CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Results Report – Residential Ducts in Conditioned Space / High Performance Attics

Measure Number: 2016-RES-ENV1-F

Residential Envelope

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team September 2015

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1. PREFACE

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE) and Southern California Gas Company (SoCalGas) – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies. The code change proposals presented in this report are now included in the 2016 Building Energy Efficiency Standards.

2. EXECUTIVE SUMMARY

2.1 Measure Description

The measure consists of two alternatives for accomplishing improved building thermal envelope and reduced HVAC distribution losses in residential buildings. These two approaches will have similar energy impacts on the building.

- **High Performance Attics** (HPA) implements measures that minimize temperature difference between the attic space and the conditioned air being transported through ductwork in the attic.
- **Ducts in Conditioned Space** (DCS), locates ducts and air handlers in the building's thermal and air barrier envelope. Installing ductless systems meets the DCS requirement.

The proposed measures add or modify mandatory and prescriptive requirements related to attic, roof, air handler, and ducts in residential buildings. The proposed measures modify compliance options for ductless systems and add or modify modeling procedures for all of the above measures in the performance method.

This proposal results in modifications to Sections 100.1, 150.1, and 150.2 of the Title 24 Building Energy Efficiency Standards. The proposal also results in changes to Reference Appendices RA2, RA3, and JA4. CEC adopted the 2016 Standards and Reference Appendices on June 10, 2015.

The compliance manuals and compliance forms will be updated to reflect the changes to the standards. This change does require changes to the Alternative Calculation Manual (ACM) Reference Manuals or the compliance software.

2.2 Summary of Revisions that Occurred during CEC Pre-rulemaking and Rulemaking

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the version of the CASE Report that CEC used as a "document relied upon" in their rulemaking package (see Appendix A). In addition to personal outreach to key stakeholders, the Statewide CASE Team conducted a public stakeholder meeting to discuss the proposal on May 8, 2014. Feedback that stakeholders provided during the utility-sponsored stakeholder meeting is summarized in Section 2.4 of the report presented in Appendix A.

The CASE Team developed and proposed language for low rise residential prescriptive envelope requirements. The language was submitted in a docketed CASE Report from February 2015 and includes two prescriptive options for low rise residential roof/ceiling insulation requirements with variations specific to the location of insulation and roofing material. The two options modify the prescriptive package specified in Table 150.1-A. The proposed language in the docketed CASE Report includes:

Option A. HPA package with below roof deck insulation values, ceiling insulation values, and radiant barrier requirements.

- Varying insulation value requirements are also specified in the table notes for use of above deck insulation and the presence or absence of an air space between the roof deck and roofing material.

Option B. DCS package with ceiling insulation values and radiant barrier requirements in conjunction with verified ducts in conditioned space.

The adopted language restructures the proposed language for improved clarity, but does not make any modifications that affect the energy savings of the intent of the requirement. Instead of providing the varying insulation value requirements for different roof and insulation scenarios as a footnote to Table 150.1-A, the adopted language includes the scenarios directly in the table. The following options were published for public review and adopted into the 2016 Building Energy Efficiency Standards:

Option A. HPA package with above roof deck insulation, ceiling insulation, and radiant barrier requirements. Two above roof deck insulation values are provided for varying roof conditions.

Option B. HPA package with below roof deck insulation, ceiling insulation, and radiant barrier requirements. Two above roof deck insulation values are provided for varying roof conditions.

Option C. DCS package with ceiling insulation values and radiant barrier requirements in conjunction with verified ducts in conditioned space.

The 45-Day Language includes roof/ceiling insulation requirements for climate zones where the CASE Team's analysis did not find the requirements to be cost-effective. The initial docketed CASE Report from October 2014 proposes requirements in these climate zones, but after investigating and refining cost assumptions in response to comments from the California Building Industry Association (CBIA) during the stakeholder feedback process, the CASE Team revised the life cycle cost analysis. The revised analysis did not find the proposed measure to be cost-effective in some climate zones, so the CASE Team revised the proposed language accordingly. The final recommended language and climate zones for the HPA and DCS requirements were submitted to CEC in the docketed CASE Report from February 2015. The adjustments were not published in the 45-Day Language, and the CASE Team submitted a docketed comment to propose modifying the applicable climate zones.

The 45-Day Language also modifies the language regarding the acceptable location of air handlers and ductwork when complying with HPA under the prescriptive requirement. The modification was made in response to a comment from NRDC prior to the pre-rulemaking process. The CASE Team worked with CEC staff to modify the language for the 45-Day Language.

CEC 15-Day Language accurately reflects the climate zones that must comply with the requirement from the final docketed CASE Report. There were no further stakeholder comments opposing the requirements or challenging the cost-effectiveness results. CEC adopted the 15-Day Language into the 2016 Building Energy Efficiency Standards without any changes.

See Section 3 for additional information about changes that occurred during CEC's pre-rulemaking and rulemaking process.

2.3 Energy Savings

The first year statewide impacts of this code proposal are 20.9 gigawatt-hours per year and 1.67 MMtherms per year of energy, and 34.3 megawatts of electrical demand. Savings are based on prescriptive Option B HPA with below deck insulation (R13) with no air space. The methodology used to estimate energy savings is described in detail in Section 5.

Table 1: First year statewide energy impacts estimate

Measure	First Year Statewide Savings			First Year TDV Savings
	Electricity Savings (GWh)	**Power Demand Reduction (MW)**	**Natural Gas Savings (MMtherms)**	**TDV Electricity and Natural Gas Savings (Million kBtu)**
HPA option B– below deck insulation (R13) with no air space	20.9	34.3	1.67	1628
TOTAL	**20.9**	**34.3**	**1.67**	**1628**

3. EVOLUTION OF REQUIREMENTS

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the version of the CASE Report that is presented in Appendix A. In addition to personal outreach to key stakeholders, the Statewide CASE Team conducted a public stakeholder meeting to discuss the proposal on May 8, 2014. Section 2.4 of the report presented in Appendix A summarizes issues that were addressed between the time the Statewide CASE Team commenced work on the project and the time the CASE Report was submitted to CEC.

The following paragraphs summarize how the code change proposals evolved between the time the most recent version of the CASE Report was submitted to CEC and the time the standards were adopted. See Appendix B for a list of comments that were submitted to CEC throughout the pre-rulemaking and rulemaking process that are relevant to this measure.

The adopted language reflects the proposed language from the latest docketed CASE Report dated February 2015 with slight editorial changes that clarify the intent of the requirement and do not affect statewide savings. The adopted language restructures the requirement as sub parts (part i through iii) to clearly show each of the HPA and DCS prescriptive compliance option.

Since the submittal of the final docketed CASE Report, very few stakeholder comments addressed the HPA/DCS proposed language, and none opposed or disputed the cost-effectiveness or feasibility of the proposed requirement. Stakeholder comments on the docketed CASE Report and the 15-Day Language are supportive of the measure. A comment from California Building Industry Association (CBIA) on the 45-Day Language supports the requirements and commends the Commission for including various options in the prescriptive and performance paths to satisfy the requirement.

3.1 High Performance Attic (HPA) Editorial Changes

The adopted language has editorial changes that support the intent of the requirement and clarify the various compliance options and requirements.

3.1.1 Location of Air Handler and Ducts for HPA

The adopted language modifies the acceptable location of air handlers and ducts when complying with the HPA requirements. The docketed CASE Report states that air handlers and ducts can be located in unconditioned spaces or vented attic spaces to comply with HPA. However, as NRDC pointed out after the CEC workshop, this language would allow users to place air handlers and ducts in crawl spaces or other unconditioned spaces that are not required to have insulation, and therefore would not result in reduced heat loss from the system. As such, the language was revised to only allow for the air handling system to be located in a vented attic to support the intent of the requirement.

3.1.2 Table 150.1-A

The adopted language includes line items in Table 150.1-A for all of the prescriptive options to meet the requirement, which were included as a table footnote in the CASE proposed language. The intent of laying out the options in the table rather than as a footnote is to provide clarity and structure to the requirements for varying types and location of insulation and roofing materials.

The editorial changes include:

- Introducing an additional HPA option (Option A) in Table 150.1-A that specifies the requirements when using continuous insulation above the roof deck to comply.
- Including line items to clearly identify the variation in required insulation value according to whether or not an air space exists between the roof deck and the roofing material; the presence of an air gap affects the thermal performance of the assembly.

The transition from a footnote in the CASE Report proposed language to line items in Table 150.1-A makes the specific requirements for each scenario more clear for users.

3.2 Ducts in Conditioned Space (DCS) Editorial Changes

The adopted language specifying air handler and ductwork location to comply with Option C – DCS has been simplified from the CASE proposed language, but maintains the intent of the requirement to ensure that ducts are tested and verified to be in conditioned space and that combustion products from air handling equipment are not released into habitable space. Ductless systems are not included as a prescriptive option to meet the DCS requirement. CEC must verify the efficiency of ductless systems in order to include them in the ACM rules.

4. ADOPTED STANDARDS

The adopted 15-Day Language and Reference Appendices are presented in the following sections. Additions released in the 45-Day Language Express Terms are underlined and deletions are struck with lines. Revisions included in the 15-Day Language are in red font and are double underlined if the language was added or struck with double lines if the language was deleted.

4.1 Building Energy Efficiency Standards Code Language

4.1.1 Section 150.1

(c) **Prescriptive Standards/Component Package.** Buildings that comply with the prescriptive standards shall be designed, constructed, and equipped to meet all of the requirements for the appropriate Climate Zone shown in TABLE 150.1-A. In TABLE 150.1-A, a NA (not allowed) means that feature is not permitted in a particular Climate Zone and a NR (no requirement) means that there is no prescriptive requirement for that feature in a particular Climate Zone. Installed components shall meet the following requirements:

1. **Insulation.**

A. Roof and Ceiling insulation shall be installed in a ventilated attic with an R-value equal to or greater than that shown in Table 150.1-A meeting options i through iii below.

i. Option A: A minimum R-value of continuous insulation installed above the roof rafters in contact with the roof deck and an additional layer of ceiling insulation located between the attic and the conditioned space when meeting Section 150.1(c)9A; or

ii. Option B: A minimum R-value of insulation installed between the roof rafters in contact with the roof deck and an additional layer of ceiling insulation located between the attic and the conditioned space when meeting Section 150.1(c)9A; or

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

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

~~Roof/Ceiling insulation shall be installed with U-factor equal to or less than, or a U-factor equal to or less than, or R-value equal to or greater than shown in TABLE 150.1-A. The maximum U-factors or the minimum R-values shown are for insulation installed between wood-framing members.~~

9. **Space Cconditioning ductsDistribution Systems.**. All ducts shall either be in directly conditioned space as confirmed by field verification and diagnostic testing in accordance with Reference Residential Appendix RA3.1.4.3.8 or be insulated to a minimum installed level as specified by TABLE 150.1-A. All ducts shall meet all applicable mandatory requirements of Section 150.0(m). All space conditioning systems shall meet all applicable requirements of A or B below:

NOTE: Requirements for duct insulation in TABLE 150.1-A do not apply to buildings with space conditioning systems that do not have ducts.

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

B. Duct and air handlers located in conditioned space. Duct systems and air handlers of HVAC systems shall be located in directly conditioned space, joist cavity between conditioned floors, or in sealed cavity below attic insulation. Air handlers containings a combustion component shall be direct-vent, and shall not use air from conditioned space as combustion air. All ducts shall be located in directly conditioned space and confirmed by field verification and diagnostic testing in accordance withto meet the criterion of Reference Residential Appendix RA3.1.4.3.8. Duct insulation levels shall meet the requirements in TABLE 150.1-A.

NOTE: Gas heating appliances installed in conditioned spaces must meet the combustion air requirements of the California Mechanical Code- Chapter 7, as applicable.

