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Codes and Standards Enhancement (CASE) Initiative

2019 California Building Energy Efficiency Standards

High Performance Attics – Final Report

Measure Number**:** 2019-RES-ENV2-F

Residential Envelope

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EXECUTIVE SUMMARY

Introduction

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

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

Measure Description

The proposed residential high performance attic (HPA) measure increases the prescriptive performance of the residential envelope in certain climates, primarily reducing the cooling season heat transfer through the roof deck, contributing to lower heating, ventilation, and air conditioning (HVAC) loads. The HPA measure as represented in Title 24, Part 6 is based on a traditional ventilated attic with insulation at the ceiling and either ducts fully located in conditioned space or additional insulation added above or below the roof deck. This proposed prescriptive measure only applies to single family and low-rise multifamily buildings in new construction. No changes to the current 2016 HPA prescriptive requirements are being proposed for additions.

In regards to the assumed Standard Design reference case (tile roof with air space between the roof deck and the roofing material) in the performance method, the proposed measure increases the below-deck insulation R-value to:

- R-19 in Climate Zones 4, and 8 through 16 for single family homes, and
- R-19 in Climate Zones 4, 8, 9, and 11 through 15 for low-rise multifamily buildings.

This specification represents the proposed prescriptive requirement for the predominant tile roof configuration seen in California production housing. Equivalent performing cases for roofing systems without an air space (typically the case for asphalt roofing materials) and above deck insulation options were also developed and are reported in Section 7.1. Using the performance path, a builder has the full flexibility to choose to follow the prescriptive path, including the proposed 2019 HPA requirements, or trading HPA off against other efficiency measures.

Scope of Code Change Proposal

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

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
High Performance Attic (HPA)	Prescriptive	150.1(c)	RA3.5 (to provide improved details on Quality Insulation Installation inspection procedures)[a]	Yes. Currently available CBECC-Res research software has been modified to improve ability to model different below-deck insulation options	Compliance documents would need to be modified to provide more clarity on HPA insulation configurations

a. Proposed HPA quality insulation installation content is presented in the Quality insulation installation (QII) CASE Report.

This proposal is also closely tied to other requirements in Title 24, Part 6 related to the quality insulation installation (QII) measure that the Statewide CASE Team proposed for the 2019 code cycle.

Market Analysis and Regulatory Impact Assessment

The concept of HPA was developed to mitigate the energy impacts of heating and cooling ducts located in ventilated attics, which achieve extreme conditions during high space conditioning time periods in many California climates. The construction of high performance attics, prescribed under the 2016 Title 24, Part 6 code update is not currently considered a mainstream residential industry practice in California, although some early adopters have begun to experiment with this measure in advance of the 2016 code update, both in demonstration projects and under the California Advanced Home Program (CAHP). There are a number of market transformation activities currently underway, providing a strong expectation of industry market shift to this technology as the Statewide CASE Team approaches 2019 Title 24, Part 6 code adoption in 2020. A wide range of technical solutions exist from multiple vendors, offering the building industry a range of construction alternatives. Early indications suggest that below-deck batt insulation is the most cost-effective approach to implement. Viable alternatives include above-deck insulation options (e.g., nail base systems) and ducts in conditioned space (the most efficient forced air ducted delivery system design option). In addition, the performance method allows for sealed attic systems to be modeled.

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

The proposed changes to Title 24, Part 6 Standards have a negligible impact on the complexity of the standards or the cost of enforcement, since HPA is already a recognized measure under the 2016 standards. When developing this code change proposal, the Statewide CASE Team interviewed building officials, Title 24 energy analysts and others involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

Cost-Effectiveness

The proposed code change was found to be cost-effective for all climate zones where it is proposed to be required. The benefit-to-cost (B/C) ratio compares the lifecycle benefits (cost savings) to the lifecycle costs. Measures that have a B/C ratio of 1.0 or greater are cost-effective. The larger the B/C ratio, the faster the measure pays for itself from energy savings. Cost-effectiveness varies significantly between single family and multifamily building prototypes used in Title 24, Part 6 Standards evaluations, suggesting the need for different requirements for the two building types. In climate zones where HPA was found to be cost-effective, the B/C ratio ranged between 1.02 and 2.68 depending on climate zone. See Section 5 for a detailed description of the cost-effectiveness analysis.

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the proposed code change. Savings are shown only for new construction as the 2019 HPA proposal does not impact additions or alterations. See Section 6 for more details.

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

Measure	First-Year Electricity Savings (GWh/yr)	First-Year Peak Electrical Demand Reduction (MW)	First-Year Water Savings (million gallons/yr)	First-Year Natural Gas Savings (million therms/yr)
New Construction	3.1	4.9	N/A	0.3
Additions	N/A	N/A	N/A	N/A
Alterations	N/A	N/A	N/A	N/A
TOTAL	**3.1**	**4.9**	**N/A**	**0.3**

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

Compliance and Enforcement

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

- Insulation manufacturers will need to continue to be engaged with builders to introduce improved products and by providing technical support to the construction industry.
- Training should be expanded to increase construction industry familiarity and proficiency with HPA options and best practices. While cost-effective HPA solutions exist, the construction industry as of August 2017 has not integrated these practices in a widespread manner. With the 2016 Title 24, Part 6 code implementation only in effect for about eight months at the time of this report, much of the construction industry is still in the early HPA adoption stage.
- Designers would need to work closely with builders and subcontractors to ensure that measure implementation is clearly conveyed. This process is expected to occur during the 2016 code cycle as the industry increases uptake of the HPA measure in anticipation of the 2019 Title 24, Part 6 update.
- HERS Raters would need to become aware of proposed changes to QII below-deck insulation inspection requirements.

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

1. INTRODUCTION

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

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

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

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during two public stakeholder workshops that the Statewide CASE Team held on September 14, 2016 and March 14, 2017, as well as additional input from the Energy Commission's June 1, 2017 pre-rulemaking workshop.

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

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

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

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

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

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

2. MEASURE DESCRIPTION

2.1 Measure Overview

The proposed residential high performance attic (HPA) measure increases the prescriptive performance of the residential envelope for newly constructed single family and low-rise multifamily residential buildings. No changes to the 2016 HPA prescriptive requirements are proposed for additions.

The HPA measure reduces the heat transfer through the roof deck, improving the performance of space conditioning ducts installed in the attic and reducing ceiling heat transfer to conditioned space. Relative to the 2016 Title 24, Part 6 Standards, the proposed measure increases prescriptive insulation requirements in Climate Zones 4, and 8 through 16 for single family homes, and zones 4, 8, 9, and 11 through 15 for low-rise multifamily buildings. This code change would modify existing code language, but would not create any new sections of code.

2.2 Measure History

High performance attics were first introduced as a residential prescriptive requirement for the 2016 code cycle. During the 2016 code cycle the 2016 Statewide CASE Team evaluated a range of HPA options for vented attics including above-deck insulation options (Option A), below-deck insulation options (Option B), and a ducts in conditioned space alternative (Option C) (California Utilities Statewide Codes and Standards Team 2015). 2016 Title 24, Part 6 Standards presented the HPA requirements for the three options in the zones where the measure was found to be cost-effective: Climate Zones 4, and 8 through 16. As the HPA strategy represents a comprehensive improvement approach for the attic, efficiency upgrades for deck insulation, ceiling insulation, and duct insulation vary based on the configuration and whether an air space is provided between the roofing material and the roof deck.[1] The 2016 Title 24, Part 6 HPA prescriptive ceiling, roof deck, and duct insulation requirements for Options A, B, and C are summarized in Table 3 below, which is an excerpt from 2016 Title 24, Part 6 Standards Table 150.1-A.

The work for the 2019 Title 24, Part 6 code cycle expands on prescriptive requirements instituted under the 2016 Title 24, Part 6 efforts. Since 2016 code adoption has been fairly recent, industry uptake of HPA in early 2017 has been slow. Market transformation activities that are currently underway include the California Advanced Home Program (CAHP) Master Builder program and the Workforce

[1] Concrete, clay, or metal tile roofs, or wood shakes are assumed to provide a 0.75" air space between the roof deck and the roofing material, equivalent to an assumed R-0.85 air space.

Instructions for Standards and Efficiency (WISE) program. [2,3] Both programs are focused on helping to transition California builders toward high performance attics.

The 2019 Title 24, Part 6 code cycle is poised to be the most aggressive yet, aiming at zero net energy in all residential buildings. The "loading order" defined in California's Energy Action Plan (State of California 2003) prescribes that cost-effective efficiency and conservation measures be prioritized prior to installing new generation. Considering this, it is important that this process investigates and supports cost-effective envelope improvement opportunities prior to introducing photovoltaic (PV) generation. With high performance attics prescriptively required under the 2016 Title 24, Part 6 code, it is expected that through the rest of 2017 and 2018 the level of construction industry comfort with the HPA approach will continue to increase. A description of current practices in California is provided in Section 3 this report.

The 2016 Title 24, Part 6 code allows for a solar photovoltaic (PV) compliance credit (PV Credit) that can be used when complying via the performance approach. The PV Credit can be used in all climate zones, except for southern California coastal zones (Climate Zones 6 and 7), which prescriptively require high performance walls and/or high performance attics. The PV Credit is capped at the magnitude of the benefit that high performance walls and attics provide in that climate zone. In addition, there is a minimum solar photovoltaic sizing requirements of 2 kW direct current (dc) for single family and 1 kWdc for multifamily units. The recognized compliance benefit of the PV Credit is intentionally less than its actual benefit in terms of annual electricity generation. Nevertheless, the PV Credit gives builders the opportunity to pursue solar in lieu of these advanced envelope measures and provides flexibility as they work towards increased familiarity and level of comfort with new construction techniques. However, the Energy Commission has indicated that sufficient market transformation activities will have occurred by the effective date of the 2019 Title 24, Part 6 Standards, and therefore, the current PV Credit will no longer be allowed for the 2019 code cycle.

There are no preemption concerns with the HPA measure.

[2] More information about the CAHP Master Builder program is available here: http://cahp-pge.com/masterbuilder/.

[3] More information about the WISE program is available here: http://www.wisewarehouse.org/.

Table 3: Existing 2016 Title 24, Part 6 Residential Prescriptive HPA Requirements

TABLE 150.1-A COMPONENT PACKAGE-A STANDARD BUILDING DESIGN

					Climate Zone															
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Building Envelope Insulation	Roofs/Ceilings	Option A (meets §150.1(c)9A)	Continuous Insulation Above Roof Rafter – Roofing Type	No Air Space[1]	NR	NR	NR	R 8	NR	NR	NR	R 8	R 8	R 8	R 8	R 8	R 8	R 8	R 8	R 8
				With Air Space[2]	NR	NR	NR	R 6	NR	NR	NR	R 6	R 6	R 6	R 6	R 6	R 6	R 6	R 6	R 6
			Ceiling Insulation		R 38	R 38	R 30	R 38	R 30	R 30	R 30	R 38	R 38	R 38	R 38	R 38	R 38	R 38	R 38	R 38
			Radiant Barrier		NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR
		Option B (meets §150.1(c)9A)	Below Roof Deck Insulation[3] – Roofing Type	No Air Space	NR	NR	NR	R 18	NR	NR	NR	R 18	R 18	R 18	R 18	R 18	R 18	R 18	R 18	R 18
				With Air Space	NR	NR	NR	R 13	NR	NR	NR	R 13	R 13	R 13	R 13	R 13	R 13	R 13	R 13	R 13
			Ceiling Insulation		R 38	R 38	R 30	R 38	R 30	R 30	R 30	R 38	R 38	R 38	R 38	R 38	R 38	R 38	R 38	R 38
			Radiant Barrier		NR	REQ	REQ	NR	REQ	REQ	REQ	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Option C (meets §150.1(c)9B)	Ceiling Insulation		R 38	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 30	R 38	R 38	R 38	R 38	R 38	R 38
			Radiant Barrier		NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR

CONTINUED: TABLE 150.1-A COMPONENT PACKAGE-A STANDARD BUILDING DESIGN (CONTINUED)

				Climate Zone															
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
HVAC SYSTEM	**Space Heating**[11]	**Electric-Resistance Allowed**		No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
		If gas, AFUE		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN
		If Heat Pump, HSPF[9]		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN
	Space cooling	**SEER**		MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN
		Refrigerant Charge Verification or Fault Indicator Display		NR	REQ	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR
		Whole House Fan[10]		NR	NR	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR	NR
	Central System Air Handlers	**Central Fan Integrated Ventilation System Fan Efficacy**		REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ
	Ducts[12]	**Roof/Ceiling Options A & B**	Duct Insulation	R-8	R-8	R-6	R-8	R-6	R-6	R-6	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
			§150.1(c)9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Roof/Ceiling Option C	Duct Insulation	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6
			§150.1(c)9B	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ
Water Heating	**All Buildings**			System Shall meet Section 150.1(c)8															

2.3 Summary of Proposed Changes to Code Documents

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

2.3.1 Standards Change Summary

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

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

TABLE 150.1-A COMPONENT PACKAGE-A STANDARD BUILDING DESIGN: The proposed code change increases the Option A and B insulation R-value prescriptive requirements for certain climate zones. The existing Table 150.1-A is expanded to more thoroughly convey differences in the prescriptive insulation requirements between single family and low-rise multifamily buildings.

