials), and 2.5.4.3 (Exterior Walls) of the Residential ACM Reference Manual. The proposal will modify existing language by updating the standard design for insulation construction quality and the standard design for exterior walls.

Compliance Forms: The proposed code change will modify the following compliance forms:

- **CF1R-NCB-01-E – CERTIFICATE OF COMPLIANCE – DATA FIELD DEFINITIONS AND CALCULATIONS.**

Wall Assembly Strategies

This measure lowers the prescriptive overall wall insulation U-factor requirements for wood framed walls in residential and low-rise multifamily buildings. The Statewide CASE Team investigated the feasibility of lowering U-factor requirements while considering the variety of framing, continuous insulation, and cavity insulation strategies available to reach lower U-factors. These strategies include:

- Increased exterior rigid insulation
- Higher R-value cavity insulation
- 2x6 -inch studs
- Structurally Insulated Panels (SIPs)
- Insulated Concrete Forms (ICFs)

The Statewide CASE Team assessed the use of batt, blown-in, spray foam, flash-and-batt, and continuous (rigid) insulation with these wall types. Currently, all of these approaches are viable to comply with the 2013 Title 24 Standards using the performance approach.

This measure affects the prescriptive requirements and therefore the basis for the performance approach for exterior walls. This measure would modify existing code language, but not modify the scope of the Standards.

Mandatory QII

The Statewide CASE Team intends to require mandatory QII when batt, blanket or loose-fill insulation is installed, which will require verification by a HERS rater to ensure proper insulation installation within the entire thermal envelope (including walls, roofs, and floors). Currently, a compliance credit is awarded for installations that perform QII. This proposal would change QII for batt, blanket or loose-fill insulation to a mandatory requirement for Climate Zones 1-5 and 9-16. Interviews with residential builders, contractors, and energy program implementers have found that the most commonly used wall insulation in California is fiberglass batt, while loose-fill fiberglass insulation is commonly used in attic insulation. Raised-floors are also commonly filled with fiberglass batts. Requiring QII for batt, blanket or loose-fill insulation would ensure that the majority of insulation installations are properly implemented, increasing the effective U-factor of these envelope assemblies.

This measure would modify the mandatory requirements, remove the current compliance credit for QII with batt, blanket or loose-fill insulation. The measure would also update Joint and Residential Appendices language, and compliance forms, as related to QII requirements. This measure would modify existing code language, but not modify the scope of the Standards.

2.1.2 Measure History

For the 2013 Title 24 code cycle, the Statewide CASE Team investigated the feasibility of requiring 2x6 inch studs at 24-inch on-center framing with R-19 cavity insulation as the prescriptive requirement for residential buildings in California. According to market research during the 2013 CASE work, most builders were only mildly familiar with this design practice,

and most preferred 2x4 inch studs at 16 inches on center framing. The 2013 CASE based the prescriptive standard on 2x4 inch framing with 1" (R-4) continuous exterior insulation, then provided look-up tables for equivalent insulation levels in 2x6 inch framing to meet the new requirements.

The 2013 CASE study Increased Wall Insulation (IOU 2013) found that, based on a very small sample of homes receiving incentives for exceeding 2008 Title 24 Standards by 15% through the California New Homes Program, many builders were using a combination of 2x6 and 2x4 framing. Of the 548 homes¹ in the sample, 67% included some 2x6 exterior wall framing. The 2x6 framed wall area, on average, only accounted for 23% of the total exterior wall area. In no case was 24-inch on center framing specified.

During the 2013 code cycle stakeholders raised a concern about the possible increase in wood demand and wood waste resulting from 2x6 studs replacing 2x4 studs. Review of USDA-published literature confirmed that milling 2x6 framing members, alongside other nominal framing sizes results in maximum board foot yield from a standard 9-inch log, and does not require more or larger trees to be cut.² Regardless, the wood remnants, not milled into lumber, are never wasted, but used to make composite materials. The milling of 2x6 framing members is therefore not an environmental concern. As an alternative to prescriptively requiring this type of framing, the Statewide CASE Team updated the look-up tables for U-factors which promote 2x6 inch studs and 24-inch on-center framing as compliance options.

The prescriptive U-factor and associated insulation values adopted for wood-framed residential buildings in the 2013 Title 24 Standards are not the most stringent values that were found to be cost-effective for each climate zone. The CEC decided to adopt one value that applies to all climate zones in order simplify requirements and encourage compliance. Although the proposed U-factors were based on insulation levels for 2x4 studs at 16-inches on-center, stakeholders were worried that the lowest U-factors found cost effective would require a learning curve for most contractors. For this reason, not all cost-effective energy savings were captured for all climate zones.

During the 2013 Title 24 code cycle, AWF and ICFs were investigated for integration into the standards for the first time, and were added as compliance options. SIPs were an existing compliance option from the 2008 Standards. The Statewide CASE Team developed tables for the Joint Appendix, including revised values for SIPs in the look up tables to better align with available products and practices, but CEC staff responded that the values would be built into the new modeling software and tables would not be necessary. The 2013 CASE work set the precedence for these framing assemblies to earn proper credit for the energy benefits that they provide.

¹ These 548 homes were collectively built by 9 different builders.

² Steele, Phillip H., "Factors Determining Lumber Recovery in Sawmilling," April 1984.

2.1.3 Existing Standards

Residential walls are currently regulated by 2013 Title 24. The prescriptive requirements are located in Table 150.1-A, and indicate that above grade wood framed walls are required to meet a U-factor of 0.065 or less in all climate zones.

Performing Quality Insulation Installation (QII) for walls is currently rewarded with a compliance credit. The Standard Design assumes that builders are not performing QII; insulation values are modeled at 70% of the R-value of the installed insulation. If a builder performs QII, the actual insulation values (100%) are credited in the modeling.

2.1.4 Alignment with Zero Net Energy Goals

The Statewide CASE Team and the CEC are committed to achieving California's zero-net-energy (ZNE) goal. This measure will help achieve ZNE goals by reducing the heating and cooling loads for HVAC systems in residential buildings. Increased insulation and advanced framing practices lead to a higher overall envelope performance, which reduces the required capacity of the HVAC needed to maintain stable interior temperature while exterior temperatures fluctuate. Reduced HVAC operation will lead to reduced electricity demand.

This measure will also set the foundation for proposing future code changes that will help ensure ZNE goals are achieved. In particular, this measure could lead directly to the following code changes in the 2019 and 2022 code change cycles:

- Introduction of advanced wall assembly techniques as prescriptive or trade-offs approaches, allowing for greater reductions in prescriptive U-factors
- Introduction of staggered studs or double walls as a prescriptive requirement or compliance option
- Further changes in QII requirements.

2.1.5 Relationship to Other Title 24 Measures

Quality Insulation Installation affects all cavity insulation, including that installed in ceilings or floors. Thus, this measure overlaps with the High-Performance Attics and Ducts / Ducts in Conditioned Space 2016 CASE measure (HPA/DCS). All of the savings associated with QII for wall, floor and ceiling/attic insulation are included in this CASE report.

2.2 Summary of Changes to Code Documents

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

2.2.1 Catalogue of Proposed Changes

Scope

Table 5 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 5: Scope of Code Change Proposal

Mandatory	Prescriptive	Performance	Compliance Option	Trade-Off	Modeling Algorithms	Forms
Yes	Yes	Yes	Yes	Yes	No	Yes

Standards

The proposed code change will modify the sections of the California Building Energy Efficiency Standards (Title 24, Part 6) identified in Table 6.

Table 6: Sections of Standards Impacted by Proposed Code Change

Title 24, Part 6 Section Number	Section Title	Mandatory (M) Prescriptive (Ps) Performance (Pm)	Modify Existing (E) New Section (N)
150.0(c)	Mandatory Features and Devices - Wall Insulation	M	E
150.1(c)1-B	Prescriptive Standards/Component Package – Insulation: Walls	Ps	E
Table 150.1-A	Component Package – A	Ps	E

Appendices

The proposed code change will modify the sections of the indicated appendices presented in Table 7. If an appendix is not listed, then the proposed code change is not expected to have an effect on that appendix.

Table 7: Appendices Impacted by Proposed Code Change

APPENDIX NAME		
Section Number	Section Title	Modify Existing (E) New Section (N)
JA4	U-factor, C-factor, and Thermal Mass Data	E
Table RA2-1	Summary of Measures Requiring Field Verification and Diagnostic Testing	E

Residential Alternative Calculation Method (ACM) Reference Manual

The proposed code change will modify the sections of the Residential ACM Manual identified in Table 8.

Table 8: Sections of Residential ACM Impacted by Proposed Code Change

Residential Alternative Calculation Method Reference		
Section Number	Section Title	Modify Existing (E) New Section (N)
2.2.6	Insulation Construction Quality	E
2.3	Building Materials	E
2.5.4.3	Exterior Walls	E

CBECC-Res Simulation Engine Adaptations

The proposed code change can be modeled using the current simulation engine (CBECC-Res³). Changes to the simulation engine are necessary, specifically, making QII part of the standard building and changing the U-factor of the wall assembly in the base case for affected climate zones (1-5 and 9-16).

2.2.2 Standards Change Summary

This proposal would modify the following sections of the Building Energy Efficiency standards as shown below. See *Section 6.1 Standards* of this report for the detailed proposed revisions to the standards language.

Changes in Scope

The proposed code change does not change the scope of the Standards. Proposed code changes add/revise mandatory and prescriptive requirements for building elements already regulated by the Standards.

Changes in Mandatory Requirements

The proposed code change will modify Section 150.0(c) Mandatory Features and Devices – Wall Insulation by adding QII as a mandatory requirement for climate zones 1-5 and 9-16.

Changes in Prescriptive Requirements

The proposed code change will modify Section 150.1(c).B Performance and Prescriptive Compliance Approaches for Newly Constructed Residential Buildings - Insulation: Walls of the Standards by changing the prescriptive U-factors required in Table 150.1-A to U-0.046 for climates zones 1-5 and 9-16.

SECTION 150.0 – MANDATORY FEATURES AND DEVICES

Subsection 150.0(a): The proposed regulations add Quality Insulation Installation (QII) requirements for residential new construction. This helps minimize the heat transfer between

³ More information available at: <http://cbecc-res.com/>

the exterior ambient air and the conditioned house. This reduces 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.

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR NEWLY CONSTRUCTED RESIDENTIAL BUILDINGS

TABLE 150.1-A COMPONENT PACKAGE-A Standard Building Design: The proposed regulations change the row heading for “2x4 Framed” above grade walls to “Wood Framed” and modify the associated U-factors in Climate Zones 1-5 and 9-16.

2.2.3 Standards Reference Appendices Change Summary

This proposal will modify JA4 of the reference appendices of the Standards. See *Section 6.2 Reference Appendices* of this report for the detailed proposed revisions to the text of the reference appendices.

JOINT APPENDICES

JA4.3 Walls

Table 4.3.1 – U-factors of Wood Framed Walls: The proposed regulations add data for the rated R-value of continuous insulation up to R-10 to reflect the updated Standards language.

RESIDENTIAL APPENDICES

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

High Quality Insulation Installation (QII): The proposed regulations make QII mandatory when batt, blanket or loose-fill insulation is used in walls, roofs, or raised floors, in climate zones 1-5 and 9-16. The language here is modified to reflect that change.

2.2.4 Residential Alternative Calculation Method (ACM) Reference Manual Change Summary

The proposed code change will modify sections 2.2.6 (Insulation Construction Quality), 2.3 (Building Materials), and 2.5.4.3 (Exterior Walls) of the Residential ACM Reference Manual. The proposal will modify existing language by updating the standard design for insulation construction quality and the standard design for exterior walls.

2.2.5 Compliance Forms Change Summary

The proposed code change will modify the following compliance forms listed below. Examples of the revised forms are presented in *Section 6.5 Compliance Forms*.

- **CF1R – B. OPAQUE SURFACE DETAILS – Framed**
- **CF1R – M. HERS VERIFICATION SUMMARY.**

2.2.6 Simulation Engine Adaptations

Add QII as a mandatory feature in climate zones 1-5 and 9-16. Change the standard design for exterior walls to include revised U-factors.

2.2.7 Other Areas Affected

No other areas affected.

2.3 Code Implementation

2.3.1 Verifying Code Compliance

The increased R-value of the wall would require visual inspection by a building inspector to ensure that the wall assembly constructed, including framing spacing, wall cavity insulation value, and external insulation value is in compliance, or matches the performance specified in the compliance software. Because visual inspections are standard practice prior to installation of drywall (for cavity insulation) and again at final inspection (for external insulation), there is no added burden for inspections for this measure.

For QII, the insulation contractor will have to provide CF2R, verifying QII was performed, and a HERS rater will have to provide a CF3R, confirming that QII was verified. This additional trip by the HERS rater is included in the incremental cost estimate for the QII measure.

2.3.2 Code Implementation

The U-factor of wall assemblies is already regulated by Title 24, this proposal strengthens those requirements. The strategies required to achieve the proposed U-factors are common practice for a small number of high-performance builders throughout the state, but will require a significant step forward in common practice for the majority of builders. The incremental cost of the compliance will vary with the strategy chosen by the builder, but should be less than \$1,000 regardless of the strategy chosen, and could be less than \$600. There may be some resistance from the building industry on the grounds of moisture issues resulting from the increased use and thickness of rigid exterior insulation, but technical solutions exist to address those concerns^{4,5,6,7}. There may be a learning curve associated with the initial implementation of these new strategies, but over time this too will become standard practice.

QII is commonly taken as a compliance credit in new construction. Making this a mandatory measure would have no impact on builders already taking advantage of QII, other than

⁴ <http://www.buildingscience.com/documents/insights/bsi-038-mind-the-gap-eh/?searchterm=mind%20the%20gap>

⁵ <http://www.buildingscience.com/documents/digests/bsd-012-moisture-control-for-new-residential-buildings/?searchterm=Moisture%20Control%20for%20New%20Residential%20Buildings>

⁶ http://www.milgard.com/_doc/products/installation/pdf/aama-2400-02.pdf

⁷ http://www.milgard.com/_doc/products/installation/pdf/aama-2400-10.pdf

increasing the efficiency required in the rest of the house that was previously being traded off. For builders that are not currently verifying QII, there may be additional time required to ensure cavity insulation is installed per manufacturers specifications, and to allow time for the HERS rater to verify the installation.

2.3.3 Field Verification and Diagnostic Testing

The proposed measure will entail the mandatory enforcement of existing requirements for field verification of QII, which was optional previously as a compliance credit. The requirements for the actual verification of QII will not be modified by this code change proposal.

2.4 Issues Addressed During CASE Development Process

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the code change proposal presented in this report. In addition to personal outreach to key stakeholders, the Statewide CASE Team conducted a public stakeholder meeting to discuss the proposals.

The Statewide CASE Team followed up with window manufacturers, insulation installers and architects, and determined that best practices can provide the structural support and framing necessary to keep moisture out of the walls using current window sizes and accommodate up to 2 inches of rigid exterior insulation, but it is not yet standard practice. Leading window manufacturers are currently working on a best practices guide for installing windows in residential walls with up to 2 inches of rigid exterior insulation. This guide is expected to be published and available to the public later this year (2014). To mitigate the issues associated with rigid exterior insulation 2 inches and thicker, the CASE Team is proposing a prescriptive requirement using rigid exterior insulation that is 1 to 1 ½ inches thick.

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 players. 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 key stakeholders including utility program staff, CEC, and a wide range of industry players who were invited to participate in a public stakeholder meeting that the Statewide CASE Team held in May 2014.