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]	~~R-8~~NR	NR~~R-8~~	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]	~~R-6~~NR	~~R-6~~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	~~R18~~NR	~~R18~~NR	~~NA~~NR	R 18	~~NA~~NR	~~NA~~NR	~~NA~~NR	R 18	R 18	R 18	R 18	R 18	R 18	R 18	R 18	R 18
				With Air Space	~~R-13~~NR	~~R-13~~NR	~~NA~~NR	R 13	~~NA~~NR	~~NA~~NR	~~NA~~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	~~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

Building Envelope Insulation																		
Option A (meets §150.1(c)9A)	Roof Deck/Rafter Insulation[3] Above Roof Rafter	Roofing Type: No Air Space[1]	R-8R-6 or U 0.12	R-8R-6 or U 0.12	NRNR	R-8R-6 or U 0.12	NRNR	NRNR	NRNR	R-8R-6 or U 0.12	R-8R-6 or U 0.12	R-8R or U 0.126	R-8R-6 or U 0.12	R-8R-6 or U 0.12	R-8R-6 or U 0.12	R-8R-6 or U 0.12	R-8R-6 or U 0.12	R-8R-6 or U 0.12
		Roofing Type: with Air Space[1]	R-6	R-6	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-3808	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)Option A (meets §150.1(c)9A)	Below Roof Deck Insulation[2] Insulation 11	Roofing Type: No Air Space	R18R 13	R18R 13	NANA	R-18R 13	NANA	NANA	NANA	R-18R-13	R-18R 13	R-18R 13	R-18R 13	R-18R 13	R-18R 13	R-18R-13	R-18R 13	R-18R 13
		Roofing Type: 3/4 in with Air Space	R-13	R-13	NA	R-13	NA	NA	NA	R-13	R-13	R-13	R-13	R-13	R-13	R-13	R-13	R-13
	Ceiling Insulation		R-38	R-38308	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	NR	REQNR	NR	NRREQ	REQNR	REQNR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Option BC (meets §150.1(c)9B)	Roof / Ceiling Insulation		U 0.025 R-38	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	U 0.031 R-30	R-30U 0.031-R-30	R-38U 0.025-R 38	R-38U 0.025-R 38	U 0.025 R-38	U 0.025 R-38	U 0.025 R-38	U 0.025 R-38
	Radiant Barrier		NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR

HVAC	Ducts Ducts[1,2]	Option A (meets §150.1(c)9A) Roof/Ceiling Options A & B	Duct Insulation Options A & B (meets §150.1(c)9A)	R-6 R-8NA	R-6 R-8NA	R-6 R-86NA	R-6 R-8NA	R-6 R-86NA	R-6 R-86NA	R-6 R-86NA	R-6 R-8NA	R-6 R-8NA	R-6 R-8NA	R-8 R-8NA	R-6 R-8NA	R-6 R-8NA	R-8 R-8NA	R-8 R-8NA	R-8 R-8NA
			§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 Option C (meets §150.1(c)9B)	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-6REQ a	R-8REQ a6REQ a	R-6REQ a	R-6REQ a	R-8REQ a6REQ a	R-8REQ a6REQ a	R-8REQ a6REQ a
			§150.1(c)9B	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ

4.2 Reference Appendices Code Language

4.2.1 Residential Appendix 2

RA2.2 ***Measures that Require Field Verification and Diagnostic Testing***

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

Measure Title	Description	Procedure(s)
	Duct Measures	
Duct Sealing	Component Packages require that space conditioning ducts be sealed. If sealed and tested ducts are claimed for compliance, field verification and diagnostic testing is required to verify that approved duct system materials are utilized, and that duct leakage meets the specified criteria.	RA3.1.4.3
~~Supply~~ Duct Location, Surface Area and R-value	Compliance credit can be taken for improved ~~supply~~ duct location, surface area and R-value. Field verification is required to verify that the duct system was installed according to the design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.[1] For buried ducts measures, Duct Sealing and High Quality Insulation Installation (QII) is required.	RA3.1.4.1
Verification of low leakage ducts located entirely in ~~directly~~ conditioned space~~, and~~ ~~Low Leakage Ducts in Conditioned Space~~	~~When the Standards specify use of the procedures in Section RA3.1.4.3.8 to determine if space conditioning system ducts are located entirely in directly conditioned space, the ducts~~Duct system location shall be verified by visual inspection and diagnostic testing. Compliance credit can be taken ~~if option A is used as specified by Section 150.1(c)9.A of the Standards~~ for verified duct systems with low air leakage to the outside when measured in accordance with Reference Residential Appendix Section RA3.1.4.3.8. Field Verification for ducts in conditioned space is required. Duct sealing is required.	RA3.1.4.3.8

4.2.2 Residential Appendix 3

RA3.1 ....
Field Verification and Diagnostic Testing of Air Distribution Systems

RA3.1.4.1.3 **Visual Verification of Ducts Located Entirely In Conditioned Space**

A visual inspection shall confirm space conditioning duct systems are located entirely ~~entirely~~ in conditioned space. If any part of the space conditioning duct system is outside of conditioned space, the system does not pass.

Table RA3.1-2 – Duct Leakage Verification and Diagnostic Test Protocols and Compliance Criteria

Case	User Application	Leakage Compliance Criteria (% of Air Handler Airflow)	Procedure(s)
~~Verified~~ Verification of Low Leakage Air Handler with Sealed and Tested Duct System Compliance Credit	Installer Testing at Final HERS Rater Testing	compliance target values 6% or less as specified on the Certificate of Compliance	RA3.1.4.3.1 and RA3.1.4.3.9
Verification of low leakage ducts located entirely in ~~directly~~ conditioned space~~, and~~ ~~Low leakage ducts in conditioned space compliance credit.~~	Installed Testing HERS Rater Testing	25 CFM Leakage to Outside	RA3.1.4.3.8

RA3.1.4.3.8 **Verification of Low Leakage ~~Ducts in Conditioned Space Compliance Credit, and~~ Ducts Located Entirely In ~~Directly~~ Conditioned Space**

~~When ducts are located in conditioned space, additional performance compliance credit is available for low leakage ducts. If duct leakage to outside is equal to or less than 25 cfm when measured in accordance with Section RA3.1.4.3.4, the system passes. The dwelling must also be qualified to receive the credit for verified ducts in conditioned space as verified by visual inspection according to Section RA3.1.4.1.3.~~

A visual inspection shall confirm the duct system location as specified by Section RA3.1.4.1.3. Additionally, ~~When the Standards specify use of the procedures in Section RA3.1.4.3.8 to determine if space conditioning system ducts are located entirely in directly conditioned space, the duct system location shall be verified by diagnostic testing according to the following criterion: If d~~dductduct ~~leakage to outside is~~ shall to have~~be equal to or~~ less than or equal to 25 cfm leakage to outside when measured ~~in accordance with~~as specified by Section RA3.1.4.3.4. ~~, the system ducts shall be considered to be located entirely in directly conditioned space. Duct systems that do not meet this criterion shall not be considered to be located entirely in directly conditioned space.~~

4.2.3 Joint Appendix 4

JA4.2 Roofs and Ceilings

Table 4.2.1 – U-factors of Wood Framed Attic Roofs

This table shall not be used for cases where insulation is located at the roof of the attic. There are ~~two~~ several situations ~~where~~ in which this may be done. ~~FoamedF~~ For example, in a sealed attic, foamed plastic may be sprayed onto the top chord of the trusses and onto the bottom of the upper structural deck (roof). The foam expands and cures ~~which~~ with the intent of ~~hich mayto~~ ~~provide~~providinge an airtight barrier and continuous insulation. Another case is where a plastic membrane or netting is installed above the ceiling (hanging below the roof deck) either in a ventilated or sealed (not ventilated) attic, ~~(hanging below the roof deck)~~ and then either batt or blown insulation is installed over the netting. ~~In both of these cases, the attic is may be sealed (not ventilated).~~ Since ~~T~~there are a number of issues related to these insulation techniques~~and~~, special CEC approval is required.

4.3 Compliance Manual

In April of 2015, the Statewide CASE Team provided CEC with proposed revisions to the Residential Compliance Manual to describe how to comply with the code change outlined in this CASE Report. The revisions that the Statewide CASE Team provided served as the first draft of CEC's revisions to the Compliance Manual. At the time of writing CEC has released a version of the Compliance Manual for public review. The Compliance Manuals are scheduled to be approved during the November 2015 CEC Business Meeting. The Statewide CASE Team recommended revisions to the following sections of the Compliance Manual:

- Chapter 3 – Section 3.6.2
- Chapter 3 – Section 3.6.3
- Chapter 4 – Section 4.2.2
- Chapter 4 – Section 4.4.2
- Chapter 9 – Section 9.6.2

5. FINAL COST-EFFECTIVENESS RESULTS

5.1 Energy Savings Estimates

Statewide energy impacts reflect the estimates in the final docketed CASE Report from February 2015. The details of the analysis are available in the CASE Report which is included in Appendix A.

The Statewide CASE Team calculated per unit impacts and statewide impacts associated with all new construction during the first year buildings comply with the 2016 Title 24 Standards. The Statewide CASE Team estimated the electricity and natural gas savings associated with the proposed code change. The CASE Team calculated energy savings on a building basis for each climate zone, and then applied the savings to the statewide new construction forecast in each climate zone.

5.2 Analysis Tools

The Statewide CASE Team utilized the latest available standard compliance software CBECC-Res version 650 to quantify energy savings and peak electricity demand reductions resulting from the proposed measure. The current compliance software can model all of the DCS options and all of the HPA measures and includes the 2016 Time Dependent Valuation (TDV) values as well as peak demand calculations.

5.3 Key Assumptions

CEC provided a number of key assumptions to be used in the energy impacts analysis, in the CEC Life Cycle Cost Methodology Guidelines including hours of operation, weather data, and prototype building design.

For the DCS measure, the CASE Team's energy savings analysis has the following assumptions:

Table 2: Key assumptions for per unit energy impacts analysis - DCS

Run	Parameter	Assumption	Source
DCS – verified ducts entirely in conditioned space	Duct location	No conduction loss, no duct leakage to outside	Default values in CBECC-Res

For the HPA measures, the CASE Team's analysis has the following assumptions:

Table 3: Key assumptions for per unit energy impacts analysis - HPA

Run	Parameter	Assumption/Input	Source
HPA – roof deck insulation	Insulation location and level	Above-deck: R-8 with no air space Below-deck: R-13 with no air space	Product availability and levels installed in Zero Energy Challenge Home/ test homes
HPA – ceiling insulation	Insulation level	R-38	Product availability and levels installed in Zero Energy Challenge Home/ test homes
HPA – duct insulation	Insulation level	R-8 for all climate zones	The higher R value requirement for the 2013 Standards
HPA – duct leakage	Duct leakage rate	5%	Data on new construction homes built under 2008 Standards

For the HPA measures, the CASE Team created runs first to assess the energy impacts from the proposed measures individually. The Statewide CASE Team then developed packages consisting of multiple measures to determine the proposed prescriptive HPA package for climate zones.

The proposed code changes in the CASE Report apply to all low-rise new construction buildings in the affected climate zones. The Statewide CASE Team estimated statewide impacts for the first year buildings complying with the 2016 Title 24 Standards by multiplying per unit savings estimates by statewide construction forecasts. For the purposes of this analysis, the CASE Team assumed buildings would comply with the HPA below-deck with no air space (R13) package of requirements.

Statewide impacts from this measure are presented in Table 4.

Table 4: Estimated first year energy savings

Measure	First Year Statewide Savings			First Year TDV Savings
	Electricity Savings (GWh)	**Power Demand Reduction (MW)**	**Natural Gas Savings (MMtherms)**	**TDV Electricity and Natural Gas Savings (Million kBtu)**
HPA – below roof deck insulation (R13) with no air space	20.9	34.3	1.67	1628
TOTAL	**20.9**	**34.3**	**1.67**	**1628**

5.4 Final Cost-effectiveness Estimates

As shown Table 5, the code change is cost-effective. The cost-effectiveness estimates have not changed since submitting the CASE Report to CEC in February 2015. The latest version of the CASE Report is included in its entirety in Appendix A of this report.