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

Section 150.2(a)1Aiii is added to clarify that the prescriptive requirements for additions greater than 700 ft^2 would not change from the 2016 prescriptive requirements.

2.3.2 Reference Appendices Change Summary

The HPA measure is associated with the quality insulation installation (QII) measure, which is also a proposed prescriptive requirement for the 2019 Title 24, Part 6 update. As part of the refinement of the HPA below-deck measure, the Statewide CASE Team is proposing modifications and enhancements to section 3.5 of the Residential Reference Appendices to clarify QII inspection procedures. Proposed code language changes related to this can be found in the QII CASE Report.

2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary

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

SECTION 2 – The Proposed Design and Standard Design

2.5.6.1 (Ceilings Below Attics): The proposed change increases the above and below deck insulation requirements.

2.2.3 (PV Credit): The Statewide CASE Team's understanding is that the Energy Commission will eliminate the PV Credit available under the 2016 Title 24, Part 6 code as outlined in section 2.2.3.

2.3.4 Compliance Manual Change Summary

The proposed code change modifies Section 3.6.2.1: Roof/Attic of the Residential Compliance Manual, which covers new construction prescriptive requirements related to HPA.

2.3.5 Compliance Documents Change Summary

The compliance documents related to specification of below-deck insulation configuration (CF2R-ENV-03-E).

2.4 Regulatory Context

2.4.1 Existing Title 24, Part 6 Standards

HPA is already prescriptively required under Title 24, Part 6. The proposed measure would be an enhancement of the existing prescriptive requirement. See Section 2.2 for a summary of existing Title 24, Part 6 requirements.

2.4.2 Relationship to Other Title 24 Requirements

The HPA measure provides specifications that encompass the performance of attics and HVAC ducts. Current HPA QII criteria for below-deck batt insulation is not clearly defined in the Residential Reference Appendices. In that regard, this measure is related to QII. Proposed modifications to the HERS inspection procedures can be found in the QII CASE Report.

2.4.3 Relationship to State or Federal Laws

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

2.4.4 Relationship to Industry Standards

The 2015 International Energy Conservation Code (IECC) does not address HPA. The issues of ducts in attics in the 2015 IECC are prescriptively addressed by requiring R-8 supply ducts, R-38 ceiling insulation (for much of California), mandatory duct sealing to a maximum of less than or equal to 4 cubic feet per minute (4CFM25) for every100 square feet of conditioned floor area when tested at a pressure of 25 Pascals (approximately equivalent to 6 percent duct leakage for a 3.5 ton system on a 2,100 square foot house), and an air handler with air leakage of less than or equal to 2 percent of design air flow rate).

2.5 Compliance and Enforcement

The Statewide CASE Team collected input during the stakeholder outreach process on what compliance and enforcement issues may be associated with these measures. This section summarizes how the proposed code change would modify the code compliance process. Appendix B presents a detailed description of how the proposed code changes could impact various market actors. When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced.

This code change proposal would primarily affect buildings that use either the prescriptive or performance approach to compliance. The key steps and changes to the compliance process are summarized below:

- **Design Phase**: Some HPA designs would require that architects, designers, and structural engineers develop new details and specifications to be provided in design drawings. These may include, but are not limited to, revised structural calculations for above deck insulating systems, insulation soffit details related to baffling, construction details related to integrating ducts in conditioned space, attic venting details, etc. For builders who have gained experience with HPA strategies prior to the potential 2019 Title 24, Part 6 adoption, these impacts would be minimal; however, for builders who are new to HPA implementation, there will likely be a learning curve depending upon their subcontractors' familiarity with the implemented strategy. The expectation is that by the time of 2019 Title 24, Part 6 standards take effect, the building industry as a whole will have acquired additional construction experience with HPA and have made determinations as to preferred practices.

- **Permit Application Phase**: There are no anticipated changes to the existing permit application phase process as the 2019 proposal is incremental in nature.
- **Construction Phase**: The builder would continue to provide necessary coordination between the subcontractors involved in implementing HPA or ducts in conditioned space strategies. Whether the builder has experience with HPA under the 2016 code cycle would determine whether there would be a learning curve for implementation. In addition, the HPA approach selected (Option A, B, or C) impacts whether additional labor is required. In general, above-deck strategies (Option A) are less likely to result in any incremental coordination, while below-deck strategies (Option B) and ducts in conditioned space (Option C) would likely require additional coordination during the construction process, as the builder initially implements the HPA strategy.
- **Inspection Phase**: Improved QII inspection procedures are proposed (see QII CASE Report) to provide better support to the HERS industry in terms of field verification procedures. New training and documentation will be developed to support this effort.

Since HPA is a prescriptive requirement under 2016 Title 24, Part 6 Standards, there are no anticipated incremental challenges to compliance and enforcement with the 2019 proposal in any of the phases identified above.[4] There would be no significant burden placed on any market actor as it relates to compliance and enforcement.

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

3. MARKET ANALYSIS

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

3.1 Market Structure

As of mid 2017, the vast majority of new production homes being constructed in California featured conventional attic/roof construction techniques with uninsulated roof decks, primarily tile roofing, R-30 or greater insulation at the ceiling level, R-6 or R-8 attic duct work, and mechanical HVAC equipment installed in the attic. This basic design approach has been the predominant new construction configuration over several decades in California.

The HPA concept arose in the last five years as an alternate approach to transition the construction industry toward the ultimate goal of achieving either ducts in conditioned space or non-ducted delivery systems to improve system operating efficiencies by significantly reducing duct conduction and leakage

[4] As of mid 2017, the California residential construction community is just starting to transition towards assessing and integrating HPA or alternative trade-off measures into their construction processes.

losses. In recent years, some builders have been exploring alternative approaches to improving the performance of their homes through the construction of unvented or sealed attics.

During the 2013 code cycle, the Energy Commission and California utilities started the effort to promote HPA and ducts in conditioned space, as well as extend research into non-ducted space conditioning systems. This included incentive programs through the CAHP, utility research activities (Pacific Gas & Electric Company 2015a, Pacific Gas & Electric Company 2015b, Pacific Gas & Electric Company 2016a, Pacific Gas & Electric Company 2016b, Southern California Edison 2014) and 2015 Electric Program Investment Charge (EPIC) funding for the WISE program, which is designed to transition the California new home construction industry to HPA and high performance wall (HPW) construction practices. The WISE program provides on-the-job training, offers resources from a range of vendors providing construction solutions, and works with the industry to identify a range of optimized solutions for different applications. The WISE program provides extensive resources to the building industry in terms of educational events and forums, manufacturer technical specifications and installation procedures, and case studies and reports documenting completed work. In addition to the WISE resource database, the CAHP program provides both the Master Builder Product Catalogue and the Master Builder Modeling Guidelines, which outlines product offerings and methods for modeling HPA within the Residential ACM (California Advanced Home Program 2016a, California Advanced Home Program 2016b).

A wide range of manufacturers provide products that can satisfy HPA requirements including traditional insulation manufacturers (including Owens Corning, Johns Manville, Knauf Insulation, CertainTeed, Insulfoam), spray foam manufacturers (including CertainTeed, Johns Manville, and Icynene), above-deck nail base system manufacturers (R-Max, GAF Cornell, and Premier SIPS), and manufacturers supplying alternative efficient roof material solutions (including WedgeIt, GreenHybrid Roofing, and EternaTile). Note that this list is not a comprehensive list of all manufacturers providing HPA product options, but is intended to reflect the wide range of existing offerings. Such a broad array of product offerings suggests an active market with considerable competition and innovation.

Vented attics are the primary focus of this report and the proposed changes to Table 150.1-A. Unvented attics are currently represented in the ACM as an alternative compliance option. In the unvented attic approach, the entire attic space becomes a semi-conditioned space as all below-roof deck and gable end wall surfaces are air sealed and insulated using either open cell spray foam insulation,[5] fiberglass batts under the roof deck and on the gable end walls, or alternatively, blown fiberglass contained by netting.[6]

3.2 Technical Feasibility, Market Availability, and Current Practices

The construction of high performance attics in California through 2016 can be counted in the hundreds of homes. While WISE and CAHP's Master Builder program have been working aggressively to engage builders and expand implementation, the uptake to date has been relatively slow. A major factor is likely that the 2016 code which sets HPA as a prescriptive requirement has only been in place for a few months, so many builders are still working off of inventory permitted under the 2013 code. In addition, builders have been challenged with labor shortages and a wet winter, so they have been strongly focused on dealing with immediate product delivery, rather than planning ahead for the upcoming change. The Statewide CASE Team's expectation is that through the remainder of 2017 and 2018, the interest level

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[5] http://www.sprayfoam.org/technical/spfa-technical-documents

[6] http://www2.owenscorning.com/literature/pdfs/HPCA%20Installation%20Instructions.pdf

and builder participation will increase. One indication of this is feedback from one insulation contractor who had completed roughly thirty HPA homes through 2016, but expects to install HPA Option B in nearly five hundred homes in 2017.

One factor slowing HPA (and HPW) implementation is the PV Credit, which is available under the 2016 Title 24, Part 6 Standards. The 2016 code allows a PV Credit[7] that can be used when complying via the performance approach. As discussed in Section 2.2, the PV Credit can be used in the climate zones that prescriptively require high performance walls and/or high performance attics, which includes all zones with the exception of southern California coastal zones 6 and 7. The credit is capped at the magnitude of the benefit that high performance walls and attics provide in that climate zone. The minimum PV sizing requirements of 2 kWdc for single family and 1 kWdc for multifamily units, the recognized compliance benefit of the PV Credit is less than its actual benefit in terms of annual electricity generation. Nevertheless, the PV Credit gives builders the opportunity to pursue solar in lieu of these advanced measures and provides flexibility as they work towards increased familiarity and level of comfort with new construction techniques. However, the Energy Commission has indicated that sufficient market transformation activities will have occurred by the effective date of the 2019 Title 24, Part 6 Standards, and therefore the current PV Credit will no longer exist for the 2019 code cycle.

For 2016, builders must consider a range of factors including cost, marketability, building design constraints, and their comfort level with advanced envelope construction techniques in determining how to achieve compliance. As of the date of drafting this report, the Statewide CASE Team has heard a variety of perspectives from builders, contractors, energy consultants and HERS Raters suggesting that some builders will be exclusively utilizing the PV Credit, some are exploring HPA (and HPW) options, and some are looking for alternative methods of compliance (i.e., using other measures to offset the impact).