3.1 Market Structure

There are many components to a high performance wall, and the market implication of each component was explored. The Statewide CASE Team investigated the implications of the following components:

- Cavity insulation – A variety of insulation types are available to place in wall cavities, including low-density batt, high-density batt, spray foam, and loose-fill. High density batt (or mineral wool batt) and loose-fill insulation products are capable of achieving R-23 in 2x6 framing construction and R-15 in 2x4 framing, and are less expensive than spray foam insulation. Open-cell spray foam at R-4 per inch can achieve R-14 in a 4” cavity and R-22 in a 6” cavity. Closed-cell spray foam (more expensive than open-cell) at R-7 per inch can achieve R-24 in a 4” cavity and R-38 in a 6” cavity.
- Rigid continuous insulation- The Statewide CASE Team found manufacturers of extruded polystyrene (XPS) and expanded polystyrene (EPS) rigid insulation covering R-values from R-2 to R-10, including products that are R-3.8, R-4, R-5, and R-6 per inch.
- Framing – The Statewide CASE Team investigated the effects of lumber usage when changing from predominantly 2x4” studs to 2x6” studs. The expected impact on the timber industry is minor. Framing crews will need to account for the additional weight of 2x6 studs as compared to 2x4 when constructing exterior walls.
- External finish – The Statewide CASE Team reached out to stucco contractors, building supply distributors, and window manufacturers to gain an understanding of the differences of external finishing over 1” versus 2” of exterior continuous insulation. Longer fasteners are required as the thickness of the rigid exterior insulation increases. Most framing nailers can accommodate nails from 2” to 3.5” in length. The minimum required penetration varies by weight of the external finish, but is generally in the range of 1” to 1.5”. This means that in most scenarios, a 3.5” nail should be of sufficient length to achieve the required minimum penetration. However, insulation thicker than 2” could potentially require builders to use a nail gun that can accommodate longer nails (if one exists), switch to screws instead of nails, or hammer longer nails manually, all of which can add to the time and/or cost of affixing the external finish to the studs through the exterior insulation.
- Window framing – Window framing attaches the window to the exterior wall. This is directly affected by the thickness of the external finish. Thicker rigid exterior insulation may require picture framing around each rough opening to provide structural support for the window and allow the frame to sit flush with the rigid insulation. Alternatively, a new cast could be developed to produce window frames that accommodate the new thickness.
- Quality Insulation Installation (QII) requires a HERS Rater to verify the insulation installation before the inside finish is installed, which may require multiple trips by the HERS Rater and affect the construction schedule. The QII credit is currently relatively common, and while it creates additional work (for both the insulation contractor and HERS rater), QII does not appear to impose an undue burden.

3.2 Market Availability and Current Practices

Current California Advanced Homes Program (CAHP) information indicates that new residential construction along coastal California continues to utilize 2x4 studs, while builders in central California have transitioned to building with 2x6 studs for houses that are built to

above-code efficiencies. The 2013 CASE Report Increased Wall Insulation (IOU 2013) found that, based on a very small sample of homes receiving incentives for exceeding 2008 Title 24 Standards by 15% through the California New Homes Program, many builders are using a combination of 2x6 and 2x4 framing. Of the 548 homes⁸ in the sample, 67% included some 2x6 exterior wall framing. The 2x6 framed wall area, on average, accounted for 23% of the total exterior wall area.

Interviews with the PG&E CAHP implementer reveal that 2x6” studs are becoming more common in the Central Valley (Climate Zones 11-13). These climates require walls with lower U-factors in order to qualify as an advanced home (15% below the Title 24 energy budget). The Statewide CASE Team also collaborated with PG&E and SCE Emerging Technology (ET) studies on high performance houses. The houses in these studies commonly incorporated 2x6” studs with cavity insulation ranging from R-19 batts to R-23 spray foam or loose-fill cellulose. Most of the houses in CAHP and the ET studies used R-4 continuous exterior insulation.

The Statewide CASE Team found that products necessary to meet the proposed prescriptive requirements are readily available in California:

- Cavity insulation – The Statewide CASE Team found that major manufacturers including John Manville, Owens Corning, Certainteed, and Knauf, have products capable of achieving R-15 in 2x4 framing and R-23 in 2x6 framing, and that these products are commercially available in California. According to interviews with insulation contractors in Northern California, open-cell spray foam at R-4 per inch can achieve R-14 in 2x4 framing and R-22 in 2x6, while closed-cell spray foam at R-7 per inch can achieve R-24 in 2x4 framing and R-38 in 2x6.
- Rigid continuous insulation – R-4 per inch is fairly common. Manufacturers that provide R-5 per inch rigid insulation include Rmax, Dow and Owens Corning. Rmax also sells an R-6 per inch product. All of these manufacturers sell a variety of rigid insulation products, ranging in performance from R-2 to R-10 and ranging in thickness from ½ inch to 2 inches. Cost estimates for EPS, XPS, and Polyisocyanurate (polyiso) products were obtained from builders and distributors in California as well as from large home improvement retailers such as Home Depot and Lowes.
- Window frame profile – A representative from Royal Building Products asserted that window frame manufacturers may need to develop new extrusion dyes to account for different thicknesses of rigid exterior insulation. Each product would require a new dye, which was estimated to cost approximately \$50,000 each. A representative from Jeld-Wen asserted that the window manufacturers are in the process of developing a guide for how to install more than 1” of rigid exterior insulation using existing window frames. One architect described an alternative solution where window moldings are placed on the plywood sheathing layer of the wall, under back-grooved rigid insulation. Another

⁸ These 548 homes were collectively built by 9 different builders.

solution is to frame the rough in window opening to bring the wood framing to the level of the wall plus rigid foam insulation.

- Wall Framing – The Statewide CASE Team spoke with representatives from the APA-The Engineered Wood Association and the American Wood Council regarding the impacts of lumber use when going from 2x4 exterior wall framing to 2x6 framing. These conversations confirmed that the lumber use impact of 2x6 framing is negligible due to the prevalence of optimal lumber sawing practices in the industry. In other words, for any given tree size, the optimal amount of cut lumber is extracted. Furthermore, 2x4s are often used in glue-laminated and other engineered products, so these smaller cuts of wood would not be wasted if California construction practices shifted to 2x6 framing. This finding confirmed similar analysis completed for the 2013 CASE Report on Increased Wall Insulation⁹.

3.3 Useful Life, Persistence, and Maintenance

The rigid insulation, cavity insulation, and framing requirements of the proposed requirements are similar to the current components, and have no maintenance if installed properly. The energy savings related to the insulation installation will persist for the lifetime of the building, assumed to be 30 years.

The methodology the Statewide CASE Team used to determine the costs associated with incremental maintenance costs (if any), relative to existing conditions, is presented in Section 4.7.1, and the analysis of those costs are presented in Section 5.2.1.

3.4 Market Impacts and Economic Assessments

3.4.1 Impact on Builders

As the analysis in Section 5 shows, there are multiple wall assemblies that can meet the new prescriptive requirements. Nonetheless, builders will need to adjust to the lower U-factor requirements by changing one or more ‘typical’ building practices. Builders can comply by changing rigid insulation thickness, cavity insulation type, or framing size and spacing. In some cases the most cost effective solution will be achieved by modifying several components.

For builders that do not commonly take the QII compliance credit, an adjustment in their building crews’ schedule will be necessary to account for additional labor required to meet the QII requirements and additional time for HERS verification. HERS verification of QII will

⁹ From the 2013 CASE Report on Increased Wall Insulation: “A shift to 2x6, 24-inch on center framing was shown to have a very small environmental impact, with regard to lumber consumption. Review of USDA-published literature confirmed that milling 2x6 framing members, alongside other nominal framing sizes results in maximum board foot yield from a standard 9-inch log, and does not require more or larger trees to be cut (Steele 1984). Regardless, the wood remnants, not milled into lumber, are never wasted, but used to make composite materials. The milling of 2x6 framing members is therefore not an environmental concern.”

generally require between two and four visits, depending on the project. It may take a few jobs (or additional training time up front) for the insulation subcontractor and crew to learn how to meet QII, after which it becomes standard practice.

3.4.2 Impact on Building Designers

Building designers and modelers will not be significantly impacted by the measure. They will be able to design walls by using U-factor calculations in modeling software, or by referencing the U-factor tables in Joint Appendices 4. This step will be unchanged from the 2013 Standards.

3.4.3 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 Department of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules will remain in place. Complying with the proposed code change is not anticipated to have any impact on the safety or health occupants or those involved with the construction, commissioning, and ongoing maintenance of the building.

3.4.4 Impact on Building Owners and Occupants

Builders incurring higher initial costs of construction for higher performing building materials may be pass off costs onto consumers. However, as shown in section 5.2, the new requirements result in cost savings to the building owner over the lifetime of the measure.

3.4.5 Impact on Retailers (including manufacturers and distributors)

Retailers, manufacturers, and distributors will see different lines of products being requested, including cavity and rigid insulations with higher R-values. The Statewide CASE Team expects that over time the cost of providing these products will decrease and cost savings estimates will improve beyond those presented in this report.

3.4.6 Impact on Energy Consultants

No significant impact is expected for energy consultants.

3.4.7 Impact on Building Inspectors

No significant impact is expected for building inspectors, as building products and practices will generally stay the same. HERS raters should expect to increase the frequency that QII verification is requested to account for all new construction in the state. Building officials note that their insulation inspections consume less time when QII verification is completed by HERS inspectors.

3.4.8 Impact on Statewide Employment

The proposed changes to Title 24 are expected to result in positive job growth as noted below in Section 3.5. The biggest impact from this particular measure is likely to be an increase in the number of HERS raters available in the state to conduct verification of QIL.

3.5 Economic Impacts

The proposed Title 24 code changes, including this measure, are expected to increase job creation, income, and investment in California. As a result of the proposed code changes, it is anticipated that less money will be sent out of state to fund energy imports, and local spending is expected to increase due to higher disposable incomes due to reduced energy costs.¹⁰ For instance, the statewide lifecycle net present value of this measure is \$254 million over the 30 year period of analysis. That is money that utility customers will be able to spend elsewhere in the economy.

These economic impacts of energy efficiency are documented in several resources including the California Air Resources Board's (CARB) Updated Economic Analysis of California's Climate Change Scoping Plan, which compares the economic impacts of several scenario cases (CARB, 2010b). CARB include one case (Case 1) with a 33% renewable portfolio standard (RPS) and higher levels of energy efficiency compared to an alternative case (Case 4) with a 20% RPS and lower levels of energy efficiency. Gross state production (GSP)¹¹, personal income, and labor demand were between 0.6% and 1.1% higher in the case with the higher RPS and more energy efficiency ((CARB 2010b, Table 26). While CARB's analysis does not report the benefits of energy efficiency and the RPS separately, we expect that the benefits of the package of measures are primarily due to energy efficiency. Energy efficiency measures are expected to reduce costs by \$2,133 million annually (CARB 2008, pC-117) whereas the RPS implementation is expected to cost \$1,782 million annually, not including the benefits of GHG and air pollution reduction (CARB 2008, pC-130).

Macro-economic analysis of past energy efficiency programs and forward-looking analysis of energy efficiency policies and investments similarly show the benefits to California's economy of investments in energy efficiency (Roland-Holst 2008; UC Berkeley 2011).

3.5.1 Creation or Elimination of Jobs

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation estimates that this scenario would result in a 1.1% increase in statewide labor demand in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Tables 26 and 27).

¹⁰ Energy efficiency measures may result in reduced power plant construction, both in-state and out-of-state. These plants tend to be highly capital-intensive and often rely on equipment produced out of state, thus we expect that displaced power plant spending will be more than off-set from job growth in other sectors in California.

¹¹ GSP is the sum of all value added by industries within the state plus taxes on production and imports.

CARB's economic analysis also estimates a 1.3% increase in small business employment levels in 2020 (CARB 2010b, Table 32).

3.5.2 Creation or Elimination of Businesses within California

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation (as described above) estimates that this scenario would result in 0.6% additional GSP in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Table ES-2). We expect that higher GSP will drive additional business creation in California. In particular, local small businesses that spend a much larger proportion of revenue on energy than other businesses (CARB 2010b, Figures 13 and 14) should disproportionately benefit from lower energy costs due to energy efficiency standards. Increased labor demand, as noted earlier, is another indication of business creation.

Table 9 below shows California industries that are expected to receive the economic benefit of the proposed Title 24 code changes. It is anticipated that these industries will expand due to an increase in funding as a result of energy efficiency improvements. The list of industries is based on the industries that the University of California, Berkeley identified as being impacted by energy efficiency programs (UC Berkeley 2011 Table 3.8).¹² This list provided below is not specific to one individual code change proposal; rather it is an approximation of the industries that may receive benefit from the 2016 Title 24 code changes. A table listing total expected job creation by industry that is expected in 2015 and 2020 from all investments in California energy efficiency and renewable energy is presented in the Appendix B: Job Creation by Industry of this CASE Report.

Table 9: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Residential Building Construction	2361
Nonresidential Building Construction	2362
Roofing Contractors	238160
Electrical Contractors	23821
Plumbing, Heating, and Air-Conditioning Contractors	23822
Boiler and Pipe Insulation Installation	23829
Insulation Contractors	23831
Window and Door Installation	23835

¹² Table 3.8 of the UC Berkeley report includes industries that will receive benefits of a wide variety of efficiency interventions, including Title 24 standards and efficiency programs. The authors of the UC Berkeley report did not know in 2011 which Title 24 measures would be considered for the 2016 adoption cycle, so the UC Berkeley report was likely conservative in their approximations of industries impacted by Title 24. Statewide CASE Team believes that industries impacted by utilities efficiency programs is a more realistic and reasonable proxy for industries potentially affected by upcoming Title 24 standards. Therefore, the table provided in this CASE Report includes the industries that are listed as benefiting from Title 24 and utility energy efficiency programs.

Asphalt Paving, Roofing, and Saturated Materials	32412
Manufacturing	32412
Other Nonmetallic Mineral Product Manufacturing	3279
Industrial Machinery Manufacturing	3332
Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manf.	3334
Computer and Peripheral Equipment Manufacturing	3341
Communications Equipment Manufacturing	3342
Electric Lighting Equipment Manufacturing	3351
Household Appliance Manufacturing	3352
Other Major Household Appliance Manufacturing	335228
Used Household and Office Goods Moving	484210
Engineering Services	541330
Building Inspection Services	541350
Environmental Consulting Services	541620
Other Scientific and Technical Consulting Services	541690
Advertising and Related Services	5418
Corporate, Subsidiary, and Regional Managing Offices	551114
Office Administrative Services	5611
Commercial & Industrial Machinery & Equip. (exc. Auto. & Electronic) Repair & Maint.	811310

3.5.3 Competitive Advantages or Disadvantages for Businesses within California

California businesses would benefit from an overall reduction in energy costs. This could help California businesses gain competitive advantage over businesses operating in other states or countries and an increase in investment in California, as noted below.

3.5.4 Increase or Decrease of Investments in the State of California

CARB's economic analysis indicate that higher levels of energy efficiency and 33% RPS will increase investment in California by about 3% in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b Figures 7a and 10a).

3.5.5 Incentives for Innovation in Products, Materials, or Processes

Updating Title 24 standards will encourage innovation through the adoption of new technologies to better manage energy usage and achieve energy savings.

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

The Statewide CASE Team expects positive overall impacts on state and local government revenues due to higher GSP and personal income resulting in higher tax revenues, as noted earlier. Higher property valuations due to energy efficiency enhancements may also result in

positive local property tax revenues. The Statewide CASE Team has not obtained specific data to quantify potential revenue benefits for this measure.

3.5.6.1 Cost of Enforcement

There are no projected impediments to, or incentives for, innovation that would result from the proposed measures. Building inspection requirements remain the same. Likewise, training or additional time spent on enforcement, which may lead to increased enforcement costs for the state or local government, are very minimal.

Cost to the State

State government already has budgeted for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 standards, including updating education and compliance materials and responding to questions about the revised standards, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.

Cost to Local Governments

All revisions to Title 24 will result in changes to Title 24 compliance determinations. Local governments will need to train permitting staff on the revised Title 24 standards. While this retraining is an expense to local governments, it is not a new cost associated with the 2016 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. For example, utilities offer compliance training such as “Decoding” talks to provide training and materials to local permitting departments. As noted earlier, although retraining is a cost of the revised standards, Title 24 energy efficiency standards are expected to increase economic growth and income with positive impacts on local revenue.

These proposed changes would revise an existing measure without significantly affecting the complexity of this measure. Therefore, on-going costs are not expected to change significantly.