Table 5: Cost-effectiveness summary[1]

Climate Zone	Benefit: TDV Energy Cost Savings + Other Cost Savings[2] (2016 PV$)	Cost: Total Incremental Cost[3] (2016 PV$)	Change in Lifecycle Cost[4] (2016 PV$)	Benefit-to-Cost Ratio[5]
Climate Zone 1	1,441	1,551	110	0.9
Climate Zone 2	1,444	1,625	181	0.9
Climate Zone 3	710	1,625	915	0.4
Climate Zone 4	1,640	1,625	(15)	1.0
Climate Zone 5	594	1,625	1,030	0.4
Climate Zone 6	782	1,625	843	0.5
Climate Zone 7	343	1,625	1,281	0.2
Climate Zone 8	1,825	1,475	(350)	1.2
Climate Zone 9	3,032	1,475	(1,557)	2.1
Climate Zone 10	2,708	1,475	(1,234)	1.8
Climate Zone 11	3,605	939	(2,665)	3.8
Climate Zone 12	3,059	1,152	(1,907)	2.7
Climate Zone 13	4,531	1,152	(3,380)	3.9
Climate Zone 14	3,125	1,025	(2,100)	3.0
Climate Zone 15	5,389	1,089	(4,299)	4.9
Climate Zone 16	2,711	1,424	(1,287)	1.9

1. Relative to existing conditions. All cost values presented in 2017 dollars.
2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta TDV\$ = \Delta TDV\$E + \Delta TDV\$G$.
3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta C = \Delta CI_{PA} + \Delta CM$.
4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta LCC = \Delta C - \Delta TDV\$$. Positive values, which are highlighted in red, indicate measures that are not cost-effective.
5. The Benefit-to-Cost Ratio is the TDV energy costs savings divided by the total incremental costs; $B/C = \Delta TDV\$ \div \Delta C$. The measure is cost-effective if the B/C ratio is greater than 1.0. Values under 1.0, which are highlighted in red, are not cost-effective.

6. ACKNOWLEDGMENTS

The Pacific Gas and Electric Company, Southern California Edison, Southern California Gas Company, San Diego Gas and Electric Company and Los Angeles Department of Water and Power sponsored this report as part of the CASE (Codes and Standards Enhancement) project for the 2016 Building Energy Efficiency Standards. Stuart Tartaglia of PG&E was the project manager for the 2016 Building Standards Advocacy Project on behalf of the utility team. Patrick Eilert is the program manager for the PG&E's CASE program; Stu Tartaglia, Marshall Hunt and Jon McHugh (McHugh Energy) supported this measure on behalf of PG&E. Randall Higa and Ishtiaq Chisti were the CASE program manager for the SCE; Bach Tsan supported this measure on behalf of SCE. Sue Kristjansson, Martha Garcia, Dipo Olatunji and Phil Pratt were SoCalGas's CASE program managers; Lovell Willmore supported this measure on behalf of SoCalGas. Chip Fox was SDG&E's CASE program manager; Adrian Salas and John

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APPENDIX A: DOCKETED VERSION OF CASE REPORT

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Residential Ducts in Conditioned Space / High Performance Attics

Measure Number: 2016-RES-ENV1-F

Residential Envelope

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team February 6, 2015

Prepared by: Julianna Wei, Abhijeet Pande (TRC Energy Services)

Cathy Chappell, Matthew Christie, Megan Dawe (TRC Energy Services)

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

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Document Information

Category: Codes and Standards

Keywords: Statewide CASE, Statewide Codes and Standards Team, Statewide C&S Team, Codes and Standards Enhancements, Title 24, 2016, efficiency, Ducts in Conditioned Space (DCS), ducts and equipment in conditioned space, High Performance Attic (HPA), ductless systems, roof deck insulation, unvented attic.

EXECUTIVE SUMMARY

Introduction

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

The overall goal of this CASE Report is to propose a code change proposal for the Residential Ducts in Conditioned Space (DCS) / High Performance Attics (HPA). The report contains pertinent information that justifies the code change including:

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

This version of the CASE report uses the 2016 Time Dependent Valuation (TDV) values and TDV cost saving.

Scope of Code Change Proposal

Residential Ducts in Conditioned Space / High Performance Attics will affect the following code documents listed in Table 1.

Table 1: Scope of Code Change Proposal

Standards Requirements (see note below)	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Forms
M, Ps	Yes	RA2, RA3, RA4	Yes	Yes	Various

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

List of other areas affected including changes to trade-offs:

- Residential Compliance Manual
- Residential Alternative Compliance Method Manual

Measure Description

The Residential Ducts in Conditioned Space (DCS) / High Performance Attics (HPA) measure consists of two alternatives, as stated in the measure name, to improve building thermal envelope and reduced HVAC distribution losses in residential buildings. These two approaches will have similar energy impacts on the building. DCS will require that ducts and equipment be located within the thermal and air boundary of the building. High Performance Attics (HPA) is a package of measures that minimizes the temperature difference between the attic and the conditioned air in ducts. The compliance options will be modified to fairly include all ductless systems[1]. This measure will affect the prescriptive and mandatory sections of code for low-rise residential buildings.

For the 2013 Title 24 Building Energy Efficiency Standards, a CASE Report[2] proposed a set of measures similar to the High Performance Attic proposal, which also included cool roof requirements. However, the total cost for the package of measures – proposed as a vented attic package – was deemed to be cost prohibitive based on industry feedback despite being life cycle cost effective. Additionally, the team investigated an unvented attic package for ducts in conditioned space as a compliance option. Although the entire proposal was not adopted, improvements were made to modeling capabilities for derating insulation at the attic eaves. Cool roofs and radiant barriers were adopted into the 2013 Standards for some climate zones.

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

[1] In the case of ductless heat pumps and mini-split systems, the CEC is currently engaging manufacturers of ductless systems to ensure that the CBECC-Res software calculates energy performance of these systems appropriately. As of the writing of this report, the software does not model ductless systems with listed efficiency features. Instead the software considers ductless systems to have the same efficiency as the baseline Split DX system. This is due to CEC concerns about the lack of installation criteria and HERS verification protocols.

[2] www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Envelope/2013_CASE_R_Roof_Measures_Oct_2011.pdf

- Table 6: Scope of Code Change Proposal (page 7)
- Table 7: Sections of Standards Impacted by Proposed Code Change (page 8)
- Table 8: Appendices Impacted by Proposed Code Change (page 8)
- Table 9: Sections of ACM Impacted by Proposed Code Change (page 9)

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

Market Analysis and Regulatory Impact Assessment

DCS and HPA strategies are not widely implemented in the California residential market which is dominated by ducts installed above the ceiling insulation in vented attics. But the numbers are increasing in the high performance homes market due to tighter energy budgets and greater difficulty in achieving the "above code targets" for incentive programs. DCS and HPA will both have adjustments to attic insulation placement and possibly insulation type. There are different options and combinations of insulation that can be used which are widely available from manufacturers, distributors and retailers. Additionally, the DCS strategy will require a sealed (direct vent) furnace, which is available from multiple manufacturers and some of these sealed furnaces meet current federal minimum efficiency requirements.

If installed properly and according to best design guidelines, these measures will be low maintenance and persist for the life of the measure.

This proposal is cost effective 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. As a result this leaves more money available for discretionary and investment purposes.

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

- **Impact on builders:** The DCS strategy will require modifications to building designs and practices that will impact builders and trades. The HPA measure package will impact building practices related to installing insulation in the attic – by requiring additional insulation at the roof deck (above or below), additional duct insulation and better duct sealing. HVAC contractors will need to be part of the design team and provide duct system layout and sizing for inclusion in the plans and will need to ensure that duct systems are installed properly to ensure reduced duct leakage. Site building superintendents will need to modify scheduling to allow access of subcontractors in the sequence needed to perform the work.
- **Impact on building designers:** The DCS strategy will require that designers integrate the HVAC system and layout with the rest of the plans as part of the design process.

From the beginning of the design process, designers will need to determine the strategy to be used and what spaces are needed to accommodate the strategy.

- **Impact on occupational safety and health:** The proposed code change is not expected to have an impact on occupational safety and health.
- **Impact on building owners and occupants:** Since this measure is cost-effective, the building owner or occupant who pays the energy bills will experience net cost savings over their additional mortgage costs. Renters, especially those in single family homes, usually pay utility costs – this measure will reduce renter's utility costs. If this measure increases the rents that can be charged equal to the increase in mortgage payments, the renter will experience lower combined costs associated with rent and utility payments.
- **Impact on equipment retailers (including manufacturers and distributors):** The DCS and HPA strategies may increase demand for certain building products, such as various options for roof deck insulation. The DCS strategy will also have impacts on certified low-leakage air handlers and sealed combustion furnaces.
- **Impact on energy consultants:** Energy consultants may be required to provide guidance to builders on best practices for application of these measures. Title 24 consultants will need to be familiar with correct modeling procedures.
- **Impact on building inspectors:** No new inspections will be introduced, and, as compared to the overall code enforcement effort, this measure has negligible impact on the effort required to enforce the building codes.
- **Statewide Employment Impacts:** The proposed measures will increase the demand for trades with specific skill, knowledge and experience working with these strategies and products. In general, compliance with this measure will increase labor time in each house built.
- **Impacts on the creation or elimination of businesses in California:** Since this measure is cost-effective, it is generating wealth in the state. It increases the use of California labor and decreases exports of funds to other states for imported electricity or natural gas.
- **Impacts on the potential advantages or disadvantages to California businesses:** The cost of this measure is less than one quarter of one percent of the sales price of the median California home, a fraction of the 14% or greater annual increase in home prices. Other factors have a significantly higher impact on home prices than the marginal impacts of the energy codes.[3] In addition, all new homes must comply with the new requirements so no one business or builder is favored or discriminated against.
- **Impacts on the potential increase or decrease of investments in California:** The impact on home construction is negligible as the cost of this measure is small, as

[3] "The median home value in California is $425,000. California home values have gone up 16.4% over the past year…" http://www.zillow.com/ca/home-values/

described above. However, this measure is an investment in the California building stock that provides returns for years to come.

- **Impacts on incentives for innovations in products, materials or processes:** The California energy standards have resulted in California being a leader in clean technology. The proposed standards are primarily prescriptive which means that one can building new homes using one of the prescriptive measures proposed here, or make use of any other combinations of efficiency measures that result in comparable levels of energy savings. As a result the standards reward innovations that reduce energy consumption.
- **Impacts on the State General Fund, Special Funds and local government:** There is no appreciable impact on any of these funds. To the extent that these improvements are reflected in the value of a house, this increases the revenues to local governments through real estate taxes.
- **Cost of enforcement to State Government and local governments:** This measure does not increase the cost of enforcement as envelope insulation levels and locations of ducts are already part of code enforcement in the performance approach.
  - State government already has budgeted for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 standards, including updating education and compliance materials and responding to questions about the revised standards, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals.
  - The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining. Although retraining is a cost of the revised standards, Title 24 energy efficiency standards are expected to increase economic growth and income with positive impacts on local revenue.
- **Impacts on migrant workers; persons by age group, race, or religion:** This proposal and all measures adopted by CEC into Title 24, part 6 do not advantage or discriminate in regards to race, religion or age group.
- **Impact on Homeowners (including potential first time home owners):** This proposal is cost-effective for the homeowner. As a result, the combined mortgage costs and utility bill payment for the homeowner are less if the measure is incorporated into all new homes.
- **Impact on Renters:** This proposal is advantageous to renters as it reduces the cost of utilities which are typically paid by renters. Since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experienced by the landlord,

the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by renters.

- **Impact on Commuters:** This proposal and all measures adopted by CEC into Title 24, part 6 are not expected to have an impact on commuters

Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the Residential Ducts in Conditioned Space and High Performance Attics.

Table 2: Estimated First Year Energy Savings

	First Year Statewide Savings			First Year TDV Savings
	Electricity Savings (GWh)	**Power Demand Reduction (MW)**	**Natural Gas Savings (MMtherms)**	**TDV Electricity and Gas Savings (Million kBTU)**
HPA – including R-13 below deck	20.9	34.3	1.67	1,628
DCS – Verified Ducts in Conditioned Space	22.4	38.6	2.85	1,981

Section 4.6.1 discusses the methodology and Section 5.1.1 shows the results for the per unit energy impact analysis.