The IOUs provide builder and contractor support through various outreach activities, including the Code Readiness and Emerging Technology programs, training centers, and incentive programs. For example, Pacific Gas and Electric Company's (PG&E's) California Advanced Homes Program (CAHP) Master Builder program offered $1,000 to $4,000 per home under the 2013 Title 24, Part 6 code to builders incorporating both high performance walls and high performance attics. This 2016 code-readiness program provided consulting services and on-site training to help builders identify the most appropriate construction path for their application. Recognizing that even with adoption of the 2016 Title 24, Part 6 Standards ongoing training and support is necessary to continue the market transformation effort of high performance walls, the current PG&E CAHP continues to offer a $200 bonus for projects that incorporate HPAs that meet the 2016 Title 24, Part 6 prescriptive code.

There are no required technological advances necessary to construct high performance attics today. The basic technology and products already exist, although there is always potential for solutions that could make HPA implementation more cost-effective. Builders are currently exploring which option offers the best value for their building designs and the framing, insulation, and roofing contractors they regularly work with. These issues would be addressed as builders, architects, and their key subs gain increased experience with HPA practices.

[7] The minimum PV capacity is 2kWdc for single family homes with conditioned floor area 2,000 square feet or less and 1kWdc for multifamily units with conditioned floor area 1,000 square feet or less. For larger homes the minimum capacity increases according to the calculations presented in the Residential ACM Reference Manual (Energy Commission 2015b).

3.2.1 Above and Below Deck HPA Options

There have not been widespread concerns over HPA constructability issues; rather the market has been slow to move towards implementation. A majority of projects underway are currently pursuing the below-deck batt insulation strategy due to its lower cost and relative ease of implementation. With traditional 2x4, 24" on-center roof truss designs, the 2016 prescriptively-required Option B tile roof insulation level of R-13 can be easily installed with batts either face stapled, or faced or unfaced batts secured with supports[8] (at about 16" intervals) to maintain the batt securely against the roof deck underside. The Statewide CASE Team has heard of at least one builder installing R-15 high density batts to achieve additional HPA benefit under the performance method. For 2019, with increased HPA insulation requirements being proposed, a new issue arises as deeper below-deck batts will require a new installation approach. One option would be to design roof trusses or roof framing with a 2x6 top chord, but this adds considerable cost to the roof trusses. An alternative approach observed in the field involves use of a steel cable to form a "U" below the framing member to secure the batt with minimal compression. The Statewide CASE Team, in working with a builder on a 2019 code readiness project who implemented R-19 below-deck batts, found that the builder and insulation contractor quickly determined that using unfaced batts with the cable "support" method was the most cost-effective strategy.

One of several new system entering the market in mid-2017 promises faster installation and reduced labor. [9] Moving forward, the preferred approach and strategies could change as new products enter the market and installers and builders gain familiarity.

Above-deck options for HPA are also available. Several vendors offer nailbase systems to be installed above the roof rafters. These systems can replace the roof deck sheathing, offsetting some of the incremental cost. In addition, the current residential compliance software (California Building Energy Code Compliance software for Residential Buildings, or CBECC-Res) indicates that above-deck insulation (Option A) is more effective per-unit R-value at saving energy than below-deck options. The rigid insulation materials and panel assemblies used in these above-deck products are typically more expensive than the below-deck batt configuration.

3.2.2 Ducts in Conditioned Space

Ducts in conditioned space (DCS) represent the preferred efficiency solution for forced air HVAC systems, which represent the vast majority of current space conditioning solutions in new California homes (i.e., split systems). Significant research has been completed across the United States (U.S.) looking at implementation strategies, costs, and builder acceptance (Hoeschele, et al. 2015, Fonorow, et al. 2010, Earth Advantage Institute 2011a, Earth Advantage Institute 2011b, Bailes 2013). Unfortunately, with the exception of unvented (sealed) attic solutions, which place mechanical equipment and ductwork in "semi-conditioned" attic zones, the mainstream California production builder has largely avoided pursuing traditional DCS strategies. Part of this reluctance can be attributed to concerns over the cost of the interior mechanical closet (in terms of lost floor space), marketability, and the need for close collaboration between builder, architect, mechanical contractor, framer, drywall contractor, and insulation contractor. A recently completed study (Pacific Gas & Electric Company 2015a) presents builder experiences in implementing DCS as a demonstration project in a larger subdivision. The collaboration challenges were evident in these projects as the builders strived to integrate DCS into existing designs. Ultimately, if the industry moves toward DCS as a more

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[8] Steel cabling at 16" intervals or tension rods are two current popular securement solutions

[9] http://ecobattird.knaufinsulation.us/

mainstream strategy, the entire building and mechanical design approach would need to evolve to a place where form and function are combined early in the design process to deliver a truly integrated design approach that optimizes performance and minimizes construction challenges and costs. In the interim, HPA and unvented attic solutions represent the approach the construction industry will likely migrate towards in delivering the higher performance buildings desired for the 2019 Title 24, Part 6 Standards.

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

It is expected that builders would not be impacted significantly by any one proposed code change or the collective effect of all of the proposed changes to Title 24, Part 6. Builders could be impacted for change in demand for new buildings and by construction costs. Demand for new buildings is driven more by factors such as the overall health of the economy and population growth than the cost of construction. The cost of complying with Title 24, Part 6 requirements represents a very small portion of the total building value. Increasing the building cost by a fraction of a percent is not expected to have a significant impact on demand for new buildings or the builders' profits. As shown in Figure 1, California home prices have increased by about $300,000 in the last 20 years. In the six years between the peak of the market bubble in 2006 and the bottom of the crashing in 2012, the median home price dropped by $250,000. The current median price is about $500,000 per single family home. The combination of all single family measures for the 2016 Title 24, Part 6 Standards was around $2,700 (California Energy Commission 2015). This is a cost impact of approximately half of one percent of the home value. The cost impact is negligible as compared to other variables that impact the home value.

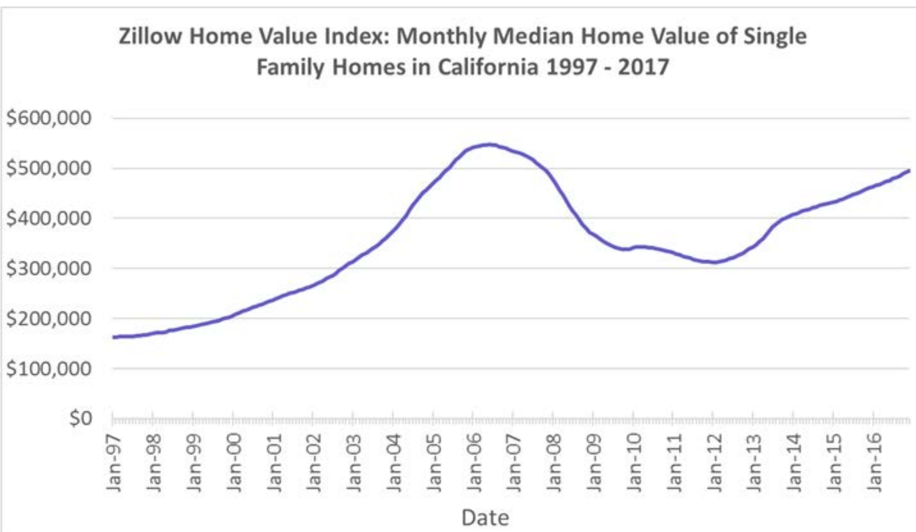

Figure 1: California median home values 1997 to 2017

Source: (Zilllow 2017)

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

Builders would need to be aware of the more stringent HPA insulation requirements and in what climate zones they apply and adjust their practices accordingly to comply. As discussed previously, there are a variety of HPA options and available products that meet the new requirements. As a prescriptive (not a mandatory) requirement, builders and their designers/energy consultants have full flexibility in pursuing the strategy that works best for their particular situation. This is especially true with the widely used performance compliance approach where combinations of above deck, below deck, roofing material, and/or alternative energy efficiency measures can be combined to meet the compliance energy budget. For example, in some specific applications, it may not be an optimal solution to install the prescriptively required insulation R-value. In that case, the design may fall short of the prescriptive HPA insulation requirement, but the Alternative Calculation Method would provide enough flexibility for the project to demonstrate compliance.

The builder is responsible for understanding the design requirements, ensuring that all subcontractors are aware of these requirements, and ultimately ensuring that all requirements are implemented per the design intent. Additional time may be required for these processes but it is not expected to have a significant impact on project schedule.

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

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Building code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials and ASHRAE 90.) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1, all market actors including building designers and energy consultants, should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team is proposing for the 2019 Title 24, Part 6 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in requirements can be met.

Architects would be responsible for developing building construction details which indicate how the HPA or DCS will be implemented. Above-deck strategies may have structural implications and would increase the roof surface height, which may impact second-floor window placement in dormers, while below-deck strategies would include specifying the details for securing insulation batts and maintaining proper ventilation through the use of eave baffles. While designers may not currently be familiar with these strategies, there are many resources available to them, both through insulation manufacturers and the WISE website.

Energy consultants would not be significantly impacted by this measure. They would continue to serve as the primary resource for designers and builders for Title 24, Part 6 compliance information. With their detailed knowledge of the Title 24, Part 6 compliance software, the energy consultant would work closely with the builder in determining the most cost-effective approach for demonstrating compliance based on builder design, project location, and construction team comfort level with alternative methods.

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

3.3.3 Impact on Occupational Safety and Health

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

One area that has received attention as the HPA measure has started to gain traction is the OSHA construction safety requirements related to fall protection.[10] Section 1669 of Cal/OSHA's Title 8 requirements relate to protections needed when working more than 15 feet above ground or floor level. These requirements may come in to effect when insulating below the roof deck, depending upon the size of the house and the roof pitch. To date, there is no clear indication of cost impacts associated with compliance, although HPA advocates suggest that any added time and expense needed to comply is minimal and represents a general construction safety cost, rather than an energy measure related cost.

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

Building owners and occupants would benefit from lower energy bills. For example, the Energy Commission estimates that on average the 2016 Title 24, Part 6 Standards would increase the construction cost by $2,700 per single family home, but the standards would also result in a savings of $7,400 in energy and maintenance cost savings over 30 years. This is roughly equivalent to an $11 per month increase in payments for a 30-year mortgage and a monthly energy cost savings of $31 per month. Overall, the 2016 Title 24, Part 6 Standards are expected to save homeowners about $240 per year relative to homeowners whose single family homes are minimally compliant with the 2013 Title 24, Part 6 requirements (California Energy Commission 2015). As discussed in Section 3.4.1, when homeowners or building occupants save on energy bills, they tend to spend it elsewhere in the economy thereby creating jobs and economic growth for the California economy. Energy cost savings can be particularly beneficial to low income occupants who typically spend a higher portion of their income on energy bills, often have trouble paying energy bills and sometimes go without food or medical care to save money for energy bills (Association, National Energy Assistance Directors 2011).

Additional benefits to the builder owner and occupants include increased interior comfort for the occupant due to reduced summer heat gains and winter heat loss resulting in greater thermal envelope integrity.

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

The proposed measure is expected to increase demand for certain insulation products and associated fasteners, supports, and cabling hardware. Manufacturers, distributors, and retailers can expect to experience requests for these products from the industry. Increased demand is expected to increase the number of products, and contribute to the optimization of solutions resulting in decrease future implementation costs.

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

3.3.6 Impact on Building Inspectors

Building inspectors and plans examiner would not be significantly impacted by this measure as this is an extension of an existing measure under the 2016 code.

[10] https://www.dir.ca.gov/title8/1669.html

3.3.7 Impact on Statewide Employment

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

3.4 Economic Impacts

The estimated impacts that the proposed code change would have on California's economy are discussed below.