3.5.6.2 Impacts on Specific Persons

The proposed changes to Title 24 are not expected to have a differential impact on any of the following groups relative to the state population as a whole:

- Migrant Workers
- Persons by age
- Persons by race
- Persons by religion
- Commuters

We expect that the proposed code changes for the 2016 Title 24 code change cycle would reduce energy costs and could put potential first-time homeowners in a better position to afford

mortgage payments. On the other hand, homeowners may experience higher first costs to the extent that builders pass the increased costs of Title 24 compliance through to home buyers. Some financial institutions have progressive policies that recognize that home buyers can better afford energy efficiency homes (even with a higher first cost) due to lower energy costs.¹³

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 more of less of the net savings based on how much landlords pass the energy cost savings on to renters.

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 (Roland-Holst 2008). Thus it seems reasonable that low-income families would disproportionately benefit from Title 24 standards that reduce residential energy costs.

4. METHODOLOGY

This section describes the methodology and approach the Statewide CASE Team used to estimate energy, demand, costs, and environmental impacts. The Statewide CASE Team calculated the impacts of the proposed code change by comparing existing conditions to the conditions if the proposed code change is adopted. This section of the CASE Report goes into more detail on the assumptions about the existing and proposed conditions, simulation prototype buildings, and the methodology used to estimate energy, demand, cost, and environmental impacts.

4.1 Existing Conditions

To assess the energy, demand, costs, and environmental impacts, the Statewide CASE Team compared current design practices to design practices that would comply with the proposed requirements. The baseline condition assumes that a building complies with the 2013 Title 24 Standards for residential walls. The existing standard is covered in Table 150.1-A of the 2013 Standards. Residential buildings built in all climate zones must meet the prescriptive U-factor requirement of 0.065 or less for above grade walls. U-factor requirements for interior, mass, and below grade walls are not being altered.

Table 150.1-A also provides examples of wall assemblies that meet the prescriptive requirements, including 2x4 framing with R13+5 and R15+4 insulation. The Statewide CASE Team assumes the lowest cost wall design meeting the 2013 CASE prescriptive requirements

¹³ For example, see US EPA's Energy Star website for examples:
http://www.energystar.gov/index.cfm?fuseaction=new_homes_partners.showStateResults&s_code=CA.

as the basis for all cost and savings calculations: 2x4 studs at 16” on-center, R-15 cavity insulation, plus 1” of R-4 continuous insulation.

Measures requiring field verification and diagnostic testing are outlined in Table RA2-1 in the Residential Reference Appendices, partially reproduced below in Table 10. Currently, QII is a compliance credit; the prescriptive baseline does not include QII.

Table 10: 2013 Summary of Measures Requiring Field Verification and Diagnostic Testing, Table RA2-1 (partial)¹⁴

Building Envelope Measures		
Building Envelope Air Leakage	Compliance credit can be taken for reduced building envelope air leakage. Field verification and diagnostic testing is required.	RA3.8
High Quality Insulation Installation (QII)	Compliance Software recognizes standard and improved envelope construction. Compliance credit can be taken for quality installation of insulation. Field verification is required.	RA3.5
Quality Insulation Installation for Spray Polyurethane Foam (SPF) Insulation	A HERS Rater shall verify the installation of SPF insulation whenever R-values other than the default R-value per inch are used for compliance.	RA3.5.6

4.2 Proposed Conditions

The proposed code change will require a wall assembly U-factor of 0.046. Table 11 shows the various assemblies and U-factors that were considered by the Statewide CASE Team.

Projected energy savings from increased U-factor requirements for residential walls in each climate zone were calculated using the CBECC-Res energy simulation software for a variety of scenarios with U-factors between 0.051 and 0.043. The boxes highlighted in green indicate the wall assemblies and U-factors that were modeled and vetted by the Statewide CASE Team. The U-factor highlighted in red is the 2013 Standards prescriptive baseline. Wall assemblies with U-factors lower than the proposed U-factor of 0.046 are assumed to provide additional energy savings.

¹⁴ 2013 Residential Appendices, Appendix RA2 – Residential HERS Verification, Testing, and Documentation Procedures, page RA2-4

Table 11: Overall wall assembly U-factors for various interior and exterior insulation levels

Framing	Spacing (on center)	Cavity Insulation	Exterior insulation					
			none	R4	R5	R6	R8	R10
2x4	16"	R15	0.095	0.065	0.061	0.057	0.050	0.045
2x6	16"	R19	0.074	0.054	0.051	0.048	0.043	0.040
2x6	16"	R21	0.069	0.051	0.048	0.046	0.042	0.038
2x6	16"	R23	0.067	0.049	0.047	0.044	0.040	0.037
2x6	24"	R19	0.071	0.052	0.049	0.047	0.042	0.039
2x6	24"	R21	0.066	0.050	0.047	0.045	0.040	0.037
2x6	24"	R23	0.064	0.048	0.045	0.043	0.039	0.036

The Statewide CASE Team is also proposing mandatory QII in Climate Zones 1-5 and 9-16. This proposal is modeled separately from the lower U-factor proposal, using the 2013 Prescriptive baseline assembly (2x4-inch studs, 16-inches on center with R-15 cavity insulation and R-4 exterior rigid insulation). QII applies to all cavity insulation, for both walls and attics; therefore the savings associated with QII include QII for both walls and attics.

4.3 Simulation Prototype Buildings

CBECC-Res is the modeling software used for energy simulation. According to CEC guidelines, the prototype buildings for this analysis are both the 2,100 and the 2,700 square foot prototypes defined in the Residential ACM Manual (Section 4.2) with 20% fenestration equally distributed across the four wall orientations and tile roofs. The framing area accounts for the surface area of all exterior walls, including sections with windows and doors. The cavity area is the total wall area minus the wood framing, windows and doors, and is used to calculate the square footage of insulation required for the house. Table 12 shows the summary characteristics and relevant components of the two prototypes, along with the relevant weighting used to represent the statewide average for costs and savings results.

Table 12: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

	Occupancy Type	Floor Area (Square Feet)	Number of Stories	Framing Area (Square Feet)	Cavity Area (Square Feet)	Relative Weighting for Statewide Estimates
Prototype 1	Residential	2,100	1	1,288	848	45%
Prototype 2	Residential	2,700	2	2,172	1,612	55%

4.4 Climate Dependent

The proposed measures have been modeled in each of California's 16 climate zones, as the impacts of envelope insulation are highly climate dependent. U-factors that proved cost-effective for individual climate zones have been proposed accordingly.

4.5 Time Dependent Valuation

The TDV (Time Dependent Valuation) of savings is a normalized format for comparing electricity and natural gas savings that takes into account the cost of electricity and natural gas consumed during different times of the day and 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.

TDV energy estimates are based on present-valued cost savings but are presented in terms of "TDV kBTUs" so that the savings are evaluated in terms of energy units and measures with different periods of analysis can be combined into a single value. The CEC derived the TDV¹⁵ values that were used in the analyses for this report (CEC 2014). The TDV energy impacts are presented in Section 5.1 of this report, and the statewide TDV cost impacts are presented in Section 5.2.

4.6 Energy Impacts Methodology

The Statewide CASE Team calculated per unit impacts and statewide impacts associated with all new construction during the first year buildings complying with the 2016 Title 24 Standards are in operation. The Statewide CASE Team used the reference method, modeling using CBECC-Res without enhancements, to perform the energy analysis.

4.6.1 Per Unit Energy Impacts Methodology

The Statewide CASE Team estimated the electricity and natural gas savings associated with the proposed code change. The energy savings were calculated on a per building basis, weighted between the prototypes according to Table 12.

Analysis Tools

Parametric modeling (e.g., running batches of models) in CBECC-Res was used to complete over 10,000 simulations to cover the ranges of climate zones and assembly types possible. The results were exported and organized in a spreadsheet for analysis.

¹⁵ As of July 3, 2014, TDV from the 2013 code cycle update was used as the 2016 TDV was not yet available.

Key Assumptions

As mentioned, the CEC provided a number of key assumptions to be used in the energy impacts analysis (CEC 2011). Some of the assumptions included in the CEC's Lifecycle Cost Methodology Guidelines (LCC Methodology) include hours of operation, weather data, and prototype building design. The key assumptions used in the per unit energy impacts analysis that are not already included in the assumptions provided in the LCC Methodology are presented in Table 13.

Table 13: Key assumptions for per unit Energy Impacts Analysis

Parameter	Assumption	Source	Notes
TDV Values	2016	CEC	-
Base Case Wall Assembly	U-factor: 0.065 2x4 16" O.C. R-15 + R-4 CI	2013 Title 24 Table 150.1-A Prescriptive Requirement for wood framed walls.	Wall assembly that is minimally compliant with 2013 Title 24 prescriptive requirements.
Weighting of results	55% 2,700 sf prototype, 45% 2,100 sf prototype	CEC	CEC assumes this 55/45 ratio is representative of typical construction statewide.

4.6.2 Statewide Energy Impacts Methodology

First Year Statewide Impacts

The CEC Demand Analysis office provided the projected annual residential dwelling starts for the single family and multifamily sectors. CEC provided three projections: low, mid and high estimates with each cases broken out by forecast climate zones (FCZ). The Statewide CASE Team translated this data to building climate zones (BCZ) using the same weighting of FCZ to BCZ as the previous code update cycle (2013), as presented in Table 14.

The Statewide CASE Team used the mid scenario of forecasted residential new construction for statewide savings estimates. The projected new residential construction forecast, presented by BCZ is presented below in Table 15.

The Statewide CASE Team estimated statewide impacts for the first year that new houses comply with the 2016 Title 24 Standards by multiplying per unit savings estimates by statewide construction forecasts.

Table 14: Translation from FCZ to BCZ

		Building Standards Climate Zones (BCZ)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Grand Total
Forecast Climate Zones (FCZ)	1	22.51%	20.62%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	9.80%	33.14%	0.16%	0.00%	0.00%	13.77%	100.00%
	2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	22.00%	75.70%	0.00%	0.00%	0.00%	2.30%	100.00%
	3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	20.95%	22.76%	54.50%	0.00%	0.00%	1.79%	100.00%
	4	0.15%	13.73%	8.36%	46.03%	8.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	22.81%	0.00%	0.00%	0.00%	0.00%	100.02%
	5	0.00%	4.23%	89.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.64%	0.00%	0.00%	0.00%	0.00%	100.00%
	6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	75.80%	7.08%	0.00%	17.12%	100.00%
	8	0.00%	0.00%	0.00%	0.00%	0.00%	40.37%	0.00%	51.08%	8.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.46%	100.00%
	9	0.00%	0.00%	0.00%	0.00%	0.00%	6.97%	0.00%	24.54%	57.85%	0.00%	0.00%	0.00%	0.00%	6.68%	0.00%	3.95%	99.99%
	10	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	74.90%	0.00%	0.00%	0.00%	12.27%	7.90%	4.93%	100.00%
	11	0.00%	0.00%	0.00%	0.00%	0.00%	33.04%	0.00%	24.75%	42.21%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	12	0.00%	0.00%	0.00%	0.00%	0.00%	0.92%	0.00%	20.20%	75.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.69%	100.00%
	13	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	69.55%	0.00%	0.00%	28.77%	0.00%	0.00%	0.00%	1.56%	0.09%	0.00%	99.97%
	14	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.12%	99.88%	0.00%	100.00%
	16	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	17	2.95%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	97.05%

Table 15: CEC Residential New Construction Forecast Households Mid Case*Source: CEC Demand Analysis Office*

Building Climate Zone	Single Family Starts	Multifamily Starts
Climate Zone 1	695	47
Climate Zone 2	2,602	507
Climate Zone 3	5,217	3,420
Climate Zone 4	5,992	1,053
Climate Zone 5	1,164	205
Climate Zone 6	4,142	2,151
Climate Zone 7	6,527	2,687
Climate Zone 8	7,110	3,903
Climate Zone 9	8,259	8,023
Climate Zone 10	16,620	1,868
Climate Zone 11	5,970	217
Climate Zone 12	19,465	1,498
Climate Zone 13	13,912	770
Climate Zone 14	3,338	492
Climate Zone 15	3,885	433
Climate Zone 16	3,135	508
Total	108,032	27,784

¹ CEC provided a low, middle, and high forecast. The Statewide CASE Team used the middle forecast for the statewide savings estimates. Statewide savings estimates do not include savings from mobile homes.

² Includes high-rise and low-rise multi-family construction.

The proposed code change will apply to all low-rise residential new construction of above grade wood-framed walls. Based on discussions with CAHP managers, who review thousands of high performance homes annually, the Statewide CASE Team assumed that 90% of new houses are constructed using batt, blanket or loose-fill insulation in the cavities. Therefore, the statewide savings from QII is calculated for 90% of the single family new construction in the applicable climate zones. As shown in Section 5.2, the proposed measures are cost effective in Climate Zones 1-5 and 9-16, therefore the statewide energy impacts do not include any impacts in climate zones 6, 7 or 8.

The total statewide savings are based on a model of the proposed U-factor (0.046) with QII for 90% of the population, and the savings from the U=0.046 simulations without QII for the remaining 10% of the population. This produces savings between 4% and 9% less than the sum of the savings from the independently modeled measures.

4.7 Cost-effectiveness Methodology

This measure proposes a mandatory and 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 two proposed measures have been proven cost-effective independently of one another, and in tandem.

CEC's procedures for calculating lifecycle cost-effectiveness are documented in LCC Methodology (CEC 2011). The Statewide CASE Team followed these guidelines when developing the Cost-effectiveness Analysis for this measure. CEC's guidance dictated which costs were included in the analysis. Incremental equipment and maintenance costs over the 30 year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were considered. Each of these components is discussed in more detail below.

Design costs were not included. However, the incremental cost of verification by a HERS rater for QII was included in the analysis. The total incremental cost for QII is based on an estimate provided by CBIA to the CEC during the 2013 Standards rulemaking process that reflected the costs of the HERS rater and overhead for the builder for enabling the HERS verification.

4.7.1 Incremental Cost Methodology

Cost estimates were primarily derived from online data from Big-Box retailers and interviews with builders, contractors, manufacturers, and residential energy efficiency program implementers. When cost information was limited or unavailable from these sources, the Statewide CASE Team relied upon RSMeans Online (RSMeans 2014). The majority of RSMeans cost estimates are higher than those received from builders and contractors, and may have led to higher incremental cost estimates. Thus, the Statewide CASE Team has a high degree of confidence that the lifecycle cost savings presented in this report are conservative – i.e. measures may be more cost-effective in practice than we assume for this analysis.

Incremental Construction Cost Methodology

As requested by CEC, the Statewide CASE Team estimated the Current Incremental Construction Costs and Post-adoption Incremental Construction Costs. The Current Incremental Construction Cost (ΔCI_C) represents the cost of the incremental cost of the measure if a building meeting the proposed standard were built today. The Post-adoption Incremental Construction Cost (ΔCI_{PA}) represents the anticipated cost assuming full market penetration of the measure as a result of the new Standards, resulting in possible reduction in unit costs as manufacturing practices improve over time and with increased production volume of qualifying products the year the Standard becomes effective.

Key assumptions used to derive costs are presented in Table 16.

Table 16: Key Assumptions for per unit Incremental Construction Cost

Parameter	Assumption	Source	Notes
Baseline wall assembly	2x4" studs, 16" on center, R-15 cavity insulation, R-4 exterior insulation	2013 Title 24 Table 150.1-A Prescriptive Requirement for wood framed walls.	The Statewide CASE Team assumes the lowest cost wall design meeting the 2013 CASE prescriptive requirements as the basis for all cost and savings calculations
Rigid insulation average costs	\$0.55 ft ² - \$1.73/ft ²	Builder survey, distributors, manufacturers, retailers	Range from R-4 to R-10, and include EPS, XPS and polyiso boards
Oriented strand board average costs	\$0.81 - \$1.85/ft ²	RSMeans Online, retailers	Average of 7/16", 1/2", and 5/8" thicknesses
Wall framing average costs	\$1.01/ft ² - \$1.13/ ft ²	RSMeans Online	Average costs for 2x4 @ 16 o.c. and 2x6 @ 16 o.c. exterior wall framing
Batt insulation average costs	\$0.41/ft ² - \$1.05/ ft ²	Online, builder survey, manufacturers, retailers	Range from R-13 low-density to R-23 high-density
Additional Framing / Rough Opening Extension Support Element	15 minutes per window plus lumber	Interview with window manufacturer	Rough Opening Extension Support Element (picture frame with 1x2 or 2x2) built out and protruding from the sheathing around each rough opening such that the window aligns with the exterior insulation in order to facilitate proper integration and alignment with exterior cladding
Prototype wall areas	1,774 ft ² wall areas 506 ft ² window areas 1,268 ft ² for wall insulation areas	2013 Title 24 Reference ACM	Areas includes 45/55 weighting of 2,100 ft ² and 2,700 ft ² prototypes
QII	\$843 per house	California Building Industry Association	CBIA provided an estimate of the incremental cost of QII during the 2013 Title 24 Standards rulemaking.