Cost-effectiveness

Results per unit Cost-effectiveness Analyses are presented in Table 3. The TDV Energy Costs Savings are the present value energy cost savings over the 30 year period of analysis using CEC's TDV methodology. The Total Incremental Cost represents the incremental initial construction and maintenance costs of the proposed measure relative to existing conditions (current minimally compliant construction practice related to existing Title 24 Standards). Costs incurred in the future (such as periodic maintenance costs or replacement costs) are discounted by a 3 percent real discount rate per CEC's LCC Methodology. The CASE Team revised the total incremental measure cost based on discussions with CBIA and ConSol on the cost estimates from the initial docketed draft CASE report. The current total incremental costs are a result of these discussions and reflect a margin of difference between CBIA and ConSol's cost estimate that is significantly smaller than the original estimates. The Benefit to Cost (B/C) Ratio is the incremental TDV Energy Costs Savings divided by the Total Incremental Costs. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is deemed to be cost effective. For a detailed description of the Cost-effectiveness Methodology see Section 4.7 of this report.

The Change in Lifecycle Cost values are negative in climate zones 4 and 8-16; the proposed DCS and HPA measure packages are cost-effective in these climate zones with proposed changes. The Statewide CASE Team has formulated the code change proposal for climate zones and requirement levels that are shown to have satisfactory cost-effectiveness results. The Statewide CASE Team proposes that the requirements apply to climate zones 4 and 8 through 16.

Table 3: Cost-effectiveness Summary for HPA

Climate Zone	Benefit: TDV Energy Cost Savings + Other Cost Savings[2] (2017 PV$)	Cost: Total Incremental Cost[3] (2017 PV$)	Change in Lifecycle Cost[4] (2017 PV$)	Benefit to Cost Ratio[5]
Climate Zone 1	$1,441	$1,551	$110	0.9
Climate Zone 2	$1,444	$1,625	$181	0.9
Climate Zone 3	$710	$1,625	$915	0.4
Climate Zone 4	$1,640	$1,625	$(15)	1.0
Climate Zone 5	$594	$1,625	$1,030	0.4
Climate Zone 6	$782	$1,625	$843	0.5
Climate Zone 7	$343	$1,625	$1,281	0.2
Climate Zone 8	$1,825	$1,475	$(350)	1.2
Climate Zone 9	$3,032	$1,475	$(1,557)	2.1
Climate Zone 10	$2,708	$1,475	$(1,234)	1.8
Climate Zone 11	$3,605	$939	$(2,665)	3.8
Climate Zone 12	$3,059	$1,152	$(1,907)	2.7
Climate Zone 13	$4,531	$1,152	$(3,380)	3.9
Climate Zone 14	$3,125	$1,025	$(2,100)	3.0
Climate Zone 15	$5,389	$1,089	$(4,299)	4.9
Climate Zone 16	$2,711	$1,424	$(1,287)	1.9

These values are based on installing R-13 insulation below the roof deck and R-38 above the ceiling, adding R8 insulation to ducts and reducing total duct leakage to 5% of the nominal air handler airflow. Section 4.7 discusses the methodology and section 5.2 shows the results of the Cost Effectiveness Analysis

Greenhouse Gas and Water Related Impacts

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

Greenhouse Gas Impacts

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

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

Table 4: Estimated Statewide Greenhouse Gas Emissions Impacts

	First Year Statewide	
	Avoided GHG Emissions ($MTCO_2e$/yr)	Monetary Value of Avoided GHG Emissions ($2017)
HPA – including R-13 below roof deck	16,199	TBD
DCS – Verified low leakage ducts in conditioned space	23,030	TBD

Values in Table 4 are for each of the options to meet the proposed code requirements and represent the savings in climate zones 4, 8-16. Each row represents one option to meet he proposed code requirements and as such the two rows should not be added for statewide savings. Section 4.8.1 discusses the methodology and Section 5.3.1 shows the results of the greenhouse gas emission impacts analysis.

Water Use and Water Quality Impacts

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

Field Verification and Diagnostic Testing

The DCS and HPA proposals will require field verification for some measures, some of which are already in the current standards. The existing field verification and diagnostic tests include:

- Duct leakage test
- House pressurization test
- Quality Insulation Installation (QII)
- Verification of ducts in conditioned space, low leakage air handlers and reduced duct surface area
- Duct leakage to outside test for DCS options

The new field verification and diagnostic tests needed or to be modified include:

- Verification of proper above or below roof deck insulation installation
- Verification of air handler location for vented attic DCS options
- Leakage to the outside in the case of a Unvented Attic

1. INTRODUCTION

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

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

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

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

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

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

2. MEASURE DESCRIPTION

2.1 Measure Overview

2.1.1 Measure Description

The measure consists of two alternatives for accomplishing improved building thermal envelope and reduced HVAC distribution losses in residential buildings. These two approaches will have similar energy impacts on the building.

- **High Performance Attics** (HPA) implements measures that minimize temperature difference between the attic space and the conditioned air being transported through ductwork in the attic.
- **Ducts in Conditioned Space** (DCS), locates ducts and air handlers in the building's thermal and air barrier envelope. Installing ductless systems meets the DCS requirement.

Appendix B: DCS and HPA Strategies provides examples of various DCS and HPA strategies.

The proposed measures will add or modify mandatory and prescriptive requirements related to attic, roof, air handler, and ducts in residential buildings. The proposed measures will modify compliance options for ductless systems and add or modify modeling procedures for all of the above measures in the performance method. Details are provided in Section 2.2 of this document.

As a result of the change, the Standards will address energy issues related to air losses from air handlers and ducts in attics while allowing several compliance options to meet the requirements with alternate systems or strategies. The proposed change does not modify or expand the scope of the Standards themselves.

2.1.2 Measure History

Common construction practice in California is slab-on-grade, with air handlers and associated ductwork located in an unconditioned attic. During the cooling season, particularly in the Central Valley and other inland climates, attic temperatures can reach temperatures much higher than the outside air temperatures (Lstiburek 2013, BSC 2010, EPA 2000), resulting in loss of cooling capacity delivered to the interior and increased energy use by the HVAC system to provide desired occupant comfort.

For the 2013 Title 24 Building Energy Efficiency Standards, the Statewide CASE Team analyzed a set of measures to reduce undesirable heat gain and loss through the roof assembly and to improve duct conditions (AEC/HMG)[4]. The Team established a vented attic package, which initially included cool roof requirements, roof deck insulation, raised heel trusses and

[4] www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Envelope/2013_CASE_R_Roof_Measures_Oct_2011.pdf

increased duct insulation. Modeling capabilities were also developed to account for the derating of insulation value when insulation is compressed at the eave (e.g. when a raised heel trusses is not used). However, the final adopted code language for the 2013 standards only modified cool roof solar reflectance requirements, increased duct insulation and required radiant barrier in specific climate zones.

Some of the measures from the 2013 CASE proposal that did not get adopted in the 2013 standards are under consideration again for 2016 as there has been more time to collect additional data on the performance and costs of these measures. Other measures have been dropped for a variety of reasons. During the 2013 Title 24 proceedings, roof deck insulation received a number of comments concerning its impact on roof longevity and moisture build-up. The CEC contracted the Building Science Corporation (BSC), a leader in advanced building methods, to conduct a moisture analysis for this option. The results indicated that air permeable insulation may be installed under the roof deck of a vented attic without moisture issues in all climate zones but CZ16. The report laid out the necessary steps required to prevent moisture issues due to roof deck insulation in a vented attic (BSC 2011[5]). Additional research has been reviewed and included in this CASE report on the topic of roof deck insulation.

- Currently, there are several national programs and organizations promoting the adoption of high performance residential building envelopes and ducts in conditioned space. The DOE Challenge Home (recently renamed the "DOE Zero Energy Ready Homes" initiative) launched new national program requirements in 2012 (and updated April 21, 2014[6]) that require ducts in conditioned space as a mandatory requirement for participation under the prescriptive path. There are several alternatives allowed to ducts in conditioned space including ducts in unvented attics or crawl spaces, fully buried low-leakage ducts, and ductless systems. DOE Building America's ongoing research projects showcase case studies and produce measure guidelines that demonstrate the options and benefits of implementing these advanced measures, and the Building America Solution Center provides specific examples of construction methods.
- The National Association of Home Builders (NAHB) has produced guidelines and case studies to inform builders and assist in identifying solutions to possible barriers for moving ducts into conditioned space.
- The Northwest Energy Efficiency Alliance (NEEA) has been sponsoring a website http://www.ductsinside.org/ as a clearinghouse for publications and training information associated with moving ducts inside the conditioned envelope.
- The Net-Zero Energy Coalition is a group headquartered in Canada which has been promoting Net Zero Energy (NZE) Homes that do not use more energy than they generate on site. An indirect result of advocating for net zero buildings results in ducts being placed in the conditioned space. In discussions with their executive director, *"In*

[5] www.buildingscience.com/documents/reports/rr-1110-hygrothermal-analysis-california-attics

[6] energy.gov/sites/prod/files/2014/04/f15/doe_zero_energy_ready_home_requirements_rev04.pdf

Canada we've always had our ducts in conditioned spaces – and builders in the US that are building NZE homes, or are on that path, are all moving their ducts into conditioned spaces. (It's not just for those in mild climates.) So for NZE, it's a given that ducts should be in conditioned spaces…"[7]

California utilities are researching these design options through emerging technology projects and working with builders to increase their knowledge and experience. Both Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) are conducting projects that work directly with builders through the design process, selection of measures, and construction phase for implementing DCS or HPA strategies. SMUD's Home of the Future program encourages locating ducts and equipment in conditioned space and other advanced building techniques. The utility emerging technology programs and projects provide expertise and assistance with the technical and implementation barriers for builders to make the transition; these efforts inform and greatly support the development of the CASE study. In addition to these programs, a national production builder has made ducts in conditioned space a standard feature for all homes, and other advanced home builders are investigating these options.

2.1.3 Existing Standards

2013 Title 24 Building Energy Efficiency Standards

The 2013 Title 24 Standard currently includes prescriptive requirements for several of the measures and construction techniques we are proposing for the 2016 update. The prescriptive requirements in Table 150.1- A relevant to this CASE topic include:

Table 5: 2013 Title 24 Part 6 Prescriptive Measures in Table 150.1-A

<table>
<tr><th></th><th colspan="6">Climate Zone</th></tr>
<tr><th>Building Component</th><th>1</th><th>2-10</th><th>11</th><th>12-13</th><th>14-15</th><th>16</th></tr>
<tr><td>Roof/Ceiling Insulation</td><td>U 0.025
R 38</td><td>U 0.031
R 30</td><td colspan="4">U 0.025
R 38</td></tr>
<tr><td>Radiant Barrier</td><td>NR</td><td colspan="4">REQ</td><td>NR</td></tr>
<tr><td>Duct Insulation</td><td colspan="2">R 6</td><td>R 8</td><td>R 6</td><td colspan="2">R 8</td></tr>
</table>

Roof deck insulation, whether above or below, is not specifically required as a prescriptive requirement, but a maximum assembly u-value of 0.031 is a mandatory measure in all climate zones whether the insulation is located at the roof deck in a non-vented attic or at the ceiling level in a vented attic. Duct sealing for new residential dwellings became a mandatory measure in the 2013 Title 24 Standards in all climate zones. Section 150.0(m).11 requires a total duct system leakage of 6% or less of the nominal air handler airflow, as confirmed through a HERS rater field verification.

The 2013 software designates the default location of the air distribution system for the performance calculations but the Standards do not regulate the location of ducts and air handler equipment. There is no requirement in the Standards for a specific duct surface area. The ACM

[7] Personal correspondence, with Sonja Winkelmann, Executive Director, Net-Zero Energy Coalition

specifies a default total supply duct surface area, and allows the user to input a lower value. If a lower value is used, additional verification and documentation for certified low leakage air handler unit is required.

Alternative design and construction techniques, including raised heel or extension trusses are not specified in the Standards, however the 2013 CBECC-Residential software can model raised heel trusses and fully extended ceiling insulation to capture the energy benefits of these techniques.