3.4.1 Creation or Elimination of Jobs

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

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.[11] Title 24, Part 6 creates jobs in all three categories with a significant amount attributed to induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., non-industry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. For example, as mentioned in Section 3.3.4, the 2016 Standards are expected to save single family homeowners about $240 per year. Money saved from hundreds of thousands of homeowners over the entire life of the building would be reinvested in local businesses. Wei, Patadia, and Kammen (2010) estimate that energy efficiency creates 0.17 to 0.59 net job-years[12] per GWh saved. By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced. Using the mid-point for the energy efficiency range (0.38 net job-years per GWh saved) it is estimated that this proposed code change would result in statewide first-year savings of 3.1 GWh, and this measure will result in approximately 1.2 jobs created per first year. See Section 6.1 for statewide energy savings estimates.

An alternative analysis of the potential for job creation within the installer industry was also conducted. The proposed measure results in an estimated labor increase of two hours per "typical" single family home and one hour per multifamily dwelling unit (based on the prototype buildings applied in this analysis). On a statewide basis, this corresponds to an increase in construction employment by 70 full time employees.

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

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

3.4.2 Creation or Elimination of Businesses in California

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

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

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

Industry	NAICS Code
Residential Building Construction	2361
Insulation Contractors	23831
Roofing Contractors	238160
Asphalt Paving, Roofing, and Saturated Materials	32412
Manufacturing	32412
Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manf.	3334
Engineering Services	541330
Building Inspection Services	541350

3.4.3 Competitive Advantages or Disadvantages for Businesses in California

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the U.S. were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can be otherwise invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code changes that impact residential buildings.

3.4.4 Increase or Decrease of Investments in the State of California

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

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

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if homeowners spend their additional discretionary income on taxable items.

Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes would increase construction costs. As discussed in Section 3.3.1, however, there is no statistical evidence that Title 24, Part 6 drives construction costs or that construction costs have a significant impact on home price. Since compliance with Title 24, Part 6 does not have a clear impact on purchase price, it can follow that Title 24, Part 6 cannot be shown to impact revenues from property taxes.

3.4.5.1 Cost of Enforcement

Cost to the State

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24, Part 6 standards, including updating education and compliance materials and responding to questions about the revised 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 proposed residential changes would not impact state buildings.

Cost to Local Governments

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2019 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining, including tools, training and resources provided by the IOU codes and standards program (such as Energy Code Ace). As noted in Section 2.5 and Appendix B, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

3.4.6 Impacts on Specific Persons

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

On average, low-income families spend less on energy than higher income families, however lower income families spend a much larger portion of their incomes on energy (Association, National Energy

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

Assistance Directors 2011). Thus, low-income families are likely to benefit more from Title 24, Part 6 Standards that reduce residential energy costs.

4. ENERGY SAVINGS

4.1 Key Assumptions for Energy Savings Analysis

The energy savings analysis relied on the CBECC-Res software to estimate energy use for single family and multifamily prototype buildings. Various HPA configurations (Options A, B, and C) were evaluated and compared to a building that minimally complies with the 2016 Title 24, Part 6 Standards. The latest 2019 TDV values were used, as updated in the software on February 13, 2017.

Simulations were conducted using the 2016.2.0+ (864) version of the software and the 2016.2.0+ (626) version of the BEM Compliance Manager with minor updates described below to the Standard Design to better reflect existing conditions.

1. The Energy Commission expects to adopt the ANSI/ASHRAE Standard 62.2-2016 (ASHRAE 2016), which requires higher mechanical ventilation airflows for single family homes than the 2010 version of the Standard (the 2010 Standard is the current requirement in California). The proposed 2016 airflows have been included in both the Standard Design and the Proposed design for the single family analysis. There is no change in ventilation requirements for multifamily, therefore no adjustments were made for ventilation rates in the multifamily prototype.
2. The 2016 California Plumbing Code (CA BSC 2016c)includes requirements that all hot water pipes be insulated. The next release of CBECC-Res is expected to incorporate this requirement but the current release does not. The Standard Design and the Proposed Design have been adjusted to include pipe insulation for both the single family and the multifamily analyses.
3. The next release of CBECC-Res is expected to automatically degrade all R-19 insulation to an installed value of R-18, due to compression of the batt in a 2x6 wall cavity. This affects the Standard Design because the 0.051 U-factor requirement is modeled as a wall with R-19 cavity insulation. This was applied to the Standard Design for the single family and multifamily analyses.

All climates zones were analyzed using the CBECC-Res compliance software, but the focus was on Climate Zones 4, and 8 through 16, since the 2016 Statewide CASE Team analysis found that the HPA requirement (R-13 for Option B tile roof) was not cost-effective in the other six climate zones, which are the milder, non-cooling climate zones.

The ACM's assumption for "Standard Design" attic construction (California Energy Commission 2015) include the following:

- Hipped roof construction with 2x4, 24" on-center roof truss design.
- Roof pitch equal to the Proposed Design (nominally five in twelve pitch).
- Roof area distributed uniformly in each cardinal orientation.
- Tile roof construction (ten pounds per ft^2) with assumed R-0.85 air space under the tile.
- Ventilated attic with 1/300 venting based on the attic floor area.

In the development of this CASE Report, the Statewide CASE Team coordinated with the Energy Commission and their software development team to address a shortcoming in the ACM and CBECC-Res software, which until early March 2017 was only able to model a single below-deck insulation configuration. This legacy CBECC-Res modeling capability assumed that insulation of greater thickness than the truss top chord member depth would be recognized as additional thermal resistance below the bottom of the top chord framing. In other words, the model assumed an idealized insulation system without any insulation voids below the bottom of the top chord member. In reality, batt insulation, even full-width 24” batts installed in the 22.5” space between trusses, would result in some level of voids below the top chord framing, as well as associated convection pathways in this irregular, sloping void space. [14] The Statewide CASE Team’s field observation of two below-deck batt installation (both R-19 and R-38) indicated good quality, but not perfect coverage over the bottom of the truss member, confirming the challenges of matching the idealized insulation configuration. The Energy Commission, desiring both a conservative performance assessment and looking to reduce the level of subjectivity in the HERS Rater’s QII inspection protocols has determined that a preferred modeling approach for below-deck batts that exceed the depth of the top chord framing would assume zero insulation below the framing. Figure 2 below schematically conveys the two below-deck modeling options that are currently accessible in the 2019 research version of CBECC-Res. The “batt configuration” will be modeled with the software user input insulation R-value in the cavity area, with no added thermal resistance assumed below the top chord framing. As the batt thickness increases, the associated performance degradation of the batt configuration would also increase.

A “full framing coverage” configuration option, which is represented by mechanically applied products (e.g. open or closed cell spray foam or blown netted system approaches) would assume the full nominal R-value per inch of insulation below the 2x4 top chord framing. The full framing coverage approaches are commonly used in unvented or sealed attics and is implemented in the 2019 research version of CBECC-Res by toggling the “Thick Cavity Insulation Covers Framing” check box in the attic roof construction editor.

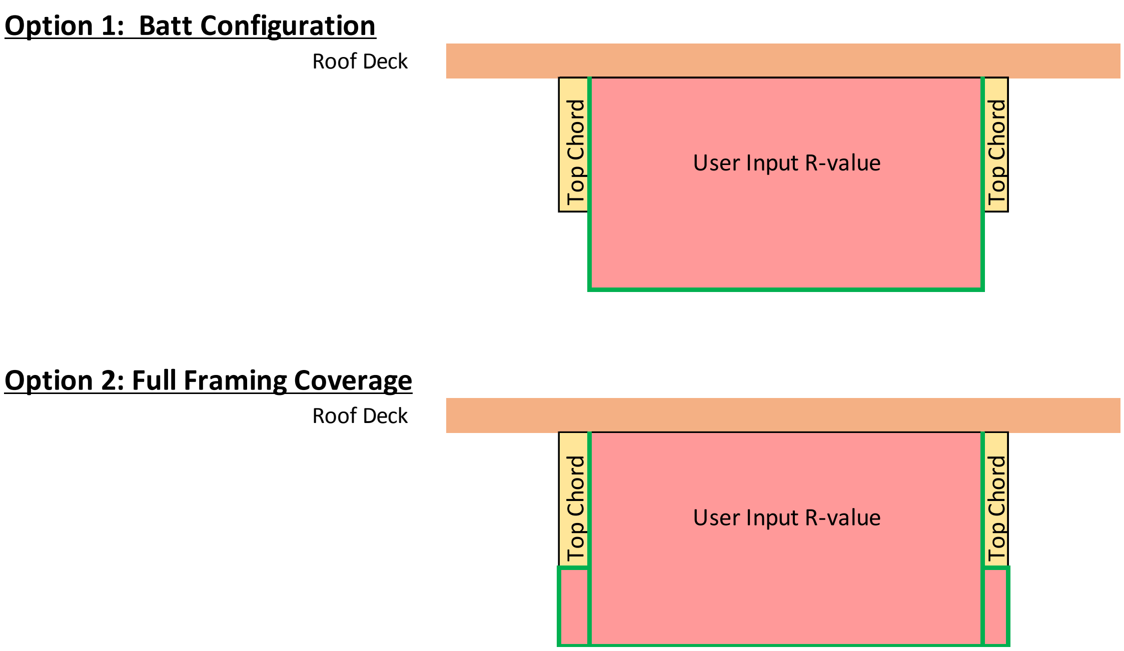

Figure 2: Schematic of below-deck configurations for insulation systems deeper than top chord framing

[14] Modeling of these irregular and inconsistent framing coverage effects is beyond the scope of a compliance simulation model.

4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, the Statewide CASE Team compared current 2016 prescriptive design practices to design practices that would comply with the proposed requirements. There is an existing Title 24, Part 6 Standard that covers the building system in question, and applies to both new construction and additions under the 2016 Title 24, Part 6 Standards. The 2016 prescriptive requirements specify R-13 below-deck insulation (for Option B, tile roof with air space) in Climate Zones 4, and 8 through16. In assessing HPA improvement opportunities, the Statewide CASE Team evaluated a range of options looking at both tile and asphalt roofing materials (distinction in the ACM being, "with" and "without" air space, respectively), and a range of above and below-deck insulation levels. This range of cases was needed to determine equivalence to the Option B below-deck batt configuration that would be deemed cost-effective for the predominant tile roof case. Runs were completed in Climate Zones 4, and 8 through 16 for roofing cases with and without air space for:

- Below-deck batt configuration: R-13 to R-27, in R-1 increments.
- Below-deck full framing coverage configuration: R-13 to R-27, in R-1 increments.
- Above deck insulation: R-7 to R-10, in R-1 increments.

In addition, runs were completed for ducts in conditioned space (Option C) with a HERS requirement for verification of duct leakage to outside[15].

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

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

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

Prototype ID	Occupancy Type	Area (square feet)	Number of Stories	Statewide Area (million square feet)
New Construction Prototype 1	Residential Single Family	2,100	1	110.6
New Construction Prototype 2	Residential Single Family	2,700	2	173.8
New Construction Prototype 3	Residential Low-Rise Multifamily	6,960	2	45.7

The energy savings from this measure varies by climate zone and between single family and multifamily building types. As a result, the energy impacts and cost-effectiveness were evaluated by climate zone and building type.

[15] The current Option C DCS configuration requires HERS verification that duct leakage to outside is less than 25 cfm under a standard 25 Pascal duct pressurization test. The ACM assumes zero leakage to outside if this test criteria is achieved. The Energy Commission and their software development team are currently evaluating whether this criteria should be changed for the 2019 Title 24, Part 6 update.

Energy savings, energy cost savings, and peak demand reductions were calculated using a TDV (Time Dependent Valuation) methodology. The latest 2019 TDV multipliers (updated February 2017) were applied in the analysis.

4.3 Per Unit Energy Impacts Results

All result tables in Sections 4 and 5 present results for both a composite single family dwelling unit (weighted by one story, two story ratio) and for the eight-unit multifamily prototype. Energy impact for each of the three prototypes are presented in Appendix D. Results reported in Sections 4 and 5 are shown for the most cost-effective HPA option with R-19 batts installed below-deck.