According to the LCC Methodology (CEC 2011), incremental maintenance costs should be included in the lifecycle cost analysis. Upon review, the Statewide CASE Team determined that there is no incremental maintenance costs associated with the proposed code change.

4.7.2 Cost Savings Methodology

Energy Cost Savings Methodology

The Present Value (PV) of the energy savings were calculated using the method described in the LCC Methodology (CEC 2011). In short, the hourly energy savings estimates for the first year of building operation were multiplied by the TDV cost values to arrive at the PV of the cost savings over the period of analysis.

This measure does not have any non-energy cost savings.

4.7.3 Cost-effectiveness Methodology

The Statewide CASE Team calculated the cost-effectiveness using the LCC Methodology (CEC 2011). According to CEC's definitions, a measure is cost effective if it reduces overall lifecycle cost from the current base case (existing conditions). The LCC Methodology clarifies that absolute lifecycle cost of the proposed measure does not need to be calculated. Rather, it is necessary to calculate the change in lifecycle cost from the existing conditions to the proposed conditions.

If the change in lifecycle cost is negative then the measure is cost-effective, meaning that the present value of TDV energy savings is greater than the cost premium, or the proposed measure reduces the total lifecycle cost as compared to the existing conditions. Propane TDV costs are not used in the evaluation of energy efficiency measures.

The Planning Benefit to Cost (B/C) Ratio is another metric that can be used to evaluate cost-effectiveness. The B/C Ratio is calculated by dividing the total present value TDV energy cost savings (the benefit) by the present value of the total incremental cost (the cost). If the B/C ratio is 1.0 or greater (i.e. the present valued benefits are greater than the present valued costs over the period of analysis), then the measure is cost effective.

4.8 Environmental Impacts Methodology

4.8.1 Greenhouse Gas Emissions Impacts Methodology

Greenhouse Gas Emissions Impacts Methodology

The Statewide CASE Team calculated avoided GHG emissions assuming an emission factor of 353 metric tons of carbon dioxide equivalents (MTCO₂e) per GWh of electricity savings. As described in more detail in Appendix A, the electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts assuming that the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020. Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 MTCO₂e/million therms (U.S. EPA 2011).

Greenhouse Gas Emissions Monetization Methodology

The 2016 TDV cost values include the monetary value of avoided GHG emissions, so the Cost-effectiveness Analysis presented in Section 5.2 of this report does include the cost

savings from avoided GHG emissions. The monetization for the TDV values includes permit (retail) cost of avoided GHG emissions, but it does not include the social costs of avoided emissions. As evident in the results of the Cost-effectiveness Analysis, the value of avoided GHG emissions is aggregated into the total TDV cost savings and the contribution of GHG emissions is not easily discernible.

4.8.2 Material Impacts Methodology

Conversations with the APA-The Engineered Wood Association and the American Wood Council determined that increased usage of 2x6 studs would have a minimal impact on lumber usage. Smaller wood comes from federally leased land, where the forests are thinned to let the larger trees grow. Those logs account for approximately 2% of the demand. Replacing 2x4 studs with 2x6 results in the smaller pieces being used for other products such as glulams (glue laminated wood). The algorithms for how boards are cut from timber are proprietary, but the capacity for lumber production has increased over time. Overall, the U.S. is adding forests, not deforesting.

The 2013 CASE Report on Increased Wall Insulation (IOU 2013) performed extensive lumber usage estimates determining that lumber usage will not be significantly affected if the building industry moves from the status quo (2x4) to more 2x6 construction:

“The proposed measure does not have substantial adverse impacts on the environment. The proposed measure will result in less lumber consumption, for homes in climates zones 1 and 11-16, where 2x6 16-inch on center framing is the assumed baseline. However, the use of 2x6 framing in place of 2x4 framing will increase the board feet of lumber for framing in homes in climate zones 2 through 10, where 2x4 framing is the baseline.”

“Results, shown in [Figure 1], estimate a 1.7% increase in total lumber use per home in climate zones 2 through 10, and a 3% decrease in climate zones 1 and 11 through 16. If 35% of all lumber consumed is for residential new construction, using new construction estimates as outlined in detail in section 7.3, the measure will reduce total lumber consumption in California by 2.12%”

	2 x6" @16" OC	2 x6" @24" OC
Board feet delta for a 2700 sq.ft home from 2x4 16-inch on center	906.67	330.67
Total board feet per standard home	18,900.00	18,900.00
Percent increase per house	4.8%	1.7%
Percent impact on lumber	1.68%	0.61%
Board feet delta for a 2700 sq.ft home from 2x6 16-inch on center		-576.00
Total board feet per standard home		18,900.00
Percent increase per house		-3.0%
Percent impact on lumber		-1.07%

Figure 1: Change in board feet from base case framing to proposed framing (2013 CASE report)

“Alternatively, if we assume that all homes are currently built with 2x4 framing - using external insulation, rather than increased cavity insulation to meet prescriptive requirements in climates zones 1 and 11-16 - we estimate a 1.7% increase in lumber per home, and a small increase of 0.61% in annual lumber demand statewide.”

As explained in section 2.1.2, the 2013 CASE report estimated that some 2x6 wall framing (23%) is used in exterior wall framing projects, so an increase in lumber usage of 3.7% is a conservative estimate.

5. ANALYSIS AND RESULTS

Results from the energy, demand, cost, and environmental impacts analyses are presented in this section.

Residential walls in climate zones 1-6 and 9-16 (all but the Southern California coast) can cost effectively achieve a U-factor of 0.046 or less using 2x6 framing spaced at 16" on center with R-21 unfaced fiberglass batt insulation in the cavities and R-6 continuous insulation (expanded polystyrene insulated sheet (EPS) or polyisocyanurate (polyiso) rigid foam insulation). Spacing the studs at 24" on center instead of 16" has the potential to use less wood, reducing the framing cost and framing factor of the wall assembly, thus increasing the cost-effectiveness of the energy savings. If a builder strongly prefers to use 2x4" studs, R-15 unfaced fiberglass batt cavity insulation in combination with 2" (R-10) continuous insulation (extruded polystyrene (XPS) or polyiso rigid foam board) will meet the proposed U-factor.

There are several other methods available for achieving a U-factor of 0.046 or less, including Structurally Insulated Panels (SIPs), Insulated Concrete Forms (ICF), staggered studs, double walls, and flash and batt insulation¹⁶. The Statewide CASE Team did not analyze these strategies for cost-effectiveness, but these options are available using the performance approach. At the CEC's request, the Statewide CASE Team has provided results from additional assemblies, specifically with a U-factor=0.049, in Appendix C: CBECC-Res Simulation Results .

Adding exterior insulation to a wall assembly increases the importance and complexity of flashing around the windows to improve moisture control within that wall. To account for the added cost and complexity of flashing around each window in the presence of exterior insulation, we included a cost estimate to frame around each rough opening. In consultation with a leading window manufacturer, we estimated this effort should take approximately 15 minutes per window once the installer is familiar with the technique.

¹⁶ "Flash and batt" refers to the use of spray foam and fiberglass batts together in a single cavity. Usually this entails at least two inches of closed cell foam in a six-inch cavity, with open faced batt insulation filling the remainder of the cavity. This technique usually provides improved air sealing, as the foam acts as an air barrier, however there are increased moisture concerns, particularly in colder climates.

5.1 Energy Impacts Results

5.1.1 Per Unit Energy Impacts Results

The Statewide CASE Team modeled the whole building energy impacts for a variety of wall assemblies at various U-factors. Based on direction from the CEC all results presented in this report are weighted as described in Section 4.3 and shown again below in Table 17.

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

	Occupancy Type	Floor Area (Square Feet)	Number of Stories	Framing Area (Square Feet)	Cavity Area (Square Feet)	Relative Weight to Statewide Estimates
Prototype 1	Residential	2,100	1	1,288	848	45%
Prototype 2	Residential	2,700	2	2,172	1,612	55%
Weighted Prototype	Residential	2,430	2	1,774	1,268	100%

The U-factors of the wall assemblies modeled are listed in Table 18. The results of the energy simulations per weighted prototype are presented in Table 19.

Table 18: U-factors of wall assemblies modeled

U-factor	Framing	Spacing (o.c.)	Cavity Insulation	Exterior Insulation
U=0.051	2x6	16"	R-21	R-4
U=0.049	2x6	16"	R-23	R-4
	2x6	16"	R-19	R-6
U=0.046	2x6	16"	R-21	R-6
U=0.044	2x6	16"	R-23	R-6
U=0.050	2x4	16"	R-15	R-8
U=0.045	2x4	16"	R-15	R-10

Table 19: Energy savings per weighted prototype for various wall assembly U-factors

Climate Zone	U=0.051		U=0.049		U=0.046		U=0.045		U=0.044	
	kWh	Therms	kWh	Therms	kWh	Therms	kWh	Therms	kWh	Therms
Climate Zone 1	30	35	35	41	41	48	41	48	46	53
Climate Zone 2	27	22	31	25	36	30	34	30	40	33
Climate Zone 3	16	18	19	21	22	24	22	24	24	27
Climate Zone 4	27	18	31	22	36	25	33	25	40	28
Climate Zone 5	15	18	18	21	20	25	20	24	22	27
Climate Zone 6	13	10	15	12	17	14	15	13	19	15
Climate Zone 7	7	5	8	5	9	6	8	6	10	7
Climate Zone 8	23	8	27	9	30	11	26	11	33	12
Climate Zone 9	43	10	49	12	56	14	51	14	62	16
Climate Zone 10	54	12	62	14	72	16	66	16	79	18
Climate Zone 11	99	22	115	25	135	30	132	30	149	33
Climate Zone 12	59	21	68	25	79	30	73	30	87	33
Climate Zone 13	104	19	121	22	142	27	139	27	157	29
Climate Zone 14	93	22	108	26	127	31	124	30	140	34
Climate Zone 15	227	4	264	4	313	5	313	5	346	6
Climate Zone 16	42	41	48	48	57	57	55	57	63	63

It is estimated that the total TDV energy savings over the 30 year period of analysis will range from 1,832 kBTU in climate zone 7 to 13,435 kBTU in climate zone 15 for U-factor=0.046, and from 2,014 kBTU in climate zone 7 to 15,383 kBTU in climate zone 16 for QII. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

Table 20: Energy Impacts per Weighted Prototype with Exterior Walls, U-factor=0.046¹

Climate Zone	Per Unit First Year Savings ²			
	Electricity Savings ⁴ (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings ⁵ (kBTU)
Climate Zone 1	41	0.00	48	8,951
Climate Zone 2	36	0.02	30	6,929
Climate Zone 3	22	0.01	24	4,982
Climate Zone 4	36	0.04	25	6,283
Climate Zone 5	20	0.00	25	4,739
Climate Zone 6	17	0.02	14	3,414
Climate Zone 7	9	0.02	6	1,832
Climate Zone 8	30	0.06	11	4,005
Climate Zone 9	56	0.12	14	6,538
Climate Zone 10	72	0.12	16	7,026
Climate Zone 11	135	0.15	30	12,473
Climate Zone 12	79	0.11	30	10,380
Climate Zone 13	142	0.19	27	12,522
Climate Zone 14	127	0.16	31	11,816
Climate Zone 15	313	0.26	5	13,435
Climate Zone 16	57	0.03	57	11,847

- ^{1.} Each unit refers to one house, using the weighting of prototypes representing average new construction as described in Section 4.3, with a wall assembly U-factor=0.046.
- ^{2.} Savings from one unit (weighted prototype building), for the first year the building is in operation.
- ^{3.} TDV energy savings for one unit (weighted prototype building) for the first year the building is in operation.
- ^{4.} Site electricity savings. Does not include TDV of electricity savings.
- ^{5.} Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

The impacts for quality insulation installation without any change to the wall-assembly U-factor are presented in Table 21.

Table 21: Energy Impacts per Weighted Prototype with QII¹

Climate Zone	Per Unit First Year Savings ²			
	Electricity Savings ⁴ (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings ⁵ (kBtu)
Climate Zone 1	51	0.00	60	11,629
Climate Zone 2	38	0.02	34	7,825
Climate Zone 3	26	0.00	29	6,104
Climate Zone 4	36	0.03	30	7,162
Climate Zone 5	24	0.00	29	5,860
Climate Zone 6	19	0.02	16	3,937
Climate Zone 7	10	0.01	7	2,014
Climate Zone 8	33	0.06	13	4,504
Climate Zone 9	56	0.10	18	6,900
Climate Zone 10	66	0.10	21	7,421
Climate Zone 11	125	0.12	40	13,451
Climate Zone 12	77	0.10	38	11,596
Climate Zone 13	130	0.15	34	12,917
Climate Zone 14	118	0.12	41	13,172
Climate Zone 15	240	0.17	6	10,183
Climate Zone 16	73	0.02	71	15,383

1. Each unit refers to one house, using the weighting of prototypes representing average new construction as described in Section 4.3, with QII applied to the 2013 Standards prescriptive baseline U=0.065.
2. Savings from one unit (weighted prototype building), for the first year the building is in operation.
3. TDV energy savings for one unit (weighted prototype building) for the first year the building is in operation.
4. Site electricity savings. Does not include TDV of electricity savings.
5. Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

Per unit energy impacts of the proposed measure are presented in Table 22. Per unit savings for the first year vary by climate zone, and are expected to range from 16 to 509 kilowatt-hours per year (kWh/yr), and between 12 and 121 therms per year.

Table 22: Energy Impacts per Weighted Prototype¹ with Exterior Walls, U-factor=0.046 and QII

Climate Zone	Per Unit First Year Savings ²			
	Electricity Savings ⁴ (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings ⁵ (kBTU)
Climate Zone 1	86	0.00	101	19,289
Climate Zone 2	69	0.03	60	13,781
Climate Zone 3	44	0.01	50	10,318
Climate Zone 4	68	0.07	52	12,547
Climate Zone 5	40	(0.01)	49	9,654
Climate Zone 6	34	0.04	27	6,887
Climate Zone 7	16	0.03	12	3,334
Climate Zone 8	58	0.12	22	7,757
Climate Zone 9	105	0.20	30	12,378
Climate Zone 10	127	0.20	35	13,292
Climate Zone 11	242	0.24	66	24,181
Climate Zone 12	145	0.19	64	20,566
Climate Zone 13	254	0.31	57	23,673
Climate Zone 14	228	0.25	67	23,352
Climate Zone 15	509	0.40	10	21,870
Climate Zone 16	123	0.05	121	25,739

1. Each unit refers to one house, using the weighting of prototypes representing average new construction as described in Section 4.3, with a wall assembly U-factor=0.046.
2. Savings from one unit (weighted prototype building), for the first year the building is in operation.
3. TDV energy savings for one unit (weighted prototype building) for the first year the building is in operation.
4. Site electricity savings. Does not include TDV of electricity savings.
5. Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

5.1.2 Statewide Energy Impacts Results

First Year Statewide Energy Impacts

The individual statewide energy impacts of high performance walls (U-factor=0.046) and Quality Insulation Installation (QII) are presented in Table 23 and Table 24, respectively, with the combined measures presented in Table 25. As shown in Section 5.2, the proposed measures are cost effective in Climate Zones 1-5 and 9-16, therefore the statewide energy impacts do not include climate zones 6, 7 or 8.