2012 International Energy Conservation Code (IECC)[8]

Section R402.2.1 Ceilings with attic spaces sets requirements for ceiling insulation similar to those in 2013 Title 24. In addition, IECC allows raised heel trusses to meet the insulation requirements with lower insulation levels installed at the ceiling. For example, when Section R402.1.1 requires R-38 in the ceiling, R-30 is deemed to satisfy the requirement wherever the full height of uncompressed R-30 insulation extends over the wall top plate at the eaves (through raised heel truss). Similarly, R-38 shall be deemed to satisfy the requirement for R-49 wherever the full height of uncompressed R-38 insulation extends over the wall top plate at the eaves. This reduction shall not apply to the U-factor alternative approach in Section R402.1.3 and the total UA alternative in Section R402.1.4.

Section R403.2.2 Ducts requires R-8 duct insulation on all supply lines in attics and has a total duct tightness requirement of 4 cubic feet per minute per one hundred square feet of conditioned floor area (with handler) at 25 Pascal. This is equal to 28 cfm per ton of AC capacity at one ton for each 700 square foot of conditioned floor area, which is 7% of the flow. Ducts that are located completely inside the building thermal envelope are exempt from the duct insulation requirement or the total duct leakage requirement. In addition, it requires that air handlers have an air leakage rate of no more than 2% of the design air flow rate, tested in accordance with the ASHRAE 193 standard.

2.1.4 Alignment with Zero Net Energy Goals

The proposed modifications to the residential standards are aligned with California's ZNE goals, and are supported by the current IOU residential single family new construction program, California Advanced Homes Program (CAHP).

A guiding principle for the "Road to ZNE" project[9] is that the ZNE goals will be most beneficial to California if a proper loading order is established. The loading order or 'steps to ZNE buildings' include (also see Figure 1):

- Minimizing building loads
- Optimizing system efficiency based on equipment efficiency, installation, and usage patterns

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[8] http://publicecodes.cyberregs.com/icod/iecc/2012/icod_iecc_2012_re4_sec002.htm

[9] The Road to ZNE Report CALMAC PGE0327.01

- Using highest efficiency appliances, such as high efficacy lighting
- Optimizing building operations to better meet occupant and energy efficiency needs, including controlling plug loads
- Improved occupant interactions with the building
- Renewable power generation when feasible and as a last step for a ZNE building

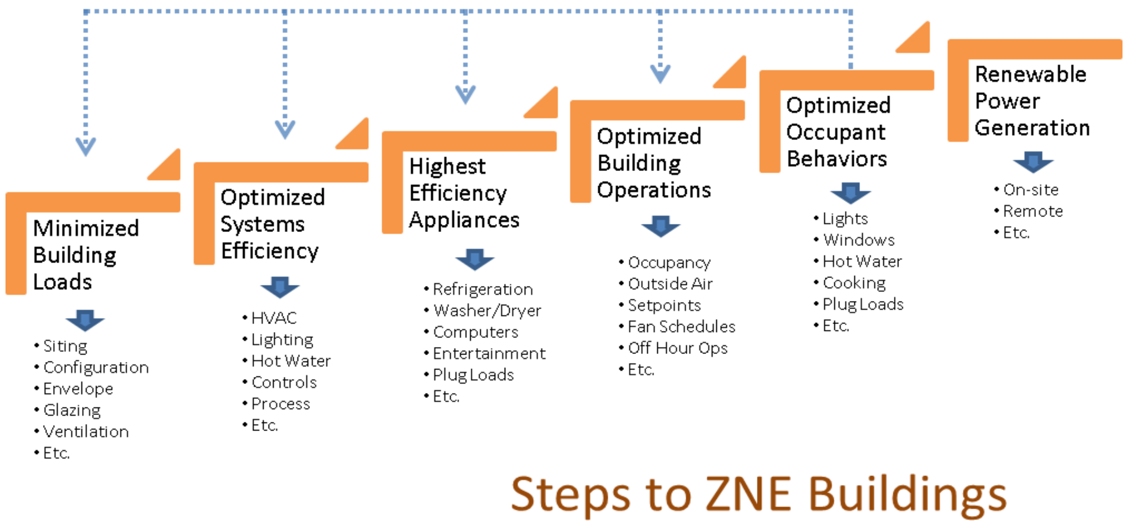

Figure 1: Steps to Achieving ZNE Designs for Individual Buildings

The *Road to ZNE* report highlights the importance of prioritizing energy efficiency before employing renewable power generation to meet ZNE for all buildings. The first step is to minimize building loads, which is the goal of this CASE measure.

Additionally, the proposal for ducts in conditioned space aligns with the recommendation in the *Technical Feasibility of Zero Net Energy Buildings in California* report written by ARUP for the California IOUs.[10]

Section 7.1.5 Residential Ducts in Conditioned Space of the study describes the ZNE rationale to support ducts in conditioned space (underlines provided by the Statewide CASE Team for emphasis)[11].

> *"The State will always be challenged in meeting its efficiency goals, and in particular in meeting its peak load reduction goals, if residential air conditioning systems are operating in high temperature attics. There are a number of viable ways to solve this challenge, and builders should be provided with a host of options to do so. <u>The most promising approach from a constructability standpoint appears to be moving the entire HVAC system out of the attic.</u>*

[10] http://www.energydataweb.com/cpucFiles/pdaDocs/904/California_ZNE_Technical_Feasibility_Report_Final.pdf

[11] Page 52 of the *Technical Feasibility* Report linked in the previous footnote

A better insulated home, with high performance windows, proper orientation, and ducts in the conditioned space can have considerably lower air conditioning loads than does a standard home today. That reduced load, in turn, allows for a much smaller duct system to provide the necessary cooling. The reduced duct sizing facilitates installation when the HVAC system is no longer located in the attic. Hydronic delivery systems are another viable strategy, with additional potential fan energy savings.

Recommendation: Rather than continuing to focus on ways to reduce attic temperatures, it appears that residential building standards should instead work towards moving HVAC systems within the conventional building envelope. Isolating the home from attic heat is then a much simpler problem, solved by adding additional blown-in insulation (perhaps with a raised heel truss). A builder could, through the Title 24 performance compliance process, achieve the same energy benefits by providing sufficient insulation at the roof deck if the builder preferred that method.

2.1.5 Relationship to Other Title 24 Measures

This DCS/HPA CASE topic is synergistic with the Residential High Performance Walls topic as both studies propose ways to increase the energy performance of building envelope, which reduces the equipment and duct size requirements.

2.2 Summary of Changes to Code Documents

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

2.2.1 Catalogue of Proposed Changes

Scope

Table 6 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 6: Scope of Code Change Proposal

Mandatory	Prescriptive	Performance	Compliance Option	Trade-Off	Modeling Algorithms	Forms
N	Y	Y	Y	Y	Y	Y

Standards

The proposed code change will modify the sections of the California Building Energy Efficiency Standards (Title 24, Part 6) identified in Table 7.

Table 7: Sections of Standards Impacted by Proposed Code Change

Title 24, Part 6 Section Number	Section Title	Mandatory (M) Prescriptive (Ps) Performance (Pm)	Modify Existing (E) New Section (N)
150.1	Performance and Prescriptive Compliance Approaches for Newly Constructed Residential Buildings	Ps, Pm	E
150.1 (b)	Performance Standards: 4. Compliance Demonstration Requirements for Performance Standards B iii. Low Leakage Air Handler	Pm	E
150.1 (c)	Prescriptive Standards: 1. Insulation A. Roof/Ceiling insulation 2. Radiant Barrier 9. Space Conditioning Ducts 11. Roofing Products 12. Ventilation Cooling Table 150.1-A COMPONENT PACKAGE-A Standard Building Design Roofs/Ceilings Radiant Barrier Ducts: Duct Insulation and Leakage	Ps	E/N

Appendices

The proposed code change will modify the sections of the indicated appendices presented in Table 8. If an appendix is not listed, then the proposed code change is not expected to have an effect on that appendix.

Table 8: Appendices Impacted by Proposed Code Change

RESIDENTIAL APPENDICES		
Section Number	Section Title	Modify Existing (E) New Section (N)
RA2	Residential HERS Verification, Testing, and Documentation Procedures	E
RA3	Residential Field Verification and Diagnostic Test Protocols	E
RA4	Eligibility Criteria for Energy Efficiency Measures	E

Modifications will be made in the Residential Appendix to field testing procedure requirements and protocols associated with each of the DCS approaches and the HPA package. The proposed code change will modify Residential Appendices RA2 for HERS verification, testing, and documentation procedures, RA3 for residential field verification and diagnostic test protocols, and RA4 for eligibility criteria for energy efficiency measures. The proposal will update Table RA2-1 Summary of Measures Requiring Field Verification and Diagnostic.

The proposed measure will require updates, deletion, and consolidations to the following subsections of RA3 for verification of installing ducts in conditioned space and quality insulation installation:

3.1 Field Verification and Diagnostic Testing of Air Distribution Systems
Table RA3.1.2 – Duct Leakage Verification and Diagnostic Test Protocols and Compliance Criteria
3.1.4 Verification and Diagnostic Procedures
3.1.4.1 Diagnostic Supply Duct Location, Surface Area and R-value[12]
3.1.4.1.1 Verified Duct System Design:
3.1.4.1.2 ~~Verification of 12 Linear Feet or Less of Duct Located Outside Of Conditioned Space~~[13]
3.1.4.1.2 Verification of Ducts Located In Conditioned Space
3.1.4.1.4 Verification of Supply Duct Surface Area Reduction
3.1.4.3.8 Verification of Low Leakage Ducts in Conditioned Space Compliance Credit
3.1.4.3.9 Verification of Low Leakage Air-Handling Unit with Sealed and Tested Duct System
3.5 Quality Insulation Installation Procedures
3.5.1 Purpose and Scope
3.5.3.3 – Roof/Ceilings (Batt and Blanket)
3.5.3.3.1 Special Situation – Enclosed Rafter Ceilings
3.5.3.3.2 Special Situations – Attics and Cathedral Ceilings
3.5.4.3 – Roof/Ceilings (Loose Fill)
3.5.5.3 – Roof/Ceilings (Rigid Foam Board)
3.5.6.3 – Roof/Ceilings (SPF)
3.5.6.3.2 Special Situations – Attics and Cathedral Ceilings

The proposed measure will require minor modification to RA4 Eligibility Criteria for Energy Efficiency Measures:

4.2 Building Envelope Measures
4.2 Radiant Barrier[14]
4.2.1.1 For Prescriptive Compliance: The attic shall be ventilated[15]

Residential Alternative Calculation Method (ACM) Reference Manual

The proposed code change will modify the sections of the Residential Alternative Calculation Method References identified in Table 9.

Table 9: Sections of ACM Impacted by Proposed Code Change

Residential Alternative Calculation Method Reference		
Section Number	**Section Title**	**Modify Existing (E) New Section (N)**
2.3	Building Envelope	E

[12] This proposal will add requirements for air handler location within conditioned space

[13] This existing compliance option is proposed to be removed

[14] The organization of subsection 4.2.1.1 regarding ventilation under 4.2.1 Radiant Barrier appears to be a mistake in the Residential Appendix.

[15] This subsection does not have a title. Instead, it just started off with the requirement text.

2.4	Building Mechanical Systems	E
2.6	Attics	E
Appendix C	Special Features	E

Simulation Computer Engine Adaptations

Some of the proposed code changes cannot be modeled using the current simulation engine. Changes to the simulation engine are necessary and the CEC and their contractors (CBECC-Res team) are actively working on implementing changes to enable modeling of the following features:

- Unvented attics – the CBECC-Res team has developed draft rule sets and procedures that were used for this CASE analysis in a research version of the software. These rule sets need to be expanded and incorporated into the production version of the CBECC-Res software.
- Ductless systems – Hydronic radiant floor and/or ceiling systems need review to ensure correct simulations are being done by the software. The CEC is currently engaging manufacturers of ductless heat pump systems to ensure that the CBECC-Res software calculates energy performance of these systems appropriately. As of the writing of this report, the software does not model ductless systems with listed efficiency features. Instead the software considers ductless systems to have the same efficiency as the baseline Split DX system (i.e. they are assumed to have “virtual ducts” that are in the attic).
- Insulated roof tile – There is currently at least one manufacturer (Green Hybrid Roofing) that makes a roof tile that has integrated insulation and is lighter weight than standard roof tiles. The CBECC-Res team is currently developing protocols to model this product in the tool since it is not a ‘standard’ option currently available in the software.
- Make the standard design the same for all options - Currently standard design changes based on change in proposed design for attic measures. This has been fixed by CBECC-Res team in the research version provided to the Statewide CASE team and will be implemented in the production version of the software before the 2013 standards come into effect.