Energy savings and peak demand reductions per unit for the blended single family prototype (45 percent one-story, 55 percent two-story) and the multifamily eight-unit prototype (new construction) are presented in Table 6 and Table 7, respectively. Results are presented only for the ten zones with a 2016 prescriptive HPA requirement.

Blended single family "per-unit" first-year savings are projected to range from a high of 125 kilowatt-hours per year (kWh/yr) and 9 therms/year to a low of 7 kWh/yr and 1 therm/year depending upon climate zone. Demand reductions are expected to range between 0.02 kilowatts (kW) and 0.09 kW depending on climate zone. The proposed measure does reduce demand in most climate zones, however the impact is marginal and therefore the impact on demand response potential is negligible.

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

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A			
2				
3				
4	7	0.03	3	2,095
5	N/A			
6				
7				
8	16	0.05	1	1,979
9	27	0.06	2	2,595
10	30	0.05	2	2,275
11	52	0.04	4	2,988
12	24	0.06	5	3,864
13	65	0.07	4	4,491
14	46	0.05	4	3,448
15	125	0.09	1	5,577
16	14	0.02	9	2,472

Multifamily "per eight-unit building" first-year savings are projected to range from a high of 162 kWh/yr and 7 therms/year to a low of 37 kWh/yr and 0 therms/year depending upon climate zone. Demand reductions are expected to range between 0.04 kW and 0.10 kW depending on climate zone. The proposed measure does reduce demand in most climate zones, however the impact is marginal and therefore the impact on demand response potential is negligible.

Although savings for both single and multifamily are fairly modest, it is important to note that the savings baseline is based on R-13 below-deck insulation; adding incremental levels of insulation to an insulated assembly results in both diminishing energy savings impacts and reduced cost-effectiveness.

Table 7: First-Year Energy Impacts Per Building (8-Unit Multifamily) – New Construction

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A			
2				
3				
4	37	0.07	3	3,341
5	N/A			
6				
7				
8	60	0.06	1	3,341
9	71	0.07	1	3,967
10	56	0.05	2	2,993
11	83	0.07	4	5,220
12	64	0.07	5	4,594
13	106	0.09	4	6,125
14	70	0.06	4	4,176
15	162	0.10	0	6,612
16	37	0.04	7	2,923

5. Lifecycle Cost and Cost-Effectiveness

5.1 Energy Cost Savings Methodology

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

5.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings over the 30-year period of analysis are presented in Table 8 and Table 9 for single family and multifamily new construction, respectively. These are presented as the discounted present value of the energy cost savings over the analysis period. HPA prescriptive requirements for additions are not proposed to be increased beyond the 2016 level.

Single family per-unit savings for the 2,430 square foot blended prototype over the 30-year period of analysis are expected to range from a high of $965 to a low of $342 depending upon climate zone. Multifamily per-building (8 units) savings over the 30-year period of analysis are expected to range from a high of $1,144 to a low of $506 depending upon climate zone. The multifamily per-building savings are only marginally higher than the single family savings, since HPA only impacts half the units in the two-story prototype and the ACM multifamily Standard Design prescriptive assumption of ducts in conditioned space diminishes potential energy savings impacts relative to single family homes.

The TDV methodology values on-peak electricity savings more than electricity savings during non-peak periods. Energy cost savings results for the R-19 below-deck batt configuration (Option B) for each prototype are presented in Appendix D.

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

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1		N/A	
2			
3			
4	$230	$133	$362
5		N/A	
6			
7			
8	$300	$43	$342
9	$388	$61	$449
10	$311	$83	$394
11	$367	$150	$517
12	$476	$193	$668
13	$619	$158	$777
14	$451	$145	$596
15	$943	$22	$965
16	$100	$328	$428

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

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1		N/A	
2			
3			
4	$458	$120	$578
5		N/A	
6			
7			
8	$542	$36	$578
9	$638	$48	$686
10	$433	$84	$518
11	$747	$157	$903
12	$614	$181	$795
13	$903	$157	$1,060
14	$578	$144	$722
15	$1,132	$12	$1,144
16	$241	$265	$506

5.3 Incremental First Cost

The Statewide CASE Team estimated the current incremental construction costs, which represents the incremental cost of the measure if a building meeting the proposed standard were built today.

Per the Energy Commission's guidance, design costs are not included in the incremental first cost. Total costs are presented as costs to the builder. Labor costs were based on a fully loaded labor rate from RSMeans of $44/hour after applying an average California regional labor multiplier of 1.1.

Incremental first costs were estimated from interviews with contractors, builders, and manufacturers. Cost databases, such as RSMeans, were also reviewed as were information available from internet research. In addition the Statewide CASE Team used information from the 2016 HPA CASE Report (California Utilities Statewide Codes and Standards Team 2015) to inform the decision to target below-deck batt configuration as the preferred cost-effective HPA strategy. In the 2016 CASE Report, the identified costs for implementing R-13 HPA was in the range of $0.45 - $0.50 per square foot of roof deck area for most climate zones. This is considerably cheaper than above-deck nailbase options with material costs alone in the range of $1.50 per square foot for product in the range of R-7 to R-8. Although there are certainly some advantages for above-deck installation approach, the current cost situation and builder familiarity have pushed the early market HPA activities towards the below-deck batt approach.[16]

As part of the 2019 Title 24, Part 6 Standards development activity, PG&E is sponsoring related work on several code-readiness projects in an effort to work with builders interested in testing advanced measures that may become part of future code cycles or are of interest in terms of assessing emerging technologies or building practices. One of the participating projects is a builder in Porterville, California who agreed to install R-19 below-deck batt insulation in one of their homes that was completed in March 2017. The builder is currently participating in the CAHP Master Builder program and installing R-13 below deck HPA in the subdivision. The builder and his insulation contractor therefore have experience with the HPA method in multiple homes. In fact, the insulation contractor has completed below-deck batt insulations for several other builders in the Fresno area. As a requirement of participation for the code-readiness project, the builder is required to provide incremental cost data for each of the advanced measures installed. The insulation contractor's total incremental cost to the builder (including any contractor incremental labor and markup) was $.08 per square foot of roof deck area. One key aspect of the R-19 batt installation is the need to develop a saddle (as shown in the Figure 3 and Figure 4) to secure the batt without significant compression. The installer has previously experimented with various techniques, including stand-offs and cabling, and arrived at the solution shown Figure 3 (note that insulation has been moved aside in the photo to highlight the cable securement method). A fairly uniform below-deck insulation layer as shown in Figure 4 is maintained by the preferred cabling technique, with cables run at 16" intervals.

[16] Other below-deck strategies, such as the full framing coverage box netting system, present a much more finished solution relative to batts, but at a cost premium over below-deck batts as reported by two builders familiar with the product and various insulation contractors. This system and spray foam systems are most commonly implemented in sealed attic construction.

Figure 3: Example batt cabling securement method (note: insulation moved for photo).

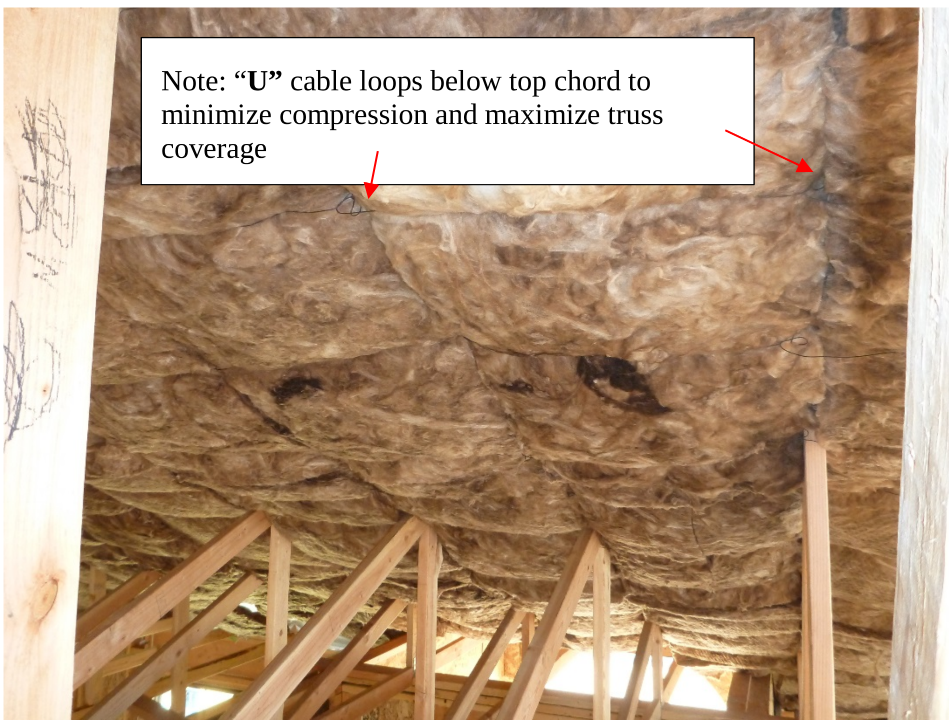

Figure 4: Example R-19 batt below-deck insulation appearance

Although the $0.08 per square foot cost represented the total incremental cost to the builder relative to the R-13 below-deck batt standard case installed in the subdivision, the Statewide CASE Team is conservatively increasing the material cost by 15 percent (to $0.093/ft^2) and adding incremental labor equal to two hours for the 2,430 square foot blended prototype (one hour additional labor per 1,050 ft^2 of roof deck area).[17] The 15 percent material cost increase assumption accommodates pricing variability and potential material increases for 2020 implementation.

Table 10 presents the assumed post-adoption incremental construction costs for the proposed measure relative to this base case for the three residential prototypes. The post-adoption incremental construction cost represents the anticipated cost assuming full market penetration of the measure as a result of the new requirements, 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.

Table 10: Incremental Costs for the Proposed Measure for Each New Construction Prototype

Measure	2,100 ft^2 Single Family Prototype	2,700 ft^2 Single Family Prototype	8-unit, 6,960 ft^2 Multifamily Prototype
R-19 Below-deck Batt HPA vs. R-13	$341	$245	$565

5.4 Lifetime Incremental Maintenance Costs

Incremental maintenance cost is the incremental cost of replacing the equipment or parts of the equipment, as well as periodic maintenance required to keep the equipment operating relative to current practices over the period of analysis. The present value of equipment and maintenance costs (savings) was calculated using a three percent discount rate (d), which is consistent with the discount rate used when developing the 2019 TDV. The present value of maintenance costs that occurs in the nth year is calculated as follows (where d is the discount rate of 3 percent):

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

The useful life of the proposed measure is expected to be the lifetime of the home or apartment. There are no anticipated maintenance requirements for high performance attics beyond those which exist for high performance attics in the 2016 Title 24, Part 6 code.

5.5 Lifecycle Cost-Effectiveness

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

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

Design costs and the incremental cost of code compliance verification were not included in the total incremental cost.

[17] Industry-wide insulation cost increases took effect in early 2017. Adding a 15 percent material cost factor is intended to accommodate some of the expected cost variability in the market.

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

Lifecycle cost-effectiveness results are presented in Table 11 and Table 12 for single family and multifamily new construction, respectively. If B/C ratios are less than one, they are highlighted in a red font.

For the 2,430 ft^2 blended single family prototype case, the proposed R-19 HPA below-deck measure demonstrates a favorable B/C ratio over the 30-year period of analysis relative to the existing assumed R-13 below-deck conditions in all the 2016 HPA Climate Zones 4, and 8 through 16. For the multifamily prototype, cost-effectiveness is slightly less favorable, and the R-19 HPA is cost-effective in zones 4, 8, 9, and 11 through 15.