Table 23: Statewide Energy Impacts of Exterior Walls, U-factor=0.046

Climate Zone	First Year Statewide Savings ¹			
	Electricity Savings ³ (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Savings ⁴ (Million kBTU)
Climate Zone 1	0.03	0.00	0.03	6
Climate Zone 2	0.09	0.05	0.08	18
Climate Zone 3	0.11	0.03	0.13	26
Climate Zone 4	0.22	0.25	0.15	38
Climate Zone 5	0.02	0.00	0.03	6
Climate Zone 6	n/a	n/a	n/a	n/a
Climate Zone 7	n/a	n/a	n/a	n/a
Climate Zone 8	n/a	n/a	n/a	n/a
Climate Zone 9	0.47	1.00	0.12	54
Climate Zone 10	1.19	2.05	0.27	117
Climate Zone 11	0.81	0.87	0.18	74
Climate Zone 12	1.54	2.23	0.58	202
Climate Zone 13	1.98	2.62	0.37	174
Climate Zone 14	0.42	0.52	0.10	39
Climate Zone 15	1.22	0.99	0.02	52
Climate Zone 16	0.18	0.10	0.18	37
TOTAL	8.3	10.7	2.2	844

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

Table 24: Statewide Energy Impacts of QII

Climate Zone	First Year Statewide Savings ¹			
	Electricity Savings ³ (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Savings ⁴ (Million kBTU)
Climate Zone 1	0.03	0.00	0.04	7
Climate Zone 2	0.09	0.04	0.08	18
Climate Zone 3	0.12	0.01	0.14	29
Climate Zone 4	0.20	0.18	0.16	39
Climate Zone 5	0.03	0.00	0.03	6
Climate Zone 6	n/a	n/a	n/a	n/a
Climate Zone 7	n/a	n/a	n/a	n/a
Climate Zone 8	n/a	n/a	n/a	n/a
Climate Zone 9	0.41	0.78	0.13	51
Climate Zone 10	0.99	1.49	0.31	111
Climate Zone 11	0.67	0.62	0.21	72
Climate Zone 12	1.34	1.67	0.66	203
Climate Zone 13	1.63	1.84	0.42	162
Climate Zone 14	0.35	0.36	0.12	40
Climate Zone 15	0.84	0.59	0.02	36
Climate Zone 16	0.21	0.07	0.20	43
TOTAL	6.9	7.7	2.5	817

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

Table 25: Statewide Energy Impacts of Exterior Walls, U-factor=0.046 and QII

Climate Zone	First Year Statewide Savings ¹			
	Electricity Savings ³ (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Energy Savings ⁴ (Million kBTU)
Climate Zone 1	0.06	0.00	0.07	13
Climate Zone 2	0.17	0.07	0.15	34
Climate Zone 3	0.22	0.04	0.25	51
Climate Zone 4	0.39	0.38	0.30	71
Climate Zone 5	0.04	-0.01	0.05	11
Climate Zone 6	n/a	n/a	n/a	n/a
Climate Zone 7	n/a	n/a	n/a	n/a
Climate Zone 8	n/a	n/a	n/a	n/a
Climate Zone 9	0.83	1.62	0.23	97
Climate Zone 10	2.02	3.18	0.54	211
Climate Zone 11	1.38	1.36	0.37	137
Climate Zone 12	2.69	3.58	1.18	380
Climate Zone 13	3.38	4.08	0.75	314
Climate Zone 14	0.73	0.81	0.21	74
Climate Zone 15	1.90	1.51	0.04	82
Climate Zone 16	0.36	0.15	0.36	76
TOTAL	14.2	16.8	4.5	1,552

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

As shown in Table 25, during the first year buildings complying with the 2016 Title 24 Standards are in operation, the proposed measures are expected to reduce annual statewide electricity use by 14.2 GWh and electricity demand by 16.8 MW. Natural gas use is expected to be reduced by 4.5 MMtherms. All assumptions and calculations used to derive per unit and statewide energy and demand savings are presented in Section 4.6.2 of this report.

5.2 Cost-effectiveness Results

5.2.1 Incremental Cost Results

The incremental cost of the proposed measure, relative to existing conditions, is presented in Table 26. The total incremental cost includes the incremental cost during initial construction and the present value of the incremental maintenance cost over the 30 year period of analysis. Upon review, the Statewide CASE Team determined that there is no incremental maintenance costs associated with the proposed code change.

Table 26: Incremental Cost of Proposed Measure 2016 Present Value Dollars¹

Condition	Initial Construction Cost		Incremental Present Value of Maintenance Cost ⁴	Total Incremental Cost ⁵
	Current ²	Post Adoption ³		
Existing Conditions	\$13,628	\$13,628	n/a	n/a
Proposed Conditions	\$14,410	\$14,410	n/a	\$783
Incremental ¹	\$783	\$783	n/a	-

1. Incremental costs equal the difference between existing conditions and proposed conditions. Negative values indicate the Proposed Conditions are less expensive than Existing Conditions.
2. Initial construction cost using current prices; ΔCI_C
3. Initial construction cost using estimated prices after adoption; ΔCI_{PA}
4. Present value of maintenance costs over 30 year period of analysis; ΔCM .
5. Total costs equals incremental cost (post adoption) plus present value of maintenance costs; $\Delta CI_{PA} + \Delta CM$

The incremental cost presented in Table 26 is based on the costs presented in Table 27 for the scenario with U-factor = 0.046.

Table 27: Incremental Cost per weighted prototype for various wall assemblies and U-factors

Stud	O.C.	Cavity Insulation	Exterior (rigid) insulation	Wall Assembly U-Value	Incremental Cost
2x4	16	R-15	R-4 (1")	0.065	-
2x6	16	R-21	R-4 (1")	0.051	\$463
2x6	16	R-23	R-4 (1")	0.049	\$507
2x6	16	R-19	R-6 (1.5")	0.049	\$477
2x6	16	R-23	R-5 (1")	0.047	\$887
2x6	16	R-21	R-6 (1.5")	0.046	\$783
2x4	16	R-15	R-10 (2")	0.045	\$989
2x6	16	R-23	R-6 (1.5")	0.044	\$827
2x6	16	R-19	R-8 (2")	0.043	\$779

The incremental cost of changing from R-4 continuous insulation to R-6 is approximately \$320 per weighted prototype, including the cost of the materials, labor and additional window

framing required. Changing from 2x4 studs to 2x6 studs increases the lumber costs by approximately \$212. Changing from a standard cavity insulation (R-19) to a high density batt (R-21) carries a cost premium of approximately \$306. The breakdown of the incremental costs by building component is detailed in **Figure 2** in the next section, Incremental Construction Cost Results.

Incremental Construction Cost Results

As described in Section 4.7.1, cost data was collected from interviews with builders, manufacturers, retailers and distributors, retailer on-line data, and supplemented with RSMeans cost data points as appropriate (RSMeans 2014). For situations when only product costs were available, the Statewide CASE Team added the estimated labor component as estimated by RSMeans. The team calculated incremental construction costs for several scenarios covering a variety of wall assemblies and U-factors. This calculation is based on the costs presented in Table 28.

Table 28: Cost basis for incremental cost calculation

Product Type	R-Value	Description	\$/Unit	Unit/home	Unit	\$/home ¹⁷
Concrete Stucco	-	Stucco, 3 coats, float finish, with mesh, on wood frame, 1" thick	\$4.89	1268	ft ²	\$6,200
	-	One-coat stucco	\$3.86			\$4,896
Batt Insulation	13	Fiberglass, foil faced and unfaced, 3.5"	\$0.70	1268	ft ²	\$883
	15	Blanket, mineral wool, 3.5"	\$0.98			\$1,244
	19	Fiberglass kraft faced, foil faced, and unfaced, 6"	\$0.79			\$998
	21	Fiberglass unfaced batt insulation, 6"	\$1.03			\$1,304
	23	Blanket, mineral wool, 5.5"	\$1.06			\$1,349
Rigid Insulation	2	EPS (Expanded Polystyrene Foam Board)	\$0.73	1268	ft ²	\$931
	4	EPS, and molded bead board	\$0.83			\$1,050
	5	XPS (Extruded Polystyrene), polyiso and molded bead board	\$1.13			\$1,429
	6	EPS, polyiso	\$1.02			\$1,300
	8	EPS, and molded bead board	\$1.21			\$1,538
	10	XPS, polyiso	\$1.50			\$1,904
Spray foam	R4/in	open cell spray foam	\$0.38	2x4 – 4,439	board	\$1,665
				2x6 – 6,975	foot	\$2,616
	R7/in	closed cell spray foam	\$1.00	2x4 – 4,439	board	\$4,439
				2x6 – 6,975	foot	\$6,975
Loose fill	21	Poured insulation, cellulose fiber, R3.8 per inch, 6" thick	\$0.90	1268	ft ²	\$1,143
Gypsum board	-	Standard and fire resistant	\$0.74	1268	ft ²	\$938
OSB	-	7/16", 1/2", 5/8"	\$1.36	1774	ft ²	\$2,414
Weather Barrier	-	Asphalt felt, polypropylene, and polyethylene	\$0.25	1774	ft ²	\$447
Wood Framing	-	2x4 16"OC	\$1.01	1774	ft ²	\$1,793
	-	2x6 16"OC	\$1.13			\$2,005
	-	2x6 24"OC	\$0.99			\$1,765
Metal Flashing	-	Sheet Metal Cladding, aluminum, window casing, up to 6 bends, .024" thick	\$4.84	118	ft ²	\$571
Additional sill flashing with exterior insulation	R4/5 (1")	Picture framing around rough opening (each window) to account for 1" of exterior insulation	\$14.31	32	wind ow	\$458
	R6 (1.5")	Picture framing around rough opening (each window) to account for 1.5" of exterior insulation	\$16.47			\$527
	R8/10 (2")	Picture framing around rough opening (each window) to account for 2" of exterior insulation	\$18.45			\$591

Figure 2 below details the cost premium for the components of each wall assembly compared to two different baselines: 1) 2x4 framed 16" o.c. with R-15 cavity and R-4 exterior insulation; and 2) 2x6 framed 16" o.c. with R-19 cavity and R-2 exterior insulation. The second baseline

¹⁷ Each home described here is the representative prototype described in Section 4.3, which weighted as 45% the 2,100 sf CEC residential prototype and 55% the 2,700 sf CEC residential prototype.

provides the estimated cost premium for builders already constructing walls using 2x6 studs to meet the 2013 prescriptive U-factor of 0.065.

Figure 2 shows that the two different baselines account for a price difference of less than ten dollars for any of the modeled scenarios. The color coding in the chart shows the tradeoff between the cost for framing and cost for insulation. The cost for 2x4 framing is cheaper than 2x6, but R-15 cavity insulation is more expensive than R-19 cavity insulation. Additionally rigid exterior insulation generally gets more expensive as the R-value increases. The rightmost scenario shows the cost savings potential from spacing 2x6 studs at 24 inches on center instead of at 16 inches.

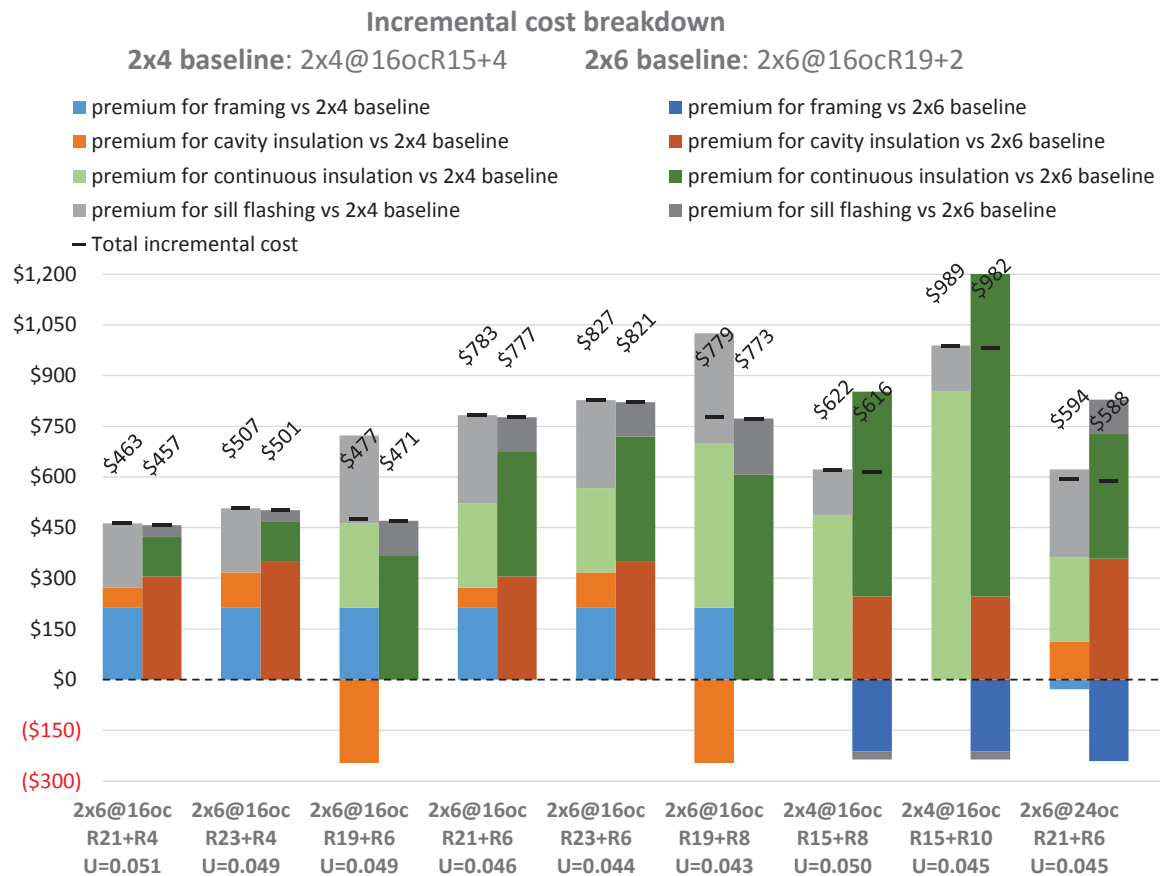


Figure 2: Incremental Cost Breakdown for various assemblies, U-factors 0.051 to 0.043

Incremental Maintenance Cost Results

As described in Section 3.3, there are assumed to be zero incremental maintenance costs associated with the code change proposal, relative to existing conditions. The higher R-value rigid insulation, cavity insulation, and deeper framing needed to meet the proposed requirements are similar to the current components, and are low maintenance if installed properly and no changes are made to the wall.

5.2.2 Cost Savings Results

Energy Cost Savings Results

The per unit TDV energy cost savings over the 30 year period of analysis are presented in Table 29. These are the present dollar value of the energy savings resulting from building a wall with a U-factor of 0.046, and separately, the present dollar value of the energy savings resulting from constructing a wall with a U-factor of 0.065 (the 2013 Standards prescriptive U-factor) and QII.

Table 29: TDV Energy Cost Savings Over 30 Year Period of Analysis - Per Weighted prototype, 2016 PV \$

Climate Zone	U-factor=0.046	QII	U-factor=0.046 and QII
Climate Zone 1	\$1,549	\$2,012	\$3,337
Climate Zone 2	\$1,199	\$1,354	\$2,384
Climate Zone 3	\$862	\$1,056	\$1,785
Climate Zone 4	\$1,087	\$1,239	\$2,171
Climate Zone 5	\$820	\$1,014	\$1,670
Climate Zone 6	\$591	\$681	\$1,191
Climate Zone 7	\$317	\$349	\$577
Climate Zone 8	\$693	\$779	\$1,342
Climate Zone 9	\$1,131	\$1,194	\$2,141
Climate Zone 10	\$1,216	\$1,284	\$2,300
Climate Zone 11	\$2,158	\$2,327	\$4,183
Climate Zone 12	\$1,796	\$2,006	\$3,558
Climate Zone 13	\$2,166	\$2,235	\$4,095
Climate Zone 14	\$2,044	\$2,279	\$4,040
Climate Zone 15	\$2,324	\$1,762	\$3,784
Climate Zone 16	\$2,050	\$2,661	\$4,453

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates TDV energy cost savings (30 year) of \$268 million for all single family houses built with a wall assembly U-factor of 0.046 and QII during the first year the 2016 Standards are in effect.

Other Cost Savings Results

This measure does not have any non-energy cost savings.