2.2.2 Standards Change Summary

This proposal would modify sections of the Building Energy Efficiency standards as shown in Section 2.2.1. See ***Section 6.1 Standards*** of this report for the detailed proposed revisions to the standards language.

2.2.3 Standards Reference Appendices Change Summary

This proposal would modify the following sections of the Standards Appendices as shown in Section 2.2.1. See ***Section 6.2 Reference Appendices*** of this report for the detailed proposed revisions to the text of the reference appendices.

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

This proposal would modify the following sections of the Alternative Calculation Method (ACM) Reference Manual as shown in Section 2.2.1. See ***Section 6.3 Reference Appendices*** of this report for the detailed proposed revisions to the text of the Alternative Calculation Method (ACM) Reference Manual.

2.2.5 Compliance Forms Change Summary

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

2.2.6 Simulation Engine Adaptations

Please see Section 2.2.1 for these details.

2.2.7 Other Areas Affected

No other areas affected.

2.3 Code Implementation

2.3.1 Verifying Code Compliance

For the DCS strategies, visual inspections and associated compliance forms (installation and verifications) are required to confirm that duct and air handler location match the design strategy selected and duct leakage rate is within the allowed threshold. The proposed DCS package does not alter the procedure and requirement for compliance verification by code enforcement staff, with the exception of the unvented attic option.

Existing 2013 Title 24 requirements to be carried over to 2016 Title 24:

- Total duct leakage test is a mandatory requirement that applies to all new construction buildings, regardless of the DCS/HPA strategy chosen
- Ducts entirely in conditioned space: visual inspection
- HERS verified ducts entirely in conditioned space with low leakage ducts: visual inspection and duct leakage to outside HERS test

New proposed requirement:

- Unvented attic: visual inspection and duct leakage to outside HERS test

The proposed HPA features are currently verified by field inspection. Duct leakage, which is a mandatory requirement under the 2013 Standards, already requires testing and verification. The enforcement process does not change. However, duct leakage to outside test is not required. Duct insulation is currently required in 2013 and this code change requires additional insulation in some climate zones. This however should not change field inspection protocols that already exist to verify duct insulation.

New inspection requirements are needed to ensure that insulation installed directly above or below the roof deck are installed correctly. These requirements need to be coordinated with the overall QII verification requirements.

Reduced duct surface area is an existing compliance option and requires verification and documentation. In order to demonstrate and claim credit, builders and their designer and contractors must provide a duct layout and specify all duct sizes on the plans and provide surface area calculations. Raters and inspectors need to verify the installed duct design and layout and surface area calculations. The Statewide CASE Team proposes that the compliance software be improved to include duct surface area calculations. This way, it will become easier for the inspector to verify accuracy of information on the HERS forms.

2.3.2 Code Implementation

As proposed, the DCS strategy will change from being a compliance option to one of the available methods to meet the prescriptive requirements for roofs/ceilings. DCS strategies require increased coordination among builders, designers and HVAC contractors during the planning process as well as construction to effectively communicate design strategies and specific construction guidelines and techniques. Depending on the strategy chosen for DCS, other contractors such as roofers, framers, insulation installers, plumbers, and electricians may be impacted. There will inherently be a learning curve for every DCS and HPA strategy, while builders investigate and implement various strategies, and contractors become comfortable with and understand the change in design and construction.

If adopted, these measures would mainly affect HVAC, roofing and insulation contractors, all of whom are familiar with Title 24 code verification requirement such as duct leakage tests and QII though they may have not direct experience with these procedures.

Some builders and the CBIA have identified concerns about costs associated with increased design, planning, and implementation of these strategies. Certain strategies to meet the proposed requirements, such as polyurethane spray foam for roof deck insulation, could have relatively high incremental cost. However, the proposed requirements are based on measures and materials that are cost-effective using the CEC LCC calculations and are designed to provide a variety of design options. Thus builders can choose a measure or combination of measures that are most compatible with their design and match their construction practices, and cost considerations.

There are potential moisture management issues associated with roof deck insulation if proper installation procedures are not followed. The Statewide CASE Team has worked with industry stakeholders to identify potential solutions. Manufacturers of insulation and roof products have various methods of alleviating moisture issues that must be followed to ensure that the roof maintains structural and hygrothermal integrity.

Reducing duct surface area is currently a compliance option, but has not been widely used because of the difficulty and time required for documentation and verification. The procedure for demonstrating compliance may become easier to perform if HVAC system designs are more integral pieces of the overall building design. There are additional costs associated with HERS verification.

2.3.3 Field Verification and Diagnostic Testing

The DCS and HPA proposals make use of the following field verification and diagnostic testing requirements in the current 2013 Title 24 standards:

- Duct leakage test: diagnostic testing; mandatory for all new construction
- House pressurization test: diagnostic testing for compliance credit
- Verified low leakage with ducts entirely in conditioned space: visual inspection and field diagnostics test that run a duct leakage test and house pressure test tougher for compliance credit

Field verification and diagnostic tests that do not currently exist, or will be modified in the standards include:

- Roof deck insulation installation: to verify proper moisture management - field verification
- Insulation and air sealing requirements to ensure that mechanical closets are inside the conditioned space: add language to the compliance forms for Ducts Entirely in Conditioned Space and the Verified case

2.4 Issues Addressed During CASE Development Process

The Statewide CASE Team solicited feedback from a variety of stakeholders when developing the code change proposal presented in this report. In addition to personal outreach to key stakeholders, the Statewide CASE Team conducted a public stakeholder meeting to discuss the proposals. The issues that were addressed during development of the code change proposal are summarized below.

Moisture Management with Insulation at Roof Deck – Based on our review of studies and conversations with a number of home builders with implementation experience and insulation manufacturers (spray foam, blown-in fiberglass), the Statewide CASE Team concludes that solutions and precautions, including proper sealing and insulation installation are available to address the issue (APA 2011; BA 2010, 2013; BSC 1998, 2007, 2011b; and ICC-ES) . See Sections ***9.1.4 (DCS)*** and ***9.2.1 (HPA)*** for additional details.

Fire Rating – Roofing product manufacturers raised the concern that above deck insulation will void their products' fire rating classifications. This is especially a concern for products used in Wildlife Urban Interface (WUI) regions, which require a Class A fire rating. The primary issue is that roof assemblies including above roof deck insulation (typically rigid foam board) have not yet been tested.

The Statewide CASE Team researched California's building fire code and relevant sections of Building Mechanical Codes to investigate the issues. The Team also collected information on insulation product fire rating requirements and extensive product specification searches. The Team then engaged and discussed the issues with roofing and insulation manufacturers and the Office of the State Fire Marshal to discuss implications from the code change proposal. From the Statewide CASE Team's discussions with the roofing industry representative and the Office of the State Fire Marshal representative, the specific application of above-deck insulation indeed affects the fire rating of the roof covering products. Even though the components of the roof assemblies (the insulation, the deck, and the roof coverings) all meet their respective fire rating tests, further testing for certification purposes is required for roofing assemblies incorporating above-deck insulation products. See ***Section 13*** for more information.

Ventilation for Roofing Products – Roofing manufacturers raised concerns that above-deck insulation physically prevents ventilation between the roof covering and deck below, causing the products to experience higher temperature and resulting in shorter product life. Through roof and insulation product research, review of Asphalt Roofing Manufacturers Association (ARMA) literature recommendation and discussion with a roof manufacturer, the Team identified solutions to provide roof product ventilation when using above-deck insulation. Roofers may either use spacers (for asphalt shingles) or counter/elevated batten and other specialty products (for tile) to maintain the small gap to provide adequate ventilation under the roofing products. The CEC, Statewide CASE Team, and ARMA are working together to provide more detailed guidance on installation practices for use of above-deck insulation products in the Residential Compliance Manual. This guidance will be developed after the code changes are finalized. See ***Section 9.1.4 (DCS - Unvented Attic) and 9.2.1 (HPA)*** for more information.

Treatment and Test Requirement of Duct Leakage to Outside for DCS Strategies – There was concern that the duct leakage to outside test was onerous to perform, and that HVAC contractors may find it hard to perform. For 2013 Title 24, this test is only required and performed if a builder chooses to apply for additional credit when placing ducts in conditioned space. It involves a simultaneous house pressurization and duct leakage test. This test will likely be performed by a HERS rater because, according to industry interviews, most HVAC contractors do not have a blower door in their possession. HERS raters are equipped with and should have the necessary knowledge to conduct the required test. The test is repeatable and dependable and such, the Statewide CASE Team proposes to require this test in the 2016 Title 24 if a builder chooses the DCS path to meeting the proposed prescriptive requirements.

Use of Sealed Combustion Furnace – There was a concern that the requirement to place air handlers into conditioned space (as part of the DCS strategy with vented attics) is federally pre-empted because it will require sealed combustion furnaces. Currently, sealed combustion furnaces are not widely installed because placing equipment in conditioned space is not common. The majority of available products are condensing units that exceed the 80% AFUE set as the minimum in Title 20. However, the pre-emption concern is addressed by the fact that the Statewide CASE Team is not proposing DCS as the only option to meet the proposed requirements. Instead, the Statewide CASE Team proposes DCS to be an alternative prescriptive path to the HPA package which continues to use equipment that meets the federal appliance standards and does not have pre-emption concerns. See details in ***Section 3.1.1***.

3. MARKET ANALYSIS

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market players. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. Estimates of market size and measure applicability were identified through research and outreach with key stakeholders including utility program staff, CEC, and a wide range of industry players who were invited to participate in a public stakeholder meeting that the Statewide CASE Team held in May 2014. It bears repeating that both of these options are for prescriptive compliance and can be traded off against other efficiency measures if, as is common in new construction, the performance compliance path is used.

3.1 Market Structure

It is important to note that almost every Zero Net Energy (ZNE) or ZNE-capable or near-ZNE building designed and constructed in the state has included one or the other option for DCS/HPA. In this section, we identify the available products for achieving these strategies and the principal manufacturers/suppliers. The market structure descriptions demonstrate that these design strategies are achievable and products available from multiple providers. Discussions on market penetrations of these strategies and measures and viabilities are included later in the report, in Section 3.2 titled Market Availability and Current Practices.

3.1.1 Ducts in Conditioned Space (DCS)

DCS is primarily a design strategy that is achieved in the field through a set of construction techniques. In other parts of the country with conditioned basements, DCS is a very common practice. Successful examples have been demonstrated through California's builder experience, California High Performance (CAHP) building programs and utility Emerging Technology projects. DCS as discussed in this report involves having both ducts and air handler within the building's thermal envelope or keep them out of unconditioned attics. There are several methods of achieving the design intent of the DCS approach as outlined in this section, which allows a homebuilder to select a method that works best with their design and construction practices.

Vented Attic Strategies

Vented attic strategies for installing ducts in conditioned space include the use of dropped ceiling, or the use of conditioned plenum space, or the use of open floor truss. The first two strategies involve additional framing, drywall and sealing to create the "new conditioned space" for duct runs which can be above or below the ceiling plane. Scissor truss or plenum trusses can be used to create the furred-out conditioned plenum. Major manufacturers of trusses include national companies Alpine and MiTek as well as various regional companies.

Construction materials associated with implementing these two strategies are widely used in residential new homes today.

Open-web floor trusses are a commonly available component in residential construction from floor joist manufacturers such as RedBuilt, TrimJoist, SpaceJoist and Open Joist.

Use of vented attic DCS strategies requires placement of the furnace in conditioned space as well. This can be done in various ways depending on the dwelling floor plan.

Unvented Attic Strategies

Implementation of an unvented attic involves installation of roof deck insulation products and sealing the interior space to roof junction which can be above the ceiling. A wide variety of roof deck insulation products are available; names of manufacturers organized by their product types are presented in Table 10 and Table 11.