Table 11: Lifecycle Cost-Effectiveness Summary per Dwelling Unit (Single Family) – New Construction

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	N/A		
2			
3			
4	$362	$283	1.28
5	N/A		
6			
7			
8	$342	$283	1.21
9	$449	$283	1.59
10	$394	$283	1.39
11	$517	$283	1.83
12	$668	$283	2.36
13	$777	$283	2.75
14	$596	$283	2.11
15	$965	$283	3.41
16	$428	$283	1.51

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) 3 percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) 3 percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if present value of proposed maintenance costs is greater than the present value of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present value costs, the B/C ratio is infinite.

Table 12: Lifecycle Cost-Effectiveness Summary Per Building (8-Unit Multifamily) – New Construction

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	N/A		
2			
3			
4	$578	$565	1.02
5	N/A		
6			
7			
8	$578	$565	1.02
9	$686	$565	1.21
10	$518	$565	0.92
11	$903	$565	1.60
12	$795	$565	1.41
13	$1,060	$565	1.88
14	$722	$565	1.28
15	$1,144	$565	2.02
16	$506	$565	0.90

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) 3 percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) 3 percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if present value of proposed maintenance costs is greater than the present value of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present value costs, the B/C ratio is infinite.

6. First-Year Statewide Impacts

6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for new construction by multiplying the per-unit savings, which are presented in Section 4.3, by the statewide new construction forecast for 2020 or expected alterations in 2020, which is presented in more detail in Appendix A. The first-year energy impacts represent the first-year annual savings from all buildings or alterations that were completed in 2020, for the climate zones where the measure is cost-effective (Climate Zones 4, and 8 through 16 for single family, and Climate Zones 4, 8, 9, and 11 through 15 for multifamily). The lifecycle energy cost savings represents the energy cost savings over the entire 30-year analysis period. The combined results are presented in Table 13 for new construction statewide impacts. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Given data regarding the new construction forecast and expected alterations in 2020, the Statewide CASE Team estimates that the proposed code change would reduce annual statewide electricity use by

3.1 GWh/yr with an associated demand reduction of 4.9 MW. Natural gas use is expected to be reduced by 0.3 million therms/yr. The energy savings for buildings constructed in 2020 are associated with a (discounted) present value energy cost savings of approximately $48 million over the 30-year period of analysis.

Table 13: Statewide Energy and Energy Cost Impacts (Combined Single Family and Multifamily) – New Construction

Climate Zone	Statewide New Construction in 2020 (units)	First-Year[a] Electricity Savings (GWh)	First-Year[a] Peak Electrical Demand Reduction (MW)	First-Year[a] Natural Gas Savings (million therms)	Lifecycle[b] Present Value Energy Cost Savings (Present Value$ million)
1	N/A				
2					
3					
4	11,283	0.07	0.23	0.03	$3.0
5	N/A				
6					
7					
8	15,100	0.19	0.53	0.01	$3.8
9	22,642	0.42	0.83	0.02	$6.4
10	18,399	0.54	0.87	0.04	$7.2
11	4,695	0.21	0.17	0.02	$2.1
12	25,438	0.52	1.22	0.10	$13.6
13	8,409	0.47	0.50	0.03	$5.6
14	4,240	0.17	0.19	0.01	$2.1
15	3,657	0.41	0.30	0.00	$3.2
16	3,188	0.05	0.06	0.03	$1.4
TOTAL	117,050	3.1	4.9	0.3	$48.4

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

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

6.2 Statewide Water Use Impacts

The proposed code change would not result in water savings.

6.3 Statewide Material Impacts

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

6.4 Other Non-Energy Impacts

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

7. Proposed Revisions to Code Language

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

7.1 Standards

The proposed measure would require updating the section of Table 150.1-A Component Package-A, which defines prescriptive HPA insulation requirements as shown below. Given that there are variations between single family and low-rise multifamily HPA requirements, the Statewide CASE Team proposes the separation of the requirements by building type. In addition, Section 150.2, which addresses additions and alterations, would require modifications to clarify that the HPA requirements for additions would remain unchanged from the 2016 prescriptive levels.

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

Table 150.1-A:

Table 14: Proposed updates to Table 150.1-A Component Package-A

Single Family Prescriptive Requirements

			Climate Zone															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Option A Continuous insulation above roof rafters	Roofing Type	No Air Space	NR	NR	NR	~~R8~~ R10	NR	NR	NR	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10
		With Air Space	NR	NR	NR	~~R6~~ R8	NR	NR	NR	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8	~~R6~~ R8
Option B Below roof deck insulation (Batt)	Roofing Type	No Air Space	NR	NR	NR	~~R18~~ R25	NR	NR	NR	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25	~~R18~~ R25
		With Air Space	NR	NR	NR	~~R13~~ R19	NR	NR	NR	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19

Multifamily Prescriptive Requirements

			Climate Zone															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Option A Continuous insulation above roof rafters	Roofing Type	No Air Space	NR	NR	NR	~~R8~~ R10	NR	NR	NR	~~R8~~ R10	~~R8~~ R10	R8	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	~~R8~~ R10	R8
		With Air Space	NR	NR	NR	~~R6~~ R7	NR	NR	NR	~~R6~~ R7	~~R6~~ R7	R6	~~R6~~ R7	~~R6~~ R7	~~R6~~ R7	~~R6~~ R7	~~R6~~ R7	R6
Option B Below roof deck insulation (Batt)	Roofing Type	No Air Space	NR	NR	NR	~~R18~~ R28	NR	NR	NR	~~R18~~ R28	~~R18~~ R28	R18	~~R18~~ R28	~~R18~~ R28	~~R18~~ R28	~~R18~~ R28	~~R18~~ R28	R18
		With Air Space	NR	NR	NR	~~R13~~ R19	NR	NR	NR	~~R13~~ R19	~~R13~~ R19	R13	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	~~R13~~ R19	R13

Section 150.2(a)1Aiii would be added to clarify existing building requirements:

HPA requirements would remain at the 2016 prescriptive levels as shown in the Table below.

			Climate Zone															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Option A Continuous insulation above roof rafters	Roofing Type	No Air Space	NR	NR	NR	**R8**	NR	NR	NR	**R8**	**R8**	**R8**	**R8**	**R8**	**R8**	**R8**	**R8**	**R8**
		With Air Space	NR	NR	NR	**R6**	NR	NR	NR	**R6**	**R6**	**R6**	**R6**	**R6**	**R6**	**R6**	**R6**	**R6**
Option B Below roof deck insulation (Batt)	Roofing Type	No Air Space	NR	NR	NR	**R18**	NR	NR	NR	**R18**	**R18**	**R18**	**R18**	**R18**	**R18**	**R18**	**R18**	**R18**
		With Air Space	NR	NR	NR	**R13**	NR	NR	NR	**R13**	**R13**	**R13**	**R13**	**R13**	**R13**	**R13**	**R13**	**R13**

7.2 Reference Appendices

The only proposed change to the Reference Appendices relates to QII inspection procedures. The reader should refer to the QII CASE Report to review proposed language changes to RA3.5.

7.3 ACM Reference Manual

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

SECTION 2 – The Proposed Design and Standard Design

2.5.6.1 Ceilings Below Attics:

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

PROPOSED DESIGN

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

STANDARD DESIGN

The Standard Design for new construction has the same ceiling below attic area as the Proposed Design. The Standard Design is a high performance attic with a ceiling constructed with 2x4 framed trusses, and insulated with the R-values specified in Section 150.1(c) and Table 150.1-A for the applicable climate zone assuming Option B with a ten pounds per square foot tile roof with an air space when the proposed roof slope is steep, and a lightweight roof when the proposed roof is low slope.

For single family dwellings, Climate Zones 1 through 3 and 5 through 7 have R-0, ~~and~~ Climate Zones 4, and 8 through 16 have R-19 insulation between the roofing rafters in contact with the roof deck. Climate Zones 1, 2, 4, and 8 through 16 have R-38 insulation on the ceiling. Climate Zones 3, and 5 through 7 have R-30 insulation on the ceiling. Climate Zones 2, 3, and 5 through 7 have a radiant barrier. Climate Zones 1, 4, and 8 through 16 have no radiant barrier.

For multifamily dwellings, Climate Zones 1 through 3 and 5 through 7 have R-0, Climate Zones 10 and 16 have R-13 insulation, and Climate Zones 4, 8, 9, and 11 through 15 have R-19 insulation between the roofing rafters in contact with the roof deck. Climate Zones 1, 2, 4, and 8 through 16 have R-38 insulation on the ceiling. Climate Zones 3, and 5 through 7 have R-30 insulation on the ceiling. Climate Zones 2, 3, 5 through 7 have a radiant barrier. Climate Zones 1, 4, and 8 through 16 have no radiant barrier.

7.4 Compliance Manuals

Chapter 3 of the Residential Compliance Manual would need to be revised as follows.

Residential Manual: Section 3.6.2.1 Roof/Attic covers new construction prescriptive requirements related to HPA.

Text changes in 3.6.2.1 A. are needed to verbally clarify the insulation requirements and equivalency for above deck and below deck cases, and for variations by climate zone, and single or multifamily building type.

Figure 3-16: Prescriptive Requirements for Roof/Ceiling Insulation (§150.1(c).1)

Strategy		How to Comply
High-Performance Ventilated Attics		
Option A	Vented attic with continuous insulation applied above the roof deck. (Figure 3-18). Ceiling insulation required separately above finished attic ceiling.	Table 150.1-A of the Energy Standards Roof Assembly Option A
Option B (Below Deck Batt)	Vented attic with below deck batt~~, spray in cellulose/fiberglass secured with netting, or SPF.~~ (Figure 3-18). Ceiling insulation required separately above finished attic ceiling.	Table 150.1-A of the Energy Standards Roof Assembly Option B
Option C	Vented attic with no insulation at roof deck. Ceiling insulation required separately above finished attic ceiling. Ducts and air handler equipment in conditioned space that is NOT a sealed attic.	Table 150.1-A of the Energy Standards Roof Assembly Option C Form: CF2R-MCH-20b

The S~~s~~tandard D~~d~~esign in the performance approach is based on Option B, as detailed in Figure 3-17, installed with a tile roof (air space).

Figure 3-17: Checklists for Prescriptive Requirements for HPVA/DCS for the Related Climate Zones

Single Family

Option A (CZ 4, 8-16)	Option B[1] (CZ 4, 8-16)	Option C (CZ 4, 8-16)
• Vented attic • R~~6~~8 (air space) or R~~8~~10 (no air space) continuous above deck rigid foam board insulation • R38 ceiling insulation • Radiant barrier • R8 duct insulation • 5% total duct leakage	• Vented attic • R~~13~~19 (air space) or R~~15~~25 (no air space) batt~~, spray in cellulose/fiberglass below roof deck secured with netting, or SPF~~ • R38 ceiling insulation • R8 duct insulation • 5% total duct leakage	• Vented attic • R30 or R38 ceiling insulation (climate zone specific) • R6 or R8 ducts (climate zone specific) • Radiant barrier • Verified ducts in conditioned space
[1] Standard Design used to set the energy budget for the Performance Approach.		

Multifamily

Option A (CZ 4, 8, 9, 11-15)	Option B[1] (CZ 4, 8, 9, 11-15)	Option C (CZ 4, 8-16)
• Vented attic • R~~6~~8 (air space) or R~~8~~10 (no air space) continuous above deck rigid foam board insulation • R38 ceiling insulation • Radiant barrier • R8 duct insulation • 5% total duct leakage	• Vented attic • R~~13~~19 (air space) or R~~15~~25 (no air space) batt~~, spray in cellulose/fiberglass below roof deck secured with netting, or SPF~~ • R38 ceiling insulation • R8 duct insulation • 5% total duct leakage	• Vented attic • R30 or R38 ceiling insulation (climate zone specific) • R6 or R8 ducts (climate zone specific) • Radiant barrier • Verified ducts in conditioned space
[1] Standard Design used to set the energy budget for the Performance Approach.		