5.2.3 Cost-effectiveness Results

The results of the lifecycle Cost-effectiveness Analyses per house for a U-factor=0.046 is presented in Table 30. The proposed measure saves money over the 30 year period of analysis relative to the existing conditions in the climate zones for which the new requirements are proposed; climate zones 1-5 and 9-16. The proposed U-factor is not cost effective in climate zones 6, 7, or 8 (the southern California coast).

Table 30: Cost-effectiveness Summary for Exterior Walls, U-factor=0.046¹

Climate Zone	Benefit: TDV Energy Cost Savings ² (2016 PV\$)	Cost: Total Incremental Cost ³ (2016 PV\$)	Change in Lifecycle Cost ⁴ (2016 PV\$)	Benefit to Cost Ratio ⁵
Climate Zone 1	\$1,549	\$783	\$(766)	2.0
Climate Zone 2	\$1,199	\$783	\$(416)	1.5
Climate Zone 3	\$862	\$783	\$(79)	1.1
Climate Zone 4	\$1,087	\$783	\$(304)	1.4
Climate Zone 5	\$820	\$783	\$(37)	1.0
Climate Zone 6	\$591	\$783	\$192	0.8
Climate Zone 7	\$317	\$783	\$466	0.4
Climate Zone 8	\$693	\$783	\$90	0.9
Climate Zone 9	\$1,131	\$783	\$(348)	1.4
Climate Zone 10	\$1,216	\$783	\$(433)	1.6
Climate Zone 11	\$2,158	\$783	\$(1,375)	2.8
Climate Zone 12	\$1,796	\$783	\$(1,013)	2.3
Climate Zone 13	\$2,166	\$783	\$(1,384)	2.8
Climate Zone 14	\$2,044	\$783	\$(1,261)	2.6
Climate Zone 15	\$2,324	\$783	\$(1,542)	3.0
Climate Zone 16	\$2,050	\$783	\$(1,267)	2.6

1. Relative to existing conditions. All cost values presented in 2016 dollars.

2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta\text{TDV\$} = \Delta\text{TDV\$E} + \Delta\text{TDV\$G}$.

3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta\text{C} = \Delta\text{CI}_{\text{PA}} + \Delta\text{CM}$.

4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta\text{LCC} = \Delta\text{C} - \Delta\text{TDV\$}$

5. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs; $\text{B/C} = \Delta\text{TDV\$} \div \Delta\text{C}$. The measure is cost effective if the B/C ratio is 1.0 or greater.

The results of the lifecycle Cost-effectiveness Analyses per weighted prototype for QII is presented in Table 31. The proposed measure saves money over the 30 year period of analysis

relative to the existing conditions in the climate zones for which the new requirements are proposed. QII is cost effective in all climate zones except for climate zones 6, 7 and 8.

Table 31: Cost-effectiveness Summary for QII¹

Climate Zone	Benefit: TDV Energy Cost Savings + Other Cost Savings ² (2016 PV\$)	Cost: Total Incremental Cost ³ (2016 PV\$)	Change in Lifecycle Cost ⁴ (2016 PV\$)	Benefit to Cost Ratio ⁵
Climate Zone 1	\$2,012	\$843	\$(1,169)	2.4
Climate Zone 2	\$1,354	\$843	\$(511)	1.6
Climate Zone 3	\$1,056	\$843	\$(213)	1.3
Climate Zone 4	\$1,239	\$843	\$(396)	1.5
Climate Zone 5	\$1,014	\$843	\$(171)	1.2
Climate Zone 6	\$681	\$843	\$162	0.8
Climate Zone 7	\$349	\$843	\$494	0.4
Climate Zone 8	\$779	\$843	\$64	0.9
Climate Zone 9	\$1,194	\$843	\$(351)	1.4
Climate Zone 10	\$1,284	\$843	\$(441)	1.5
Climate Zone 11	\$2,327	\$843	\$(1,484)	2.8
Climate Zone 12	\$2,006	\$843	\$(1,163)	2.4
Climate Zone 13	\$2,235	\$843	\$(1,392)	2.7
Climate Zone 14	\$2,279	\$843	\$(1,436)	2.7
Climate Zone 15	\$1,762	\$843	\$(919)	2.1
Climate Zone 16	\$2,661	\$843	\$(1,818)	3.2

^{1.} Relative to existing conditions. All cost values presented in 2016 dollars.

^{2.} Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta\text{TDV\$} = \Delta\text{TDV\$E} + \Delta\text{TDV\$G}$.

^{3.} Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta\text{C} = \Delta\text{CI}_{\text{PA}} + \Delta\text{CM}$.

^{4.} Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta\text{LCC} = \Delta\text{C} - \Delta\text{TDV\$}$

^{5.} The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs; $\text{B/C} = \Delta\text{TDV\$} \div \Delta\text{C}$. The measure is cost effective if the B/C ratio is 1.0 or greater.

Table 32: Cost-effectiveness Summary for U-factor=0.046 and QII¹

Climate Zone	Benefit: TDV Energy Cost Savings + Other Cost Savings ² (2016 PV\$)	Cost: Total Incremental Cost ³ (2016 PV\$)	Change in Lifecycle Cost ⁴ (2016 PV\$)	Benefit to Cost Ratio ⁵
Climate Zone 1	\$3,337	\$1,626	(\$1,711)	2.1
Climate Zone 2	\$2,384	\$1,626	(\$758)	1.5
Climate Zone 3	\$1,785	\$1,626	(\$159)	1.1
Climate Zone 4	\$2,171	\$1,626	(\$545)	1.3
Climate Zone 5	\$1,670	\$1,626	(\$45)	1.0
Climate Zone 6	\$1,191	\$1,626	\$434	0.7
Climate Zone 7	\$577	\$1,626	\$1,049	0.4
Climate Zone 8	\$1,342	\$1,626	\$284	0.8
Climate Zone 9	\$2,141	\$1,626	(\$516)	1.3
Climate Zone 10	\$2,300	\$1,626	(\$674)	1.4
Climate Zone 11	\$4,183	\$1,626	(\$2,558)	2.6
Climate Zone 12	\$3,558	\$1,626	(\$1,932)	2.2
Climate Zone 13	\$4,095	\$1,626	(\$2,470)	2.5
Climate Zone 14	\$4,040	\$1,626	(\$2,414)	2.5
Climate Zone 15	\$3,784	\$1,626	(\$2,158)	2.3
Climate Zone 16	\$4,453	\$1,626	(\$2,827)	2.7

1. Relative to existing conditions. All cost values presented in 2016 dollars.

2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta\text{TDV\$} = \Delta\text{TDV\$E} + \Delta\text{TDV\$G}$.

3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta\text{C} = \Delta\text{CI}_{\text{PA}} + \Delta\text{CM}$.

4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta\text{LCC} = \Delta\text{C} - \Delta\text{TDV\$}$

5. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs; $\text{B/C} = \Delta\text{TDV\$} \div \Delta\text{C}$. The measure is cost effective if the B/C ratio is 1.0 or greater.

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates a 30 year lifecycle cost savings of \$114 million for all single family houses built with a wall assembly U-factor of 0.046 and QII during the first year the 2016 Standards are in effect.

There are various strategies available to achieve the proposed prescriptive U-factor of 0.046 or less in climate zones 1-5 and 9-16. The cost-effectiveness of three such scenarios are presented below in Figure 3. The scenario with a U-factor of 0.046 constructed with 2x6 framing spaced

16” on center with R-6 rigid exterior (continuous) insulation provides the basis for energy savings and cost-effectiveness calculations supporting this code change proposal. Some builders may choose an alternative compliant assembly in some climate zones, such as R-23 cavity insulation in place of R-21 to cost-effectively increase the energy performance of the building, or there may be reasons other than energy performance that would prompt a builder to want to meet the code requirements while still using 2x4 framing at 16” on center with R-10 continuous insulation. Regardless of the assembly chosen, there are multiple options available to meet the proposed requirements in a cost effective manner.

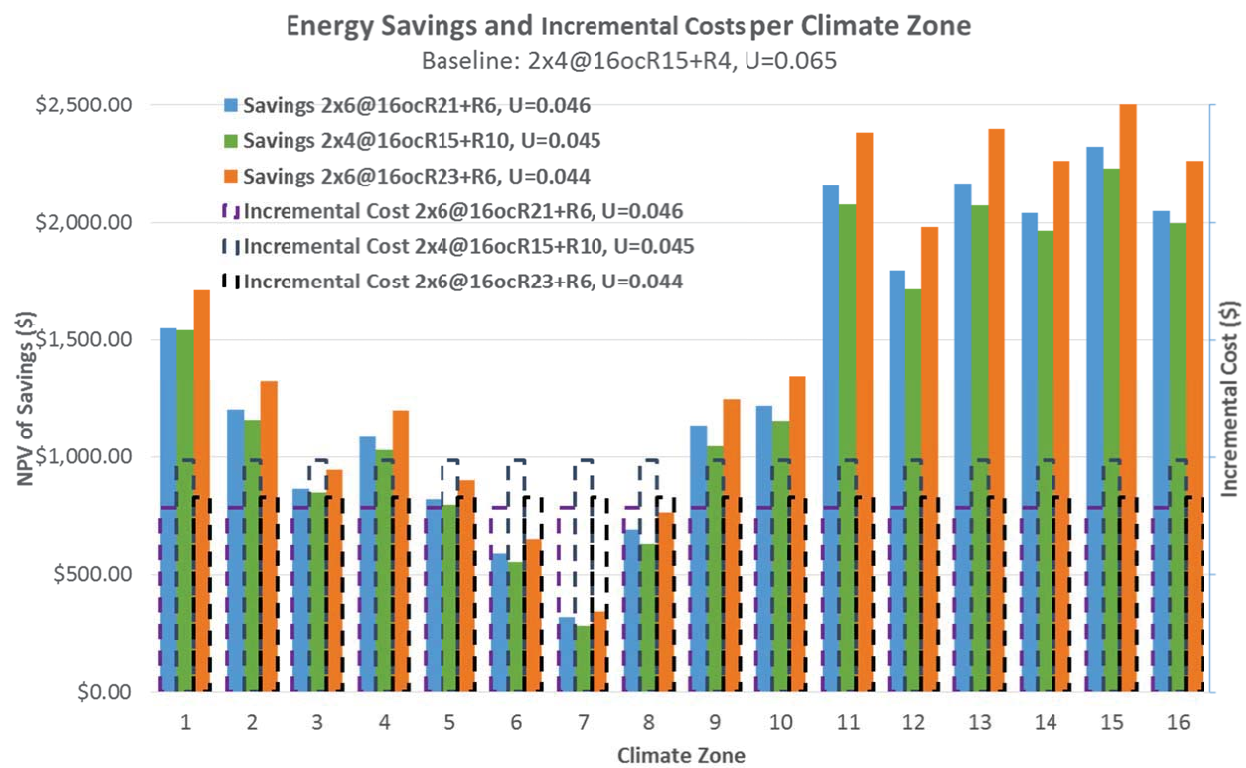


Figure 3: Energy Savings and Incremental Costs of Assemblies with U-factors 0.046 or less

5.3 Environmental Impacts Results

5.3.1 Greenhouse Gas Emissions Results

Table 35 presents the estimated first year avoided GHG emissions of the proposed code change. During the first year the 2016 Standards are in effect the proposed measure will result in avoided GHG emissions. The monetary value of avoided GHG emissions is included in TDV cost factors (TDV \$) for each hour of the year and thus included in the Cost-effectiveness Analysis presented in this report.

Table 33: Statewide Greenhouse Gas Emissions Impacts for Exterior Walls, U-factor=0.046

Climate Zone	First Year Statewide Avoided GHG Emissions ¹ (MTCO ₂ e/yr)
Climate Zone 1	187
Climate Zone 2	446
Climate Zone 3	716
Climate Zone 4	886
Climate Zone 5	161
Climate Zones 6, 7, 8	n/a
Climate Zone 9	791
Climate Zone 10	1858
Climate Zone 11	1,241
Climate Zone 12	3,601
Climate Zone 13	2,667
Climate Zone 14	690
Climate Zone 15	537
Climate Zone 16	1,005
TOTAL	14,788

¹. First year savings from buildings built in 2017; assumes 353 MTCO₂e/GWh and 5,303 MTCO₂e/MMTherms.

Table 34: Statewide Greenhouse Gas Emissions Impacts for QII

Climate Zone	First Year Statewide Avoided GHG Emissions ¹ (MTCO ₂ e/yr)
Climate Zone 1	209
Climate Zone 2	452
Climate Zone 3	776
Climate Zone 4	927
Climate Zone 5	172
Climate Zones 6, 7, 8	n/a
Climate Zone 9	843
Climate Zone 10	1,985
Climate Zone 11	1,368
Climate Zone 12	3,990
Climate Zone 13	2,803
Climate Zone 14	771
Climate Zone 15	407
Climate Zone 16	1,140
TOTAL	15,844

^{1.} First year savings from buildings built in 2017; assumes 353 MTCO₂e/GWh and 5,303 MTCO₂e/MMTherms.

Table 35: Statewide Greenhouse Gas Emissions Impacts for Exterior Walls, U-factor=0.046 and QII

Climate Zone	First Year Statewide Avoided GHG Emissions ¹ (MTCO ₂ e/yr)
Climate Zone 1	372
Climate Zone 2	849
Climate Zone 3	1386
Climate Zone 4	1715
Climate Zone 5	306
Climate Zones 6, 7, 8	n/a
Climate Zone 9	1536
Climate Zone 10	3599
Climate Zone 11	2460
Climate Zone 12	7191
Climate Zone 13	5169
Climate Zone 14	1379
Climate Zone 15	859
Climate Zone 16	2032
TOTAL	28,852

¹. First year savings from buildings built in 2017; assumes 353 MTCO₂e/GWh and 5,303 MTCO₂e/MMTherms.

5.3.2 Water Use and Water Quality Impacts

Impacts on water use and water quality are presented in Table 36.

Table 36: Impacts of Water Use and Water Quality

	On-Site Water Savings ¹ (gallons/yr)	Embedded Energy Savings ² (kWh/yr)	Impact on Water Quality Material Increase (I), Decrease (D), or No Change (NC) compared to existing conditions			
			Mineralization (calcium, boron, and salts)	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC	NC	NC
Per Unit Impacts ³	N/A	N/A	N/A	N/A	N/A	N/A
Statewide Impacts (first year)	N/A	N/A	N/A	N/A	N/A	N/A
Comment on reasons for your impact assessment	N/A	N/A	N/A	N/A	N/A	N/A

^{1.} Does not include water savings at power plant

^{2.} Assumes embedded energy factor of 10,045 kWh per million gallons of water.

^{3.} Unit means per prototype building. For description of prototype buildings refer to section 4.3.

5.3.3 Material Impacts Results

The proposed requirements recommend, but do not require changing standard practice from 2x4 studs to 2x6 studs. The material impacts below conservatively estimate the increase in lumber of all wall construction previously used 2x4 studs and as a result of this code change will use 2x6 studs. A weight of 33lbs per cubic foot of wood framing material is assumed.

Table 37: Impacts of Material Use

	Impact on Material Use Material Increase (I), Decrease (D), or No Change (NC) compared to base case (lbs/year)					
	Mercury	Lead	Copper	Steel	Plastic	Wood (lumber)
Impact (I, D, or NC)	NC	NC	NC	NC	NC	I
Per Unit Impacts	N/A	N/A	N/A	N/A	N/A	21
Statewide Impacts (first year)	N/A	N/A	N/A	N/A	N/A	2,287,428

6. PROPOSED LANGUAGE

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

This measure is modifying the prescriptive U-factor requirements for residential wood-framed walls from 0.065 to 0.046 in all climate zones that were proven cost effective (1-5 and 9-16).

This measure also proposes making Quality Insulation Installation (QII) mandatory when batt, blanket, or loose-fill insulation is installed in walls, roofs, or raised floors in all climate zones except for climate zones 6, 7, or 8.

6.1 Standards

This measure requires updating the language contained in Sections 150.0(c) and updating row two (2) of Table 150.1-A Component Package A with the values in Table 22, below, and editing associated footnotes.

SECTION 150.0 – MANDATORY FEATURES AND DEVICES

- (a) **Ceiling and Rafter Roof Insulation.** The opaque portions of ceilings separating conditioned spaces from unconditioned spaces or ambient air shall meet the requirements of 1 or 2 below~~²~~. If batt, blanket or loose-fill insulation is used to meet requirements 1 or 2 below, HERS verification of Quality Insulation Installation is required.