Since the primary insulation layer in a building with unvented attic is at the roof deck, below-deck spray polyurethane foam is typically used to achieve the higher insulation value needed. However, unvented attic construction can also utilize a combination of above- and below-deck insulation at the roof deck. Even though an unvented attic construction allows the ducts and equipment to remain in the attic space, only direct vent furnaces or air handlers can be installed. Builders who do not want to use direct vent furnaces can chose to build an HPA. Also, some builders are using a hot water coil in an air handler for heating. This system is known as "combined hydronic" since the same water heater is used for both heating and domestic hot water. This approach meets the "in conditioned space" requirement by allowing the air handler to be in an indoor location. Finally, a builder has to option to install a ductless system of which there are multiple types and equipment choices available.

Roof Deck Insulation

Roof deck insulation can either be placed above deck with rigid insulation or below deck with a number of insulation types available.

Above Deck Insulation

Rigid insulation, also called foam board or board insulation, is a viable method of reducing thermal bridging and heat transfer through the roof. There are three main product types available for application above a roof deck:

- Polystyrene
- Polyisocyanurate
- Polyurethane

Polystyrene comes in two types: Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS); both are water resistant. XPS typically has a slightly higher R-value per inch (R-5 compared to R-4) and lower water permeability than EPS.

Polyisocyanurate (polyiso) has the highest R-value per inch and can be air and water impermeable depending on the facing. The polyiso industry has also has products available with integrated nailable bases. Products with integrated nailable bases come with spacers on top of the rigid board that support a wood sheathing layer. The design provides the nailable base needed for installation with asphalt shingles as well as more roof for continuous ventilation below the roofing products to prolong product service life[16].

Polyurethane foam board can come in open or closed-cell forms. All closed-cell products are air and water impermeable (when applied with a layer thicker than 2"), while some open-cell products are not, and closed-cell generally has a higher R-value per inch. Above deck product types by manufacturer are provided in the table below:

Table 10: Above-Deck Insulation Types and Manufacturers

Above-Deck Insulation Type	Company/Manufacturer
Polystyrene (EPS and XPS)	ACH Foam Technologies, Atlas Roofing, Dow Chemical, INSULFOAM, Owens Corning Foam
Polyisocyanurate (Polyiso)	Atlas Roofing, Carlisle Syntec, Dow Chemical, Hunter Panels
Polyiso + nail base	Atlas Roofing, Hunter Panels, Thermasote
Polyurethane Board	Dow Chemical, Duna USA, Dyplast Products, ITW Insulation Systems

Below Deck Insulation

There are several product options and manufacturers for below-deck insulation. A sample of manufacturers is provided in Table 11. Cellulose and mineral wool insulation are available both as batt and loose fill products. Batt is the least expensive option but must be supported to prevent sagging. Loose-fill and blown-in are better than batt in hard to fill spaces (DOE 2012). Even though loose-fill installation requires a netting system and special equipment, it still tends to be less expensive than spray polyurethane foam (SPF) but does not provide the air seal provided by SPF. Both open cell and closed cell SPF are the more expensive options for below-deck application, but they provide better air-sealing and closed cell SPF provides better moisture migration prevention abilities[17]. "Flash-and-batt" methods that combine spray foam for sealing and batt or loose fill for insulation value are also an option.

[16] Example product images are available at http://www.polyiso.org/

[17] Both open-cell and closed-cell spray foam can act as air barriers (when a layer thicker than 2" and 5 ½" is used for open-cell and closed-cell respectively). In terms of vapor permeability, open-cell is moisture permeable and needs a vapor retarder on its interior surface, and closed-cell is a Class II vapor retarder at more than 2".

Table 11: Below-Deck Insulation Type and Manufacturers

Below-Deck Insulation Type	Company/Manufacturer
Batt (Cellulose or Mineral)	Applegate Insulation Systems, Bonded Logic, Bay Insulation of California, CertainTeed
Loose Fill/Blown-in (Cellulose or Mineral)	Applegate Insulation Systems, Cell Park, CertainTeed, Guardian Fiberglass Insulation, Hamilton MFG Inc.
Spray Polyurethane Foam (open and closed cell)	Arnco Construction Products, BASF, Bayer Material Science, CertainTeed, Dow Chemical

Ductless Systems

Ductless systems may be used to meet the ducts in conditioned space criteria. Many HVAC equipment manufacturers carry a selection of ductless systems, as shown in the following table.

Table 12: Ductless System Type and Manufacturers

Ductless System Type	Manufacturers (sample)
Mini-split heat pump	Carrier, Daikin AC, Fujitsu General America, Gree Comfort, Lennox, Mitsubishi, Ramsond, Trane
Hydronic system	Baxi, Grand Hall Enterprises Co. Ltd., HTP Inc., Noritz America Corp., Takagi Industrial, Rheem, Heat Transfer Products, Daikin, Aermec.
PTAC/PTHP	ACP International Ltd., Airedale North America, Carrier, Daikin AC, General Electric, Gree Comfort, Sharp Electronics

3.1.2 High Performance Attics (HPA)

An HPA is vented to the level required by code and is made efficient by implementing a set of efficiency measures. The HPA prescriptive requirement is adding roof deck insulation below the roof deck, raising the duct insulation level to R-8 across all climate zones, lowering the total duct leakage rate to 5% of rated air handler airflow, and for a few climate zones increasing the insulation between the attic and the conditioned space from the current level of R-30 to R-38.

Ceiling Insulation

A variety of insulation types and products are typical for ceiling installations. The same product categories and major manufacturers as described in the previous section on below deck insulation apply to ceiling insulation; batt and loose-fill insulation types are the most common.

Table 13: Ceiling Insulation Type and Manufacturers

Ceiling Insulation Type	Company/Manufacturer
Batt (Cellulose or Mineral)	Applegate Insulation Systems, Bonded Logic, Bay Insulation of California, CertainTeed
Loose Fill/Blown-in (Cellulose or Mineral)	Applegate Insulation Systems, Cell Park, CertainTeed, Guardian Fiberglass Insulation, Hamilton MFG Inc.

Insulated Roof Tiles

A newer type of product is now available in the market that combines concrete/clay tiles with insulation as a packaged product. A product developed by Green Hybrid Roofing called Engineered Roof Tiles incorporates a 2 lb. density EPS foam core encapsulated in polymerized concrete. These tiles are lighter than typical roof tiles and have better thermal performance than traditional tiles due to the insulation core.

Furnaces

There are no specific requirements for direct vent furnaces because the HPA is vented.

Duct Insulation

Duct insulation may come in the form of a wrap or jacket to be installed over ducts. Duct insulation may also be an integration part of duct and ductboard products. Major insulation type and manufacturers are listed in the table blow.

Table 14: Duct Insulation Type and Manufacturers

Duct Insulation Type	Company/Manufacturer
Duct Wrap (cellulose or mineral fiber)	Carlisle Syntec, CertainTeed, Garudian Fiberglass Insulation, Johns Manville, Knauf Insulation, M-D Building Products; Owens Corning,
Duct Liner Board	Owens Corning, CertainTeed, Knauf

Duct Leakage

Lowering duct leakage may be accomplished by two primary ways: through better duct installation practices and through the use of equipment with lower leakage rate (such as use of Low Leakage Air Handlers as defined and certified by the CEC). According to the 2013 CEC database, the major manufacturers with certified LLAH are listed in the following table.

Table 15: Low Leakage Air Handler Manufacturers

Type	Company/Manufacturer
LLAH	Bryant Heating & Cooling Systems, Carrier Corporation, Goodman Manufacturing Co., International Comfort Products, Payne Heating and Cooling, Rheem Sales Company, Lennox Industries

Standard duct installations in CA often meet or exceed the mandatory duct leakage requirement (less than 6%) in Title 24. The CHEERS database tracks actual duct leakage rates, and the Statewide CASE Team was provided a copy of the measured duct leakage values for a sample of homes constructed in 2012 by CEC Staff with access to the CHEERS registry.

Analysis of these homes show that more than half of the homes were tested with duct leakage at 5% or less of nominal air handler airflow as seen in the figure below.

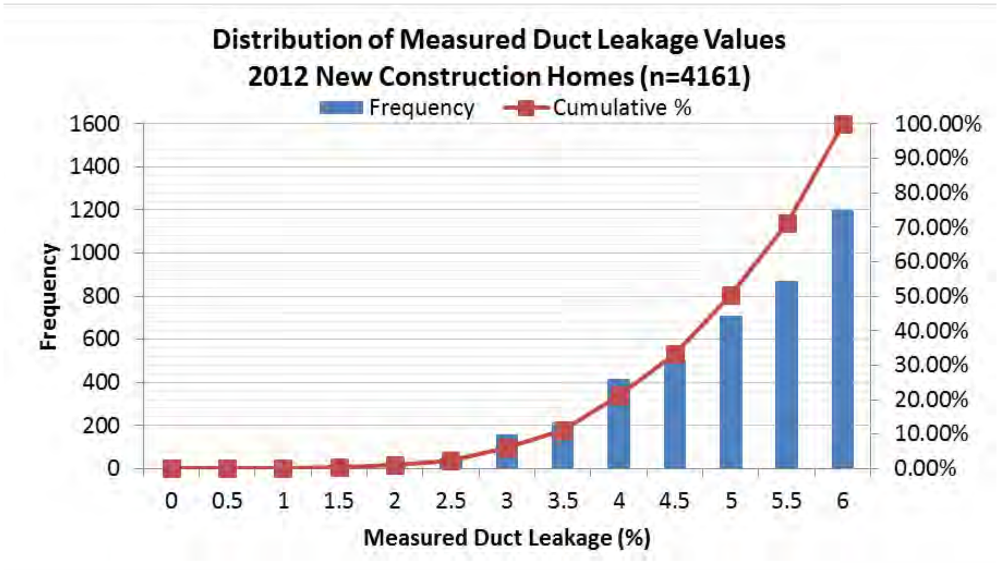

Figure 2: Measured Duct Leakage Values for a Sample of 2012 New Construction Homes

The CASE team supplemented this with interviews with industry experts. These experts also confirmed that reducing duct leakage below the current 6% requirement is common among advanced new home construction in California where HERS testing has been required for a while and there is overall intent to improve building performance.

Roof Deck Insulation

The analysis of the roof deck insulation market is in Section 3.1.1.

3.2 Market Availability and Current Practices

3.2.1 Overview of Market Acceptance of DCS/HPA

DCS and HPA strategies are relatively new to the market place; however, a growing number of builders (production and custom) are including these strategies in their high performance homes as shown in Table 16. Almost all ZNE homes in the state and elsewhere incorporate one of the methods being proposed in this CASE measure.

Table 16: Home Builders in California with DCS Strategy Experience

Strategy Implemented	Builders with DCS strategies implementation experience
Dropped ceiling	Elliott Homes, De Young Properties, GJ Gardner
Conditioned plenum	Pulte Homes, K. Hovnanian Homes, GJ Gardner, Wathan Castanos, Northwest Homes
Unvented attic	Meritage Homes, RJ Walter Homes, Mission West Properties, Inc., Shea Homes, KB Homes, Brookfield Homes
Ductless systems	Brookfield Homes

There are several efforts underway in California and nationally to support DCS/HPA such as:

- California utilities Emerging Technology Projects: PG&E, SCE, SMUD
- National Programs
  - DOE Building America[18]
  - DOE Challenge Home[19] - Now called "DOE Zero Energy Ready Home" as of April 21, 2014
- National Association of Home Builders (NAHB) Home Innovation Research Lab guidelines for ducts in conditioned space[20]

Table 17 provides a snapshot of the strategies promoted by these national programs and California utilities:

Table 17: Ducts in Conditioned Space Strategies in High Performance Building Programs

Design Strategy	CA Utilities Emerging Technology Programs			National Programs	
	PG&E	SCE	SMUD	Building America	DOE Challenge Home
Dropped ceiling	●			●	●
Conditioned plenum	●	●		●	●
Open web truss				●	●
Unvented attic	●	●	●	●	●
Ductless systems	●	●			●

The California Emerging Technologies (ET) programs have successfully implemented DCS and HPA strategies throughout California as summarized in Table 18. The programs have produced case study reports to assist and inform builders about the opportunities, benefits and findings when adopting advanced building practices such as DCS. The PG&E ZNE pilot

[18] U.S. Department of Energy. EERE, Building America: http://www.energy.gov/eere/buildings/building-america-bringing-building-innovations-market

[19] U.S. Department of Energy. EERE, Challenge Home: http://www.energy.gov/eere/buildings/doe-challenge-home

[20] http://toolbase.org/pdf/techinv/ductsinconditionedspace_techspec.pdf

project has five builders participating with a total of eight homes. The projects are a mix of single story and two-story houses ranging from 1,800 to 3,200 square feet located in various northern California climate zones and have implemented dropped ceilings, sealed attics and modified trusses. The SCE Green Door project is a two-story 1,828 square foot house with a sealed attic with closed-cell spray polyurethane foam below the roof deck and installation of ductless mini-split heat pump system. The PG&E and SCE teams collect valuable implementation technique information. To characterize the energy performance of these projects, the teams performed house pressurization and duct leakage tests. The ET teams also performed continuous performance monitoring on a subset of these buildings to enable deeper assessment of the various strategies implemented. SMUD's Home of the Future program has three project homes, located in Sacramento, that implemented sealed attics through roof deck insulation and, in one case, structurally insulated panels (SIPs) roof.