Option A (CZ 10 and 16)	Option B[1] (CZ 10 and 16)	
• Vented attic • R6 (air space) or R8 (no air space) continuous above deck rigid foam board insulation • R38 ceiling insulation • Radiant barrier • R8 duct insulation • 5% total duct leakage	• Vented attic • R13 (air space) or R18 (no air space) batt • R38 ceiling insulation • R8 duct insulation • 5% total duct leakage	
[1] Standard Design used to set the energy budget for the Performance Approach.		

7.5 Compliance Documents

The Statewide CASE Team proposes changes to the CF2R-ENV-03E compliance document to separate Roof Deck Insulation from Ceiling Insulation.

CERTIFICATE OF INSTALLATION CF2R-ENV-03-E CF2R-ENV-03-E Insulation Installation (Page 1 of 5)		
Project Name:	Enforcement Agency:	Permit Number:
Dwelling Address:	City:	Zip Code:

[sections of document omitted]

A. Roof Deck Insulation

01	02	03	04	05	06	07	08	09	10	11
I.D.	Manufacturer & Brand	Assembly/ Framing Material	Thickness (inches)	Framing Size & Spacing	Insulation Type	ESR Number	Core/Cavity Insulation R-value	Insulation Depth (inches)	Above Roof Deck Insulation R-value	Below Roof Deck insulation R-Value

B. ~~A. Roof/~~Ceiling Insulation

01	02	03	04	05	06	07	08	09	10
I.D.	Manufacturer & Brand	Assembly/ Framing Material	Thickness (inches)	Framing Size & Spacing	Insulation Type	ESR Number	Core/Cavity Insulation R-value	Insulation Depth (inches)	Continuous Insulation R-value

[sections of document omitted]

J. Roof Deck Insulation	
01	Roof deck insulation extends to the outside edge of the exterior top plates and is flush against any ventilation dams/baffles.
02	Roof deck insulation should not reduce net free ventilation area at eave vents.
03	Insulation is in direct contact with the roof deck, so there are no gaps between the roof deck and the insulation.
04	If tension rods or cabling is used to install batts, support is no further than 8" from end of batt and maximum interval between supports is 16".
05	Batt insulation supports must not compress insulation
06	Roof deck insulation shall not provide any obstruction to roof deck vents;
07	Insulate soffits by adding an air barrier and covering with insulation, or insulate the entire soffit including floor and walls.
08	For chimneys and flues, the insulation is in contact with the sheet metal collar.
09	
10	Batt insulation is cut to fit around cross bracings and truss webs in the attic.
The responsible person's signature on this compliance document affirms that all applicable requirements in this table have been met.	

8. BIBLIOGRAPHY

ASHRAE. 2016. "ANSI/ASHRAE Standard 62.1-2016. Ventilation for Acceptable Indoor Air Quality."

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

Bailes, Allison A. III. 2013. "How to Get Your Ducts Inside teh Building Enclosure." *Green Building Advisor.* http://www.greenbuildingadvisor.com/blogs/dept/building-science/how-get-your-ducts-inside-building-enclosure.

Beal, D, J McIlvaine, K Fonorow, and E Martin. 2011. *Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts.* US DOE Building America Program. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-385-11.pdf.

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

CA BSC. 2016c. "2016 California Plumbing Code. California Code of Regulations Title 24, Part 5." Building Standards Comission. htpp://www.bsc.ca.gov/Codes.aspx.

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

California Advanced Home Program. 2016b. "CAHP Master Builder Modeling Guidelines." Accessed February 15, 2017. http://cahp-pge.com/wp-content/uploads/2016/08/2013-Title-24-CAHP-Master-Builder-Modeling-Guidebook-V5-Formatted.pdf.

California Advanced Home Program. 2016a. "CAHP Master Builder Product Catalogue." Accessed February 15, 2017. http://cahp-pge.com/wp-content/uploads/2016/09/CAHP-Master-Builder-Product-Catalogue.pdf.

California Energy Commission. 2015. "2016 Alternative Calculation Method Approval Manual for the 2016 Building Energy Efficiency Standards." http://www.energy.ca.gov/2015publications/CEC-400-2015-039/CEC-400-2015-039-CMF.pdf.

California Energy Commission. 2015. "2016 Building Energy Efficiency Standards: Frequently Asked Questions." Accessed February 2, 2017. http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/2016_Building_Energy_Efficiency_Standards_FAQ.pdf.

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

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

California Utilities Statewide Codes and Standards Team. 2015. "Residential Ducts in Conditioned Space/ High Performance Attics." http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/dru_title24_parts_01_06/2016%20T24%20CASE%20Report%20-%20HPA_-_DCS_2015-02-06_TN-74503.pdf.

Earth Advantage Institute. 2011a. *Building with Ducts in Conditioned Spaces.* Northwest Energy Efficiency Alliance. Accessed July 3, 2017. https://ductsinside.files.wordpress.com/2011/04/ducts-inside-training-manual.pdf.

—. 2011b. *Ducts Inside.* Accessed July 3, 2017. http://www.ductsinside.org/.

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

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

Fonorow, K, D Jenkins, S Thomas-Rees, and S Chandra. 2010. *Low Cost Interior Duct Systems for High Performance Homes in Hot Climates.* Florida Solar Energy Center. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-451-10.pdf.

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

Hoeschele, M, R Chitwood, A German, and E Weitzel. 2015. "High-Performance Ducts in Hot-Dry Climates." US DOE Building America Program. http://www.nrel.gov/docs/fy15osti/64366.pdf.

Pacific Gas & Electric Company. 2015a. *Evaluation of Ducts in Conditioned Space in New California Homes.* Davis Energy Group and Chitwood Energy. http://www.etcc-ca.com/reports/evaluation-ducts-conditioned-space-new-california-homes.

Pacific Gas & Electric Company. 2016b. *Field Assessment of Residential Radiant Ceiling Panel Space Conditioning Systems.* Davis Energy Group, Inc. http://etcc-ca.com/reports/field-assessment-residential-radiant-ceiling-panel-space-conditioning-systems.

Pacific Gas & Electric Company. 2015b. *Initial Assessment of High Performance Attics in New California Homes.* Davis Energy Group and Chitwood Energy. http://www.etcc-ca.com/reports/initial-assessment-high-performance-attics-new-california-homes.

Pacific Gas & Electric Company. 2016a. *Variable Compressor Speed Heat Pumps.* Bruce Wilcox, Proctor Engineering, and Chitwood Energy. http://www.etcc-ca.com/reports/variable-compressor-speed-heat-pumps.

Southern California Edison. 2014. "Zero Net Energy New Home." http://www.etcc-ca.com/reports/et11sce2030-zne-new-home?dl=1486697336 .

State of California. 2003. "Energy Action Plan." California Power Authority, California Energy Commission, and California Public Utilities Commission. http://www.energy.ca.gov/energy_action_plan/2003-05-08_ACTION_PLAN.PDF.

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

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

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

Wei, Max, Shana Patadia, and Daniel M. Kammen. 2010. "Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?" *Energy Policy* 38: 919-931.

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

Zilllow. 2017. "Zillow Home Value Index: Single-Family Homes Time Series ($)." Accessed February 20, 2017. https://www.zillow.com/research/data/#median-home-value.

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Appendix A: STATEWIDE SAVINGS METHODOLOGY

The projected new residential construction forecast that would be impacted by the proposed code change in 2020 is presented in Table 15. All impacts for the proposed code change proposal are associated with newly construction buildings as no changes from 2016 are proposed for HPA prescriptive requirements for additions and alterations.

The Statewide CASE Team estimated statewide impacts for the first year that new single family and multifamily buildings comply with the 2019 Title 24, Part 6 Standards by multiplying per-unit savings estimates by statewide construction forecasts that the California Energy Commission Demand Analysis Office provided. The construction forecast from the Energy Commission presented annual new construction estimates for single family and multifamily dwelling units by forecast climate zones (FCZ). The Statewide CASE Team converted estimates from FCZ, which are not used for Title 24, Part 6, to building standards climate zones (BSCZ) using a conversion factors that the Energy Commission provided. The conversion factors, which are presented in Table 16, represent the percentage of dwelling units in a FCZ that are also in a BSCZ. For example, looking at the first column of conversion factors in see Table 16, 22.5 percent of the homes in FCZ 1 are also in BSCZ 1 and 0.1 percent of homes in FCZ 4 are in BSCZ 1. To convert from FCZ to BSCZ, the total forecasted construction in each FCZ was multiplied by the conversion factors for BSCZ 1, then all homes from all FCZs that are found to be in BSCZ 1 are summed to arrive at the total construction in BSCZ 1. This process was repeated for every climate zone. See Table 17 for an example calculation to convert from FCZ to BSCZ. In this example, BSCZ 1 is made up of homes from FCZs 1, 4, and 14.

After converting the statewide construction forecast to BSCZs, the Statewide CASE Team made assumptions about the percentage of buildings in each climate zone that will be impacted by the proposed code change. Assumptions are presented in Table 15.

Table 15: Projected New Residential Construction Completed in 2020 by Climate Zone[a]

Building Climate Zone	Single Family Buildings					Multifamily Dwelling Units[b]				
	Total Buildings Completed in 2020	Percent of Total Construction in Climate Zone	Percent of New Buildings Impacted by Proposal	Buildings Impacted by Proposal	Percent of Total Impacted by Proposal in Climate Zone	Total Dwelling Units Completed in 2020	Percent of Total Construction in Climate Zone	Percent of New Dwelling Units Impacted by Proposal	Dwelling Units Impacted by Proposal	Percent of Total Impacted by Proposal in Climate Zone
1	465	0.4%	0%	0	0.0%	111	0.2%	0%	0	0.0%
2	3,090	2.6%	0%	0	0.0%	1,582	3.0%	0%	0	0.0%
3	11,496	9.8%	0%	0	0.0%	8,432	16.1%	0%	0	0.0%
4	7,435	6.4%	100%	7,435	8.4%	3,848	7.3%	100%	3,848	13.4%
5	1,444	1.2%	0%	0	0.0%	747	1.4%	0%	0	0.0%
6	6,450	5.5%	0%	0	0.0%	3,379	6.4%	0%	0	0.0%
7	5,779	4.9%	0%	0	0.0%	3,939	7.5%	0%	0	0.0%
8	9,948	8.5%	100%	9,948	11.3%	5,153	9.8%	100%	5,153	18.0%
9	12,293	10.5%	100%	12,293	13.9%	10,350	19.7%	100%	10,350	36.1%
10	18,399	15.7%	100%	18,399	20.8%	4,191	8.0%	0%	0	0.0%
11	3,947	3.4%	100%	3,947	4.5%	747	1.4%	100%	747	2.6%
12	19,414	16.6%	100%	19,414	22.0%	6,023	11.5%	100%	6,023	21.0%
13	7,034	6.0%	100%	7,034	8.0%	1,375	2.6%	100%	1,375	4.8%
14	3,484	3.0%	100%	3,484	3.9%	756	1.4%	100%	756	2.6%
15	3,203	2.7%	100%	3,203	3.6%	454	0.9%	100%	454	1.6%
16	3,188	2.7%	100%	3,188	3.6%	1,441	2.7%	0%	0	0.0%
Total	**117,069**	**100.0%**		**88,344**	**100.0%**	**52,528**	**100%**		**28,706**	**100%**

Source: Energy Commission Demand Analysis Office

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

b. Includes high-rise and low-rise multifamily construction.

Table 16: Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ) Conversion Factors

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

Table 17: Converting from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ) – Example Calculation

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

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

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

Table 18 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated.

The proposed measure does not present any significant challenges to compliance and enforcement. The compliance process generally fits within the current work flow of market actors, although some new tasks would be required (see Table 18). Market actors would continue to coordinate and collaborate with the same actors with whom they currently engage. There would not be any new documentation practices required, such as new compliance document.

From the date of drafting this report, it is clear that current and expanded training offerings would be needed in the future to help the designers and implementers acquire knowledge and familiarity with the HPA approach. As builders and their subcontractors gain experience with different methods and installation approaches, improved techniques would be developed. This is clearly a measure that is still being evaluated and adopted, since the 2016 Title 24 Standards were adopted very recently and many builders are still working off of permits secured under the 2013 code.