EXCEPTION to Section 150.0(c): Buildings constructed in Climate Zone 6, 7 or 8 shall be exempt from the mandatory requirement for HERS verification of Quality Insulation Installation.

1. Ceilings and rafter roofs shall be insulated between wood-framing members with insulation resulting in an installed thermal resistance of R-30 or greater for the insulation alone. Attic access doors shall have permanently attached insulation using adhesive or mechanical fasteners. The attic access shall be gasketed to prevent air leakage.

EXCEPTION to Section 150.0(a)1: Insulation of rafter roofs in an alteration shall be insulated between wood-framing members with insulation resulting in an installed thermal resistance of R-19 or greater.

2. The weighted average U-factor shall not exceed 0.031 that would result from installing R-30 insulation between wood-framing members.
- (b) **Loose-fill Insulation.** When loose-fill insulation is installed, the minimum installed weight per square foot shall conform with the insulation manufacturer's installed design weight per square foot at the manufacturer's labeled R-value.
- (c) **Wall Insulation.** Insulation installed in opaque portions of above grade framed walls separating conditioned spaces from unconditioned spaces or ambient air shall meet the requirements of Items 1, 2 or 3 below~~²~~. If batt, blanket or loose-fill insulation is used to meet requirements 1, 2, or 3 below, HERS verification of Quality Insulation Installation is required.

EXCEPTION to Section 150.0(c): Buildings constructed in Climate Zone 6, 7 or 8 shall be exempt from the mandatory requirement for HERS verification of Quality Insulation Installation.

1. Walls shall be insulated between framing members with insulation having an installed thermal resistance of not less than R-13 in 2x4 inch framing, or the U-factor shall not exceed U-0.102 that results from installing R-13 in a 2x4 inch wood framed assembly; and

EXCEPTION to Section 150.0(c)1: Existing walls already insulated to an installed thermal resistance of R-11 or greater.

2. Walls shall be insulated between framing members with insulation having an installed thermal resistance of not less than R-19 in framing of 2x6 inch or greater, or the U-factor shall not exceed the U-0.074 that results from installing R-19 in a 2x6 inch or greater wood framed assembly; and
 3. Bay Window roofs and floors shall be insulated to meet the wall insulation requirements of TABLE 150.1- A.
- (d) **Raised-floor Insulation.** Raised floors separating conditioned space from unconditioned space or ambient air shall meet the requirements of 1 or 2 below: If batt, blanket or loose-fill insulation is used to meet requirements 1, or 2 below, HERS verification of Quality Insulation Installation is required.

EXCEPTION to Section 150.0(d): Buildings constructed in Climate Zone 6, 7 or 8 shall be exempt from the mandatory requirement for HERS verification of Quality Insulation Installation.

1. Floors shall be insulated between wood-framing members with insulation having an installed thermal resistance of R-19 or greater.
2. The weighted average U-factor of floor assemblies shall not exceed 0.037 that would result from installing R-19 insulation between wood-framing members and accounting for the effects of framing members.

EXCEPTION to Section 150.0(d): A building with a controlled ventilation or unvented crawlspace may omit raised floor insulation if all of the following are met:

- A. The foundation walls are insulated to meet the wall insulation minimums as shown in TABLE 150.1-A; and
- B. A Class I or Class II vapor retarder is placed over the entire floor of the crawlspace; and
- C. Vents between the crawlspace and outside air are fitted with automatically operated louvers that are temperature actuated; and
- D. The requirements in Reference Residential Appendix RA4.5.1.

SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR NEWLY CONSTRUCTED RESIDENTIAL BUILDINGS

Table 150.1-A

Table 38: Proposed changes to the 2013 Standards Table 150.1-A Component Package A

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Building Envelope, Insulation, Walls, Above Grade, 2x4 Wood Framed ¹	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U-	U-	U-	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U- 0.065	U- 0.065
	R 15+4	R 15+4	R 15+4	R 15+4	R 15+4	R	R	R	R 15+4	R 15+4	R 15+4	R 15+4	R 15+4	R 15+4	R 15+4	R 15+4
	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or	or	or	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5	or R13+ 5
	U- 0.046	U- 0.046	U- 0.046	U- 0.046	U- 0.046				U- 0.046	U- 0.046	U- 0.046	U- 0.046	U- 0.046	U- 0.046	U- 0.046	U- 0.046
	or	or	or	or	or				or	or	or	or	or	or	or	or
	R- 21+6	R- 21+6	R- 21+6	R- 21+6	R- 21+6				R- 21+6	R- 21+6	R- 21+6	R- 21+6	R- 21+6	R- 21+6	R- 21+6	R- 21+6

¹ U-factors can be met by cavity insulation alone or with continuous insulation alone, or with both cavity and continuous insulation that results in a U-factor equal to or less than the U-factor shown. “~~R-15+4~~ R-21+6” means ~~R-15~~ R-21 cavity insulation plus ~~R-4~~ R-6 continuous insulation sheathing. Any combination of cavity insulation and/or continuous insulation that results in a U-factor equal to or less than ~~0.065~~ 0.046 is allowed.

6.2 Reference Appendices

Table 39: Table RA2-1 – Summary of Measures Requiring Field Verification and Diagnostic Testing

Building Envelope Measures		
High Quality Insulation Installation (QII)	Compliance Software recognizes standard and improved envelope construction. Compliance credit can be taken for quality installation of insulation <u>other than batt, blanket or loose-fill insulation</u> . QII is <u>automatically modeled for batt, blanket and loose-fill insulation for the standard design</u> . Field verification is <u>mandatory when batt, blanket and loose-fill insulation is installed, and required when compliance credit is taken for other types of insulation</u> .	RA3.5

6.3 ACM Reference Manual

The proposed code change will modify section 2.2.6 (Insulation Construction Quality) of the Residential ACM Reference Manual. The proposal will modify existing language by updating the standard design for insulation construction quality.

2.2.6 Insulation Construction Quality

The compliance software user may specify either standard (unverified) or improved (verified high quality insulation installation, also called Quality Insulation Installation or QII) for the proposed design. Buildings with standard insulation installation are modeled in the program with lower performing cavity insulation in framed walls, ceilings and floors and with added winter heat flow between the conditioned zone and attic to represent construction cavities open to the attic (see Table 2-3). Standard insulation does not affect the performance of continuous sheathing in any construction.

PROPOSED DESIGN

The compliance software user may specify improved quality insulation installation at the building level. The default is unverified/standard insulation installation. See Section 2.3.3 for information on modeling spray foam insulation.

STANDARD DESIGN

The standard design is modeled with ~~standard quality~~ insulation installation ~~quality~~ except in Climate Zones 6, 7, and 8. The standard design is modeled with standard quality insulation installation in Climate Zones 6, 7, and 8.

VERIFICATION AND REPORTING

The presence of improved/verified high quality insulation installation is reported in the HERS Required Verification listings on the CF1R. Improved quality insulation installation is certified by the installer and field verified to comply with RA3.5. Credit for verified quality insulation installation is applicable to ceilings/attics, knee walls, exterior walls and exterior floors.

Table 2-3: Modeling Rules for Standard Insulation Installation Quality

Component	Modification
Walls	Multiply the cavity insulation R-value/inch by 0.7
Ceilings/Roofs	Multiply the blown and batt insulation R-value/inch by 0.96-0.00347*R
Ceiling below attic	Add a heat flow from the conditioned zone to the attic of 0.015 times the area of the ceiling below attic times (the conditioned zone temperature - attic temperature) whenever the attic is colder than the conditioned space

6.4 Compliance Manuals

The following sections of the Residential Compliance Manual will need to be revised:

- 1.6.3 – Prescriptive Package A – 150.1(c)
- 3.6 – Envelope Features.

Specific edits to the manual will be determined at the conclusion of the CEC rulemaking process.

6.5 Compliance Forms

The proposed code change will modify the following compliance forms listed below.

- **CF1R-NCB-01-E** – CERTIFICATE OF COMPLIANCE – DATA FIELD DEFINITIONS AND CALCULATIONS.

6.5.1 B. OPAQUE SURFACE DETAILS – Framed

1. Tag/ID: A label (if any) from the plans, such as A1.4 or wall.
2. Assembly Type: Roof, Ceiling, Wall, Floor over crawlspace or floor over exterior.
3. Frame type: Wood or Metal.
4. Frame Depth: Nominal dimensions (in inches) of framing material such as 2x4 or 2x6.
5. Frame Spacing: 16 or 24 (inches on center).
6. Cavity R-value: Cavity R-value: insulation installed between framing members. NOTE: Wall U-factor required for all climate zones 6, 7, and 8 is 0.065. Wall U-factor required for climate zones 1-5 and 9-16 is 0.046.
~~This~~ The U-factors of 0.065 can be met by wood framed 2x4 walls with R-13 cavity + R5 continuous insulation (not interrupted by framing), R-15 cavity plus R-4 continuous insulation, or any combination of cavity and/or continuous insulation that results in a U-factor equal to or less than 0.065. The U-factor of 0.046 can be met by wood framed 2x6 walls with R-21 cavity + R6 continuous insulation (not interrupted by framing), 2x4 walls with R-15 cavity + R10 continuous insulation, or any combination of cavity and/or continuous insulation that results in a U-factor equal to or less than 0.046. Continuous Insulation: R-value of rigid or continuous insulation (not interrupted by framing).
7. U-factor: The U-factor for the proposed assembly. Must be less than or equal to column 10 or have an attached CF1R-ENV-02-E to show that a weighted U-factor for multiple assemblies will meet the maximum value in column 11.
8. Appendix JA4 Table: Table number used to determine the R-value or U-factor (e.g., an ICF wall is 4.3.13).
9. Appendix JA4 Cell: Cell number used to determine the R-value or U-factor (e.g., an 8-inch thick ICF wall with 2 inches of EPS (R-15.4) is A6).
10. Required U-factor: from Package A: Value required based on climate zone and assembly type.

...

6.5.2 M. HERS MEASURES

...

5. Quality Insulation Installation: Batt, blanket and loose-fill insulation in the opaque portions of ceilings and walls separating conditioned spaces from unconditioned spaces or ambient air must meet Quality Insulation Installation requirements as per RA3.5.

7. REFERENCES AND OTHER RESEARCH

- APA - The Engineered Wood Association. 2012. “Advanced Framing: Time to Green-up Your Structure.”
- Baczek, S., Yost, P., & S. Finegan. 2002. “Advanced Framing: Using Wood Efficiently From Optimizing Design to Minimizing the Dumpster.” Building Science Corporation.
- [BSC] Building Science Corporation. 2009. “Moisture Control for New Residential Buildings.” Building Science Digest 012 prepared by Joseph Lstiburek.
- Broniek, J. 2010. “Thermal Enclosure Design Challenges for a Cold Climate Net Zero Energy House.” Presented at the 2010 ACEEE Summer Study.
- Building America. 2011. “Case Study: David Weekley Homes.” Houston, TX.
- [CARB] California Air Resources Board. 2010. “Proposed Regulation for a California Renewable Electricity Standard Staff Report: Initial Statement of Reasons Appendix D.” <http://www.arb.ca.gov/regact/2010/res2010/res10d.pdf>. Accessed November 12, 2013.
- . 2011a. California Air Resources Board. “Appendix C: Cost Effectiveness Calculation Methodology.” http://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/appc_3_10_11.pdf. March 10.
- . 2011b. “Emission Reduction Offsets Transaction Cost Summary Report for 2011.” <http://www.arb.ca.gov/nsr/erco/erco.htm>.
- . 2012. “Emission Reduction Offsets Transaction Cost Summary Report for 2012.” <http://www.arb.ca.gov/nsr/erco/erco.htm>.
- . 2013a. “Mail-Out #MSC 13-09.” <http://www.arb.ca.gov/msprog/mailouts/msc1309/msc1309.pdf>. March 25.
- . 2013b. “California Air Resources Board Quarterly Auction 3, May 2013 – Summary Results Report.” <http://www.arb.ca.gov/cc/capandtrade/auction/may-2013/results.pdf>.
- [CARB] Consortium for Advanced Residential Buildings. 2009. “Double Wall: Staggered or In-Line Studs?” CARB News. Norwalk, Ct.
- [CEC] California Energy Commission. 2014. “Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2016 Time Dependent Valuation (TDV) Data Sources and Inputs.” July 2014. http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/Title24_2016_TDV_Methodology_Report%20v3.docx. Accessed July 2014.
- [CEC] California Energy Commission. 2011. “Lifecycle Cost Methodology: 2013 California Building Energy Efficiency Standards. July 2011.

- http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf. Accessed August 2014.
- _____. 2014. “Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2016 Time Dependent Valuation (TDV) Data Sources and Inputs.” July 2014.
http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/Title24_2016_TDV_Methodology_Report%20v3.docx. Accessed July 2014.
- [IOU] California Utilities Statewide Codes and Standards Team. 2011. “Increased Wall Insulation.”
http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Envelope/2013_CASE_R_Increased_Wall_Insulation_Oct_2011.pdf
- _____. 2011a. California Utilities Statewide Codes and Standards Team. 2011. “Advanced Envelope Assemblies.”
http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Envelope/2013_CASE_R_Advanced_Wall_Assemblies_Sept_2011.pdf
- Lstiburek, J. & A. Grin. 2010. “Building America Special Research Project: Deployment of Advanced Framing at the Community Scale.” Building Science Corporation.
- Roland-Holst, David. “Energy Efficiency, Innovation, and Job Creation in California.” October 2008.
http://are.berkeley.edu/~dwrh/CERES_Web/Docs/UCB%20Energy%20Innovation%20and%20Job%20Creation%2010-20-08.pdf. Accessed May 27, 2014.
- RSMeans. 2014. RSMeans Online. Reed Construction Data. <http://rsmeansonline.com/>. Accessed March 2014.
- Southface Energy Institute & U.S. Department of Energy’s Oak Ridge National Laboratory (ORNL). 2000. “Wall Insulation: Provide Moisture Control and Insulation in Wall Systems.”
- Straube, J. & J. Smegal. 2012. “Building America Special Research Project: High-R Walls Case Study Analysis.” Building Science Corporation.
- Thompson, M. & J. Wiehagen. 2008. “Advanced Framing: An Examination of its Practical Use in Residential Construction.” Prepared as part of HUD’s Partnership for Advancing Technology in Housing.
- [UC Berkeley] University of California Berkeley Donald Vial Center on Employment in the Green Economy. “California Workforce Education and Training Needs Assessment for Energy Efficiency, Distributed Generation, and Demand Response”. 2011.
http://www.irle.berkeley.edu/vial/publications/WET_Part1.pdf, Accessed May 27, 2014.
- [U.S. EPA] United States Environmental Protection Agency. 2011. “Emission Factors for Greenhouse Gas Inventories.”
<http://www.epa.gov/climateleadership/documents/emission-factors.pdf>. Accessed December 2, 2013.

Personal Communications:

Karyn Beebe, P.E., LEED AP, APA – The Engineered Wood Association
Payam Bozorgchami, California Energy Commission
Rick Chitwood, Chitwood Energy Management, Inc.
Matthew Christie, TRC and PG&E lead for California Advanced Homes Program
Dave Hegarty, Duct Testers
C.R. Herro, Meritage Homes
Marc Hoeschle, Davis Energy Group
Katy Hollbacher, P.E., Beyond Efficiency Inc.
Marshall Hunt, Pacific Gas and Electric Company
John Kindorf, Pulte Group
Ron Kliewer, Southern California Edison
Bill Lilly, California Living and Energy
Jay Madden, Southern California Edison
Amber Mahrou, Energy Inspectors
Cody McGhie, Energy Inspectors
Vinny Molluzzo, Energy Inspectors
John Mortin, Southern California Edison lead for California Advanced Homes Program
Ken Nittler, Enercomp
Dennis Richardson, American Wood Council (AWC)
Dave Rivers, Southern California Edison
Mazi Shirakh, California Energy Commission
Tim Sloan, Harris & Sloan Consulting Group, Inc.
Will Vicent, Southern California Edison
Bruce Wilcox
William Zoeller, Consortium for Advanced Residential Buildings (Steven Winter Associates)

APPENDIX A: ENVIRONMENTAL IMPACTS

METHODOLOGY

Greenhouse Gas Emissions Impacts Methodology

The avoided GHG emissions were calculated assuming an emission factor of 353 metric tons of carbon dioxide equivalents (MTCO₂e) per GWh of electricity savings. The Statewide CASE Team calculated air quality impacts associated with the electricity savings from the proposed measure using emission factors that indicate emissions per GWh of electricity generated.¹⁸ When evaluating the impact of increasing the Renewable Portfolio Standard (RPS) from 20 percent renewables by 2020 to 33 percent renewables by 2020, California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The Statewide CASE Team used data from CARB's analysis to inform the air quality analysis presented in this report.