However, the new procedures utilize materials and skills with which installers have familiarity and any required training is expected to be minimal. The new procedures may require a small amount of additional labor time during installation, depending upon the installation strategy.

Table 18: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) in Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Builder	• Coordinate with design team & trades (e.g., DCS integration could involve HVAC, truss manufacturer, framer, and insulation contractor • Ensure construction superintendents know all the requirements • Schedule inspections & post forms onsite	• Meet project budgets & schedule • Minimal inspection failures • Minimal paperwork required • Owner satisfied • No warranty issues	• Improved HPA documentation would provide new information and clarity on HPA installation details, options, and QII inspection methods • Would require more builders and their subs to be aware of QII requirements • Streamline coordination between subs on required implementation • Help to refine installation details based on improved HERS inspection criteria	• Revise compliance document to streamline HERS verification step

Market Actor	Task(s) in Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Architect/ designer	• Identify any application issues (i.e., climate) related to HPA design, as well as relevant requirements • Verify proposed HPA specification meets all code requirements • Develop required construction details for proposed HPA implementation approach • Coordinate with key subs, as needed. For example, DCS integration involves HVAC, truss manufacturer, framer, and insulation contractor • Provide correction comments, if necessary	• Balances form/function to satisfy owner desires • Plans completed to concisely specify HPA requirements and installation details • Meet project budgets • Quickly and easily determine requirements based on scope • Quickly and easily determine if plans/ specs match forms • Quickly and easily provide correction comments to resolve any issues	• Need to verify new calculations are compliant and match plans • Designer expertise would improve as industry experience with HPA increases, resulting in enhanced training opportunities and designer skill	• Enhanced training materials and Energy Code Ace content to streamline process
Title-24 consultant	• Confirm data on plans is compliant • Perform required calculations to confirm compliance • Provide feedback on the energy impact of HPA approach on compliance • Ensure builder is aware of code requirements	• Project team is clearly aware of requirements • Energy goals are met • Minimal plan check comments • Modeling can be completed in a straightforward and consistent manner (no code ambiguity)	• Improved clarity on HPA options and details should simplify process	• Modeling software would need to be updated to enhance modeling capabilities to reflect alternative configurations

Market Actor	Task(s) in Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Work Flow	Opportunities to Minimize Negative Impacts of Compliance Requirement
Subcontractors	• Install product/ components to meet requirements • Coordinate, as needed with other trades to ensure work does not negatively impact others	• Meet builder's schedule • Coordinate work activities with other subs to optimize implementation • Minimal inspection failures & callbacks • Minimal paperwork required • Finish within budget	• Added clarity for subcontractors with increased HPA experience and better industry training and tools • Improved clarity on HPA options and details should simplify process	• Improved vendor information on HPA details and specifications • Training opportunities building on 2016 HPA implementation experiences
Building inspector/Plans Examiner	• Understand code requirements and verify they are met • Verify that CF-1R is consistent with building plans and meets compliance criteria for local jurisdiction • Verify that all paperwork is in order and CF-2R and CF-3Rs are signed off and certified • Sign occupancy permit	• Minimal paperwork • No additional time needed to demonstrate compliance	• None	• None
HERS Rater	• Review CF2Rs • Make sure parties are aware of requirements • Verify QII is being met • Communicate any inspection issues • Submit CF-3R's	• Project meets QII requirements • Minimal inspection failures & callbacks • Minimal paperwork needed • Maintain positive relationships with team	• Help to refine installation details based on improved HERS inspection criteria	• Revise compliance document to streamline HERS verification step

Appendix C: PROTOTYPE DETAILS

Following are details on the residential prototypes applied in this analysis. Table 19 is a re-creation of the table in Section 4.2. Table 20 provides details on the CBECC-Res modeling inputs.

Table 19: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype ID	Occupancy Type (Residential, Retail, Office, Other)	Area (square feet)	Number of Stories	Statewide Area (million square feet)
New Construction Prototype 1	Residential Single Family	2,100	1	110.6
New Construction Prototype 2	Residential Single Family	2,700	2	173.8
New Construction Prototype 3	Residential Low-Rise Multifamily	6,960	2	45.7

Table 20: Prototype Details

Item	Description	Unit	Single Family New Construction Prototype 1	Single Family New Construction Prototype 2	Multifamily New Construction Prototype 3
1	Number of Dwelling Units		1	1	8
2	Floor Area	Square Feet	2,100	2,700	6,960
3	Slab Perimeter	Linear Feet	162	128	292
4	Wall Area	Square Feet	1,018	2,130	3,760
5	Wall Area Between House and Garage	Square Feet	250	250	0
6	Wall Area Between House and Attic	Square Feet	0	42	0
7	Window Area	Square Feet	420	540	1,044
8	Roof Deck Area	Square Feet	2,520	1,740	4,176
9	Door Area	Square Feet	20	20	160
10	Door Area Between House and Garage	Square Feet	20	20	0

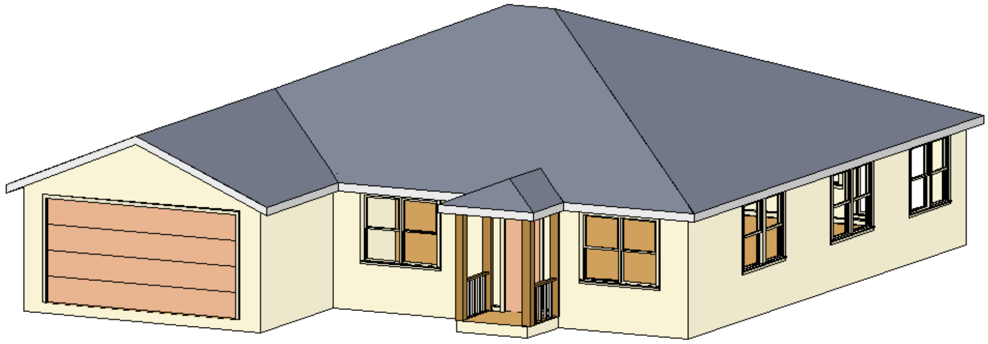

Figure 5: 2,100 ft^2 single family prototype configuration

Figure 6: 2,700 ft^2 single family prototype configuration

Figure 7: 6,960 ft^2 multifamily eight-unit building prototype configuration

Appendix D: ENERGY AND COST-EFFECTIVENESS RESULTS BY PROTOTYPE

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

Per-Unit Energy Impacts Results

Energy savings and peak demand reductions for the three residential new construction prototypes are presented in Table 21, Table 22, and Table 23

Table 21: First-Year Energy Impacts Per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A			
2				
3				
4	7	0.02	4	2,016
5	N/A			
6				
7				
8	15	0.06	1	2,121
9	27	0.06	2	2,730
10	31	0.05	2	2,415
11	58	0.06	5	4,494
12	24	0.07	6	3,801
13	69	0.07	5	4,767
14	49	0.06	4	3,801
15	131	0.10	1	5,859
16	14	0.01	10	2,688

Table 22: First-Year Energy Impacts Per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A			
2				
3				
4	8	0.03	3	2,160
5	N/A			
6				
7				
8	16	0.05	1	1,863
9	27	0.06	1	2,484
10	29	0.04	2	2,160
11	48	0.02	3	1,755
12	25	0.05	4	3,915
13	61	0.07	4	4,266
14	43	0.05	3	3,159
15	121	0.09	1	5,346
16	15	0.02	8	2,295

Table 23: First-Year Energy Impacts Per-Building – 8 Unit Multifamily Prototype

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	N/A			
2				
3				
4	37	0.07	3	3,341
5	N/A			
6				
7				
8	60	0.06	1	3,341
9	71	0.07	1	3,967
10	56	0.05	2	2,993
11	83	0.07	4	5,220
12	64	0.07	5	4,594
13	106	0.09	4	6,125
14	70	0.06	4	4,176
15	162	0.10	0	6,612
16	37	0.04	7	2,923

Energy Cost Savings Results

Per-unit energy cost savings over the 30-year period of analysis are presented in Table 24, Table 25 and Table 26 for the three residential new construction prototypes.

Table 24: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	N/A		
2			
3			
4	$196	$152	$349
5	N/A		
6			
7			
8	$312	$54	$367
9	$400	$73	$472
10	$320	$98	$418
11	$592	$185	$777
12	$429	$229	$658
13	$639	$185	$825
14	$483	$174	$658
15	$988	$25	$1,014
16	$91	$374	$465

Table 25: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	N/A		
2			
3			
4	$257	$117	$374
5	N/A		
6			
7			
8	$290	$33	$322
9	$378	$51	$430
10	$304	$70	$374
11	$182	$121	$304
12	$514	$163	$677
13	$603	$135	$738
14	$425	$121	$547
15	$906	$19	$925
16	$107	$290	$397

Table 26: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per-Building – 8 Unit Multifamily Prototype

Climate Zone	30-Year TDV Electricity Cost Savings (2020 Present Value $)	30-Year TDV Natural Gas Cost Savings (2020 Present Value $)	Total 30-Year TDV Energy Cost Savings (2020 Present Value $)
1	N/A		
2			
3			
4	$458	$120	$578
5	N/A		
6			
7			
8	$542	$36	$578
9	$638	$48	$686
10	$433	$84	$518
11	$747	$157	$903
12	$614	$181	$795
13	$903	$157	$1,060
14	$578	$144	$722
15	$1,132	$12	$1,144
16	$241	$265	$506

Lifecycle Cost-Effectiveness

Results per-unit lifecycle cost-effectiveness analyses are presented in Table 27, Table 28, and Table 29 for the three residential new construction prototypes.

Table 27: Lifecycle Cost-Effectiveness Summary Per Dwelling Unit – 2,100 Square Foot Single Family Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	N/A		
2			
3			
4	$349	$341	1.02
5	N/A		
6			
7			
8	$367	$341	1.08
9	$472	$341	1.39
10	$418	$341	1.23
11	$777	$341	2.28
12	$658	$341	1.93
13	$825	$341	2.42
14	$658	$341	1.93
15	$1,014	$341	2.97
16	$465	$341	1.36

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) 3 percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) 3 percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if present value of proposed maintenance costs is greater than the present value of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present value costs, the B/C ratio is infinite.

Table 28: Lifecycle Cost-Effectiveness Summary Per Dwelling Unit – 2,700 Square Foot Single Family Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	N/A		
2			
3			
4	$374	$235	1.59
5	N/A		
6			
7			
8	$322	$235	1.37
9	$430	$235	1.83
10	$374	$235	1.59
11	$304	$235	1.29
12	$677	$235	2.88
13	$738	$235	3.14
14	$547	$235	2.33
15	$925	$235	3.94
16	$397	$235	1.69

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) 3 percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) 3 percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if present value of proposed maintenance costs is greater than the present value of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present value costs, the B/C ratio is infinite.

Table 29: Lifecycle Cost-Effectiveness Summary Per-Building – 8 Unit Multifamily Prototype

Climate Zone	Benefits TDV Energy Cost Savings + Other Present Value Savings[a] (2020 Present Value $)	Costs Total Incremental Present Value Costs[b] (2020 Present Value $)	Benefit-to-Cost Ratio
1	N/A		
2			
3			
4	$578	$565	1.02
5	N/A		
6			
7			
8	$578	$565	1.02
9	$686	$565	1.21
10	$518	$565	0.92
11	$903	$565	1.60
12	$795	$565	1.41
13	$1,060	$565	1.88
14	$722	$565	1.28
15	$1,144	$565	2.02
16	$506	$565	0.90

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) 3 percent rate. Other present value savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if present value of proposed maintenance costs is less than the present value of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement, and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) 3 percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes present value of maintenance incremental cost if present value of proposed maintenance costs is greater than the present value of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental present value costs, the B/C ratio is infinite.