The GHG emissions factor is a projection for 2020 assuming the state will meet the 33 percent RPS goal. CARB calculated the emissions for two scenarios: (1) a high load scenario in which load continues at the same rate; and (2) a low load rate that assumes the state will successfully implement energy efficiency strategies outlined in the AB32 scoping plan thereby reducing overall electricity load in the state.

To be conservative, the Statewide CASE Team calculated the emissions factors of the incremental electricity between the low and high load scenarios. These emission factors are intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario. The incremental emissions were calculated by dividing the difference between California emissions in the high and low generation forecasts by the difference between total electricity generated in those two scenarios. While emission rates may change over time, 2020 was considered a representative year for this measure.

Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 MTCO₂e/million therms (U.S. EPA 2011).

Water Use and Water Quality Impacts Methodology

There are no direct water impacts as a result of this proposed measure.

¹⁸ California power plants are subject to a GHG cap and trade program and linked offset programs until 2020 and potentially beyond.

APPENDIX B: JOB CREATION BY INDUSTRY

Table 40 shows total job creation by industry that is expected from all investments in California energy efficiency and renewable energy (Source: UC Berkeley 2010b, Appendix D). While it is not specific to codes and standards, this data indicates the industries that generally will receive the greatest job growth from energy efficiency programs.

Table 40: Job Creation by Industry

NAICS	Industry Description	Direct Jobs	
		2015	2020
23822	Plumbing, Heating, and Air-Conditioning Contractors	8,695	13,243
2361	Residential Building Construction	5,072	7,104
2362	Nonresidential Building Construction	5,345	6,922
5611	Office Administrative Services	2,848	4,785
23821	Electrical Contractors	3,375	4,705
551114	Corporate, Subsidiary, and Regional Managing Offices	1,794	3,014
54133	Engineering Services	1,644	2,825
5418	Advertising and Related Services	1,232	2,070
334413	Semiconductor and Related Device Manufacturing	1,598	1,598
541690	Other Scientific and Technical Consulting Services	796	1,382
23831	Drywall and Insulation Contractors	943	1,331
3334	Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manf.	453	792
3351	Electric Lighting Equipment Manufacturing	351	613
926130	Regulation and Administration of Communications, Electric, Gas, Other Utilities	322	319
23816	Roofing Contractors	275	277
54162	Environmental Consulting Services	151	261
484210	Used Household and Office Goods Moving	137	239
23835	Finish Carpentry Contractors	120	120
23829	Other Building Equipment Contractors	119	113
3352	Household Appliance Manufacturing	63	110
other	other	454	547
	Total	35,788	52,369

APPENDIX C: CBECC-RES SIMULATION RESULTS FOR ADDITIONAL WALL ASSEMBLIES

Energy modeling simulation results for various construction assemblies are provided below.

Table 41: Alternate Assembly U-Values

	U-Value of Assembly						
Assembly	2x6@ 16ocR 21+R4	2x4@ 16oc R15+R8	2x6@ 16ocR 23+R4	2x6@ 16ocR 19+R6	2x6@ 16ocR 21+R6	2x4@ 16ocR 15+R10	2x6@ 16ocR 23+R6
U-Value	0.051	0.050	0.049	0.049	0.046	0.045	0.044

Table 42: Alternate Assembly TDV Savings

Climate Zone	Savings (Baseline – Proposed) in TDV kBTU/ft2						
	2x6@ 16ocR 21+R4	2x4@ 16oc R15+R8	2x6@ 16ocR 23+R4	2x6@ 16ocR 19+R6	2x6@ 16ocR 21+R6	2x4@ 16ocR 15+R10	2x6@ 16ocR 23+R6
1	2.7	3.7	3.1	3.2	3.7	3.7	4.1
2	2.1	2.8	2.4	2.5	2.9	2.8	3.1
3	1.5	2.0	1.7	1.8	2.1	2.0	2.3
4	1.9	2.5	2.2	2.3	2.6	2.5	2.8
5	1.4	1.9	1.7	1.7	2.0	1.9	2.1
6	1.0	1.3	1.2	1.3	1.4	1.3	1.6
7	0.6	0.7	0.7	0.7	0.8	0.7	0.8
8	1.3	1.5	1.4	1.5	1.6	1.5	1.8
9	2.0	2.5	2.3	2.4	2.7	2.5	3.0
10	2.1	2.7	2.5	2.5	2.9	2.7	3.2
11	3.8	4.9	4.4	4.5	5.1	4.9	5.7
12	3.1	4.1	3.6	3.8	4.3	4.1	4.7
13	3.8	4.9	4.4	4.5	5.2	4.9	5.7
14	3.6	4.7	4.2	4.3	4.9	4.7	5.4
15	4.1	5.3	4.5	4.7	5.5	5.3	6.1
16	3.5	4.8	4.1	4.3	4.9	4.8	5.4

Table 43: Alternate Assembly First Costs

Wall Assembly	2x6@ 16ocR 21+R4	2x4@ 16oc R15+R8	2x6@ 16ocR 23+R4	2x6@ 16ocR 19+R6	2x6@ 16ocR 21+R6	2x4@ 16ocR 15+R10	2x6@ 16ocR 23+R6
Measure First Costs (\$)	\$ 463	\$ 622	\$ 507	\$ 477	\$ 783	\$ 989	\$ 827

Table 44: Alternate Assembly PV of Energy Cost Savings

Climate Zone	PV of Energy Cost Savings (\$)						
	2x6@ 16ocR 21+R4	2x4@ 16oc R15+R8	2x6@ 16ocR 23+R4	2x6@ 16ocR 19+R6	2x6@ 16ocR 21+R6	2x4@ 16ocR 15+R10	2x6@ 16ocR 23+R6
1	\$ 1,115	\$ 1,153	\$ 1,305	\$ 1,361	\$ 1,549	\$ 1,542	\$ 1,708
2	\$ 871	\$ 869	\$ 1,017	\$ 1,057	\$ 1,199	\$ 1,156	\$ 1,319
3	\$ 623	\$ 636	\$ 728	\$ 762	\$ 862	\$ 847	\$ 949
4	\$ 805	\$ 776	\$ 934	\$ 959	\$ 1,087	\$ 1,032	\$ 1,194
5	\$ 604	\$ 604	\$ 702	\$ 724	\$ 820	\$ 793	\$ 898
6	\$ 440	\$ 418	\$ 511	\$ 527	\$ 591	\$ 553	\$ 653
7	\$ 248	\$ 216	\$ 280	\$ 285	\$ 317	\$ 283	\$ 342
8	\$ 525	\$ 478	\$ 607	\$ 614	\$ 693	\$ 632	\$ 763
9	\$ 838	\$ 792	\$ 979	\$ 996	\$ 1,131	\$ 1,049	\$ 1,244
10	\$ 900	\$ 869	\$ 1,049	\$ 1,071	\$ 1,216	\$ 1,150	\$ 1,343
11	\$ 1,579	\$ 1,561	\$ 1,843	\$ 1,897	\$ 2,158	\$ 2,079	\$ 2,384
12	\$ 1,312	\$ 1,286	\$ 1,530	\$ 1,584	\$ 1,796	\$ 1,714	\$ 1,984
13	\$ 1,588	\$ 1,555	\$ 1,856	\$ 1,910	\$ 2,166	\$ 2,075	\$ 2,397
14	\$ 1,505	\$ 1,475	\$ 1,755	\$ 1,803	\$ 2,044	\$ 1,965	\$ 2,265
15	\$ 1,732	\$ 1,601	\$ 1,902	\$ 1,983	\$ 2,324	\$ 2,231	\$ 2,548
16	\$ 1,484	\$ 1,500	\$ 1,734	\$ 1,810	\$ 2,050	\$ 1,999	\$ 2,263

Table 45: Alternate Assembly Life Cycle Cost

Climate Zone	Life Cycle Cost (\$)						
	2x6@ 16ocR 21+R4	2x4@ 16oc R15+R8	2x6@ 16ocR 23+R4	2x6@ 16ocR 19+R6	2x6@ 16ocR 21+R6	2x4@ 16ocR 15+R10	2x6@ 16ocR 23+R6
1	\$ (652)	\$ (531)	\$ (798)	\$ (884)	\$ (766)	\$ (553)	\$ (881)
2	\$ (408)	\$ (247)	\$ (510)	\$ (580)	\$ (416)	\$ (167)	\$ (492)
3	\$ (160)	\$ (14)	\$ (221)	\$ (285)	\$ (79)	\$ 142	\$ (122)
4	\$ (342)	\$ (154)	\$ (427)	\$ (482)	\$ (304)	\$ (43)	\$ (367)
5	\$ (141)	\$ 18	\$ (195)	\$ (247)	\$ (37)	\$ 196	\$ (71)
6	\$ 23	\$ 204	\$ (4)	\$ (50)	\$ 192	\$ 436	\$ 174
7	\$ 215	\$ 406	\$ 227	\$ 192	\$ 466	\$ 706	\$ 485
8	\$ (62)	\$ 144	\$ (100)	\$ (137)	\$ 90	\$ 357	\$ 64
9	\$ (375)	\$ (170)	\$ (472)	\$ (519)	\$ (348)	\$ (60)	\$ (417)
10	\$ (437)	\$ (247)	\$ (542)	\$ (594)	\$ (433)	\$ (161)	\$ (516)
11	\$ (1,116)	\$ (939)	\$ (1,336)	\$ (1,420)	\$ (1,375)	\$ (1,090)	\$ (1,557)
12	\$ (849)	\$ (664)	\$ (1,023)	\$ (1,107)	\$ (1,013)	\$ (725)	\$ (1,157)
13	\$ (1,125)	\$ (933)	\$ (1,349)	\$ (1,433)	\$ (1,383)	\$ (1,086)	\$ (1,570)
14	\$ (1,042)	\$ (853)	\$ (1,248)	\$ (1,326)	\$ (1,261)	\$ (976)	\$ (1,438)
15	\$ (1,269)	\$ (979)	\$ (1,395)	\$ (1,506)	\$ (1,541)	\$ (1,242)	\$ (1,721)
16	\$ (1,021)	\$ (878)	\$ (1,227)	\$ (1,333)	\$ (1,267)	\$ (1,010)	\$ (1,436)

At the CEC's request, additional details for a U-factor=0.049 are provided below. The energy impacts per weighted prototype (as described in Section 4.3) are presented in Table 46. The extrapolated statewide impact is presented in Table 47, and the Cost-effectiveness summary is contained in Table 48.

Table 46: Energy Impacts per Weighted Prototype with Exterior Walls, U-factor=0.049¹

Climate Zone	Per Unit First Year Savings ²			
	Electricity Savings ⁴ (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	Total TDV Savings ⁵ (kBTU)
Climate Zone 1	35	0.00	41	7,543
Climate Zone 2	31	0.02	25	5,877
Climate Zone 3	19	0.01	21	4,209
Climate Zone 4	31	0.04	22	5,397
Climate Zone 5	18	0.00	21	4,057
Climate Zone 6	15	0.02	12	2,954
Climate Zone 7	8	0.01	5	1,620
Climate Zone 8	27	0.06	9	3,506
Climate Zone 9	49	0.11	12	5,661
Climate Zone 10	62	0.11	14	6,065
Climate Zone 11	115	0.13	25	10,651
Climate Zone 12	68	0.10	25	8,843
Climate Zone 13	121	0.16	22	10,726
Climate Zone 14	108	0.14	26	10,146
Climate Zone 15	264	0.21	4	10,997
Climate Zone 16	48	0.03	48	10,025

- ^{1.} Each unit refers to one house, using the weighting of prototypes representing average new construction as described in Section 4.3, with a wall assembly U-factor=0.049.
- ^{2.} Savings from one unit (weighted prototype building), for the first year the building is in operation.
- ^{3.} TDV energy savings for one unit (weighted prototype building) for the first year the building is in operation.
- ^{4.} Site electricity savings. Does not include TDV of electricity savings.
- ^{5.} Calculated using CEC's 2016 TDV factors and methodology. Includes savings from electricity and natural gas.

Table 47: Statewide Energy Impacts of Exterior Walls, U-factor=0.049

Climate Zone	First Year Statewide Savings ¹			
	Electricity Savings ³ (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	Total TDV Energy Savings ⁴ (Million kBTU)
Climate Zone 1	0.02	0.00	0.03	5
Climate Zone 2	0.08	0.04	0.07	15
Climate Zone 3	0.10	0.03	0.11	22
Climate Zone 4	0.19	0.23	0.13	32
Climate Zone 5	0.02	0.00	0.02	5
Climate Zone 6	0.06	0.07	0.05	12
Climate Zone 7	0.05	0.09	0.04	11
Climate Zone 8	0.19	0.41	0.07	25
Climate Zone 9	0.40	0.88	0.10	47
Climate Zone 10	1.03	1.81	0.23	101
Climate Zone 11	0.68	0.76	0.15	64
Climate Zone 12	1.32	1.92	0.48	172
Climate Zone 13	1.68	2.29	0.31	149
Climate Zone 14	0.36	0.46	0.09	34
Climate Zone 15	1.02	0.80	0.02	43
Climate Zone 16	0.15	0.09	0.15	31
TOTAL	7.4	9.9	2.0	768

1. First year savings from all buildings built statewide during the first year the 2016 Standards are in effect.
2. First year TDV savings from all buildings built statewide during the first year the 2016 Standards are in effect.
3. Site electricity savings.
4. Calculated using CEC's 2016 TDV factors and methodology.

Table 48: Cost-effectiveness Summary for Exterior Walls, U-factor=0.049¹

Climate Zone	Benefit: TDV Energy Cost Savings ² (2016 PV\$)	Cost: Total Incremental Cost ³ (2016 PV\$)	Change in Lifecycle Cost ⁴ (2016 PV\$)	Benefit to Cost Ratio ⁵
Climate Zone 1	\$1,361	\$477	\$(884)	2.9
Climate Zone 2	\$1,057	\$477	\$(581)	2.2
Climate Zone 3	\$762	\$477	\$(285)	1.6
Climate Zone 4	\$959	\$477	\$(482)	2.0
Climate Zone 5	\$724	\$477	\$(247)	1.5
Climate Zone 6	\$527	\$477	\$(50)	1.1
Climate Zone 7	\$285	\$477	\$192	0.6
Climate Zone 8	\$614	\$477	\$(137)	1.3
Climate Zone 9	\$996	\$477	\$(519)	2.1
Climate Zone 10	\$1,071	\$477	\$(594)	2.2
Climate Zone 11	\$1,897	\$477	\$(1,420)	4.0
Climate Zone 12	\$1,584	\$477	\$(1,107)	3.3
Climate Zone 13	\$1,910	\$477	\$(1,433)	4.0
Climate Zone 14	\$1,803	\$477	\$(1,326)	3.8
Climate Zone 15	\$1,983	\$477	\$(1,506)	4.2
Climate Zone 16	\$1,810	\$477	\$(1,333)	3.8

1. Relative to existing conditions. All cost values presented in 2016 dollars.

2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta\text{TDV\$} = \Delta\text{TDV\$E} + \Delta\text{TDV\$G}$.

3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta\text{C} = \Delta\text{CI}_{\text{PA}} + \Delta\text{CM}$.

4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta\text{LCC} = \Delta\text{C} - \Delta\text{TDV\$}$

5. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs; $\text{B/C} = \Delta\text{TDV\$} \div \Delta\text{C}$. The measure is cost effective if the B/C ratio is 1.0 or greater.