Table 18: High Performance Building in California with DCS/HPA

Project Type	Roof/Ceiling	Ducts & Indoor Equipment	CZ	Status/Number of Homes Built
Production Bldr	conditioned plenum above ceiling plane using modified truss	Indoor mechanical closet with ducts in conditioned plenum	13	starting construction on five homes
Production Bldr	conditioned attic with R-30/38 spray foam under roof deck	ducts and equipment in conditioned attic	Various	have been building this way since 2011; 3700 built/sold in CA to date, 18,000 nationwide
Production Bldr	R-38 + air barrier, conditioned plenum above ceiling plane	Indoor mechanical closet with ducts in plenum	11	under construction
Production Bldr	conditioned plenum space	ducts in conditioned plenum, furnace in interior closet or unconditioned attic	Various	production advanced houses
Production Bldr	dropped ceiling below ceiling plane	ducts in dropped ceiling projects; considering open web floor truss	12	production advanced houses
Production Bldr	ccSPF below deck	Multi mini-splits (ductless)	10	ZNE production house
DOE Challenge Home	R-22 blown-in with netting	ducts and equipment in conditioned attic	10	construction complete
Modified existing	R-11 batt at roof deck; R-38 ceiling insulation	R-8 attic ducts; 4% duct leakage	12	construction complete
Test House	R-38 + air barrier, conditioned plenum above ceiling plane using modified truss	Indoor mechanical closet with ducts in conditioned plenum	13	complete, considering another test house
Demonstration House	conditioned attic; spray foam(R-50) insulation + air barrier at roof deck	ducts and furnace in conditioned attic	12	SMUD Home of the Future

Project Type	Roof/Ceiling	Ducts & Indoor Equipment	CZ	Status/Number of Homes Built
Demonstration House	conditioned attic; insulation + air barrier at roof deck (R-38)	ducts and furnace in conditioned attic	12	SMUD Home of the Future
Demonstration House	dropped ceiling below ceiling plane; R-49 blown-in with RB in the attic	ducts and handler in dropped ceiling	13	ZNE demonstration house
Production Builder	Typical	Multi mini-splits (ductless)	1	26 lots planned

In addition to California, there are builders implementing these strategies in other parts of the nation, as shown in Table 19. Although construction practices are not always aligned throughout the U.S., these builders have implemented the techniques discussed in this study.

Table 19. High Performance Building in the U.S. with DCS/HPA

Project Type	Roof/Ceiling	Ducts & Indoor Equipment	CZ	Status/Number of Homes Built
Production Builder	conditioned attic with netted blown cellulose	ducts in conditioned attic	Las Vegas NV	started building this way since 2008; ~1500/yr in Vegas metro area
Production Builder	spray foam under roof deck	ducts in conditioned attic	San Antonio TX	for all its homes since 2008
Production Builder	vented attic with R-49 blown-in cellulose	ducts in dropped ceiling or open web truss; with interior mech closet	Northwest	4 test homes in 2008
Production Builder	vented attic with R-49 blown-in cellulose	ducts in open web truss with interior mech closet	Northwest	300 in 2008
Production Builder	vented attic with R-38 to R-42 blown-in cellulose	ducts in open web truss; handler in 2nd floor sealed utility closet	Seattle, WA	37 detached townhouses
Production Builder	vented attic with R-49 blown-in cellulose	ducts in open web truss; handler in sealed utility closet in the garage	Portland, OR	20 homes
Production Builder	R-38 open-cell spray foam under roof deck	ducts in conditioned attic; heat pump	Aztec NM	132 homes completed in AZ, NM and CO

The DOE Building America program utilizes national laboratories and research teams, including Davis Energy Group, Building Science Corporation, CARB (led by Steven Winters Associates), IBACOS, and six other teams to provide technical support and implementation expertise to investigate improved building practices. Publications from the Building America program are located in an extensive library[21] available to the public and industry members. These publications include research reports on ducts in conditioned space, reports, and findings from projects that have implemented advanced building strategies, and best practice guidelines for industry trades. Building American has established a Building America Solution Center to provide builders with detailed measure descriptions, code references, implementation tips, and case studies.

The DOE Zero Energy Ready Home program (ZERH, formerly Challenge Home) was established based on the innovation and best practices from the Building America program and applies and exceeds the requirements of Energy Star Version 3. The ZERH program provides builder resources and trainings, including marketing materials and access to profiles and case studies from participating builders. ZERH provides the opportunity for innovative builders who are early adopters and pursue high performance strategies such as DCS to receive recognition for their commitment and efforts.

3.2.2 Multiple Options for Ducts in Conditioned Space and High Performance Attics

As identified in Section 3.2.1 there are multiple methods that have been tried, tested, and used by various home builders across California as well as the rest of the nation. In Appendix B of this document, we provide details on these construction/design options and provide the potential pros and cons of the various options.

3.2.3 Need for Additional Training and Industry Support

Despite the increasing use of DCS design strategies, additional support to designers, builders, subcontractors (HVAC, insulation, drywall, etc.), and site superintendents is needed. Support would include design guidelines, fact sheets, training classes, product information, and informational materials. The placement of ducts in conditioned space requires planning and integration of the HVAC system with other building systems and components which is currently not common practice. It is essential to communicate the DCS plan from the beginning for successful implementation and avoidance of errors. In addition to coordination between designers and HVAC contractors, communication must occur with other building trades that might experience impacts to their routine schedules and installation practices. These trades will also require training to correctly implement these construction techniques. For instance, electricians and plumbers must be made aware of the HVAC design plans and where penetrations can and cannot be made, as has always been the case. In order to ensure plans and direction are followed, additional project oversight will initially be required.

The following are reports and best practice guidelines that provide insight and recommendations for trade coordination and design implementation from projects that have implemented DCS strategies, such as those listed above. A partial list of currently available (as of April 2014) resources is:

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[21] http://www1.eere.energy.gov/library/default.aspx?page=2&spid=2

- CEC 2003 Home Builders Guide to Ducts in Conditioned Space - http://www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-16.PDF
- CEC 2003 Residential Duct Placement: Market Barriers - http://www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-30.PDF
- DOE EERE Measure Guidelines: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts - http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-385-11.pdf
- DOE Building America Solution Center - https://basc.pnnl.gov/
- DuctsInside.org for Building with Ducts in Conditioned Spaces, 2011; a joint project by the DOE and Northwest Energy Efficiency Alliance (NEEA) - http://ductsinside.org/

California IOUs provide classes and trainings that are available to audiences including builders, architects, HVAC contractors, HERS raters, building inspectors, and other audiences. Current classes and trainings available from various resources include:

- PG&E's Pacific Energy Center (PEC) and the Energy Training Center (ETC):
  - Introduction to ACCA Quality Installation Training Series: ACCA Manual J – Equipment Sizing & Selection; Manual D and Advanced Manual D – Duct Design
  - Go Ductless California, Try Mini-Splits!
- SCE's Energy Education Centers:
  - Zero Net Energy Homes – Design Fundamentals, Integrated Project Delivery, Enclosures and Assemblies, Mechanical Systems

3.3 Useful Life, Persistence, and Maintenance

Field inspection and diagnostic tests where applicable help secure the energy savings from proposed measures. All of the measures proposed are assumed to last for the entire residential building lifetime of 30 years. See the Field Verification and Diagnostic Testing in *Section 6*.

The methodology the Statewide CASE Team used to determine the costs associated with incremental maintenance costs, relative to existing conditions, is presented in *Section 4.7.1*. The incremental maintenance costs of the proposed code change are presented in *Section 5.2.1*.

3.4 Market Impacts and Economic Assessments

3.4.1 Impact on Builders

The proposed DCS strategies will require designers to alter practices to implement these design changes. Depending on the design, trades that will see the most impact include roofers, insulation installers, framers, and HVAC contractors. There will be a learning curve to communicate the design intent, details, and associated testing requirements for the whole construction team. There are modest cost implications as well; details on implementation costs are provided in *Section 5.2.1*.

The proposed prescriptive HPA measure requires insulating the roof deck. For roof deck insulation, builders, and building material suppliers will likely have to develop new standard procedures to ensure the roof assemblies address fire rating and moisture management requirements.

3.4.2 Impact on Building Designers

Depending upon the proposed DCS strategies selected, the changes could involve quite small to fairly substantial changes to the design practices. The designers and architects would need to consider and integrate the HVAC equipment and layout into the house design. Enhanced coordination between designers and HVAC designer is needed for designs that include moving ducts into conditioned space. Currently, HVAC contractors are responsible for HVAC designs and layouts, but the system is not considered an integral component when planning the overall house design. Although there may be a modification in the design and planning process to focus around the HVAC system design, performing this step at the beginning of planning will minimize redesign and burden later in the construction process. A positive result of the increased efficiency of dwellings is that the cooling capacity needed for comfort can be cut in half compared to historical levels of one ton AC per 500 square feet of conditioned floor area. This cuts the air moving through the ducts in half allowing the ducts to be much smaller.

The proposed HPA approach has minimal impact on building design as it is simply adding a layer of insulation above or below the roof deck.

3.4.3 Impact on Occupational Safety and Health

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

3.4.4 Impact on Building Owners and Occupants

If the proposed measures are implemented according to their design intent, the building and their systems should provide the occupants a more thermally comfortable living space. Since this measure is cost-effective, building owners who pay their energy bills are reducing their energy costs more than the additional mortgage costs to pay for the incremental cost of the measure (i.e. there are experiencing net cost savings). For building occupants that are paying for their energy bills, since the measure saves more energy cost on a monthly basis than the measure costs on the mortgage as experienced by the building owner, the pass-through of added mortgage costs into rents is less than the energy cost savings experienced by occupants.

3.4.5 Impact on Retailers (including manufacturers and distributors)

The proposed DCS strategies may increase the demand for certain building products, such as various types of roof deck insulation, certified low-leakage air handlers and sealed combustion furnaces. The likely result is slightly greater income for these groups.

3.4.6 Impact on Energy Consultants

Energy consultants will continue to provide value by identifying and advising builders on design options and efficiency measures. Impact on energy consultants include understanding new prescriptive requirements and performance modeling rule sets as is the case each code cycle.

3.4.7 Impact on Building Inspectors

None of the field verification aspects associated with proposed measures are new to the standards and how building officials conduct inspections. For HPA the primary change to inspection is to inspect for roof deck insulation. For DCS, the primary inspection effort is to assure that all ducts and the air handler are not in the attic unless the attic is a conditioned attic.

3.4.8 Impact on Statewide Employment

The proposed measures will increase the demand for trades with specific skills, knowledge and experience working with these strategies and products. Examples of the increase workforce demand include:

- Roofing contractors with above-deck rigid foam boards installation experience.
- Insulation installers with roof deck product and procedures experience, including air sealing procedures for use of blow-in fiberglass below the roof deck and spray foam installers with appropriate certification.
- Framing contactors with experience incorporating modified trusses, such as raised heel, scissor or plenum trusses.

3.5 Economic Impacts

The proposed Title 24 code changes, including this measure, are expected to increase job creation, income, and investment in California. As a result of the proposed code changes, it is anticipated that less money will be sent out of state to fund energy imports, and local spending is expected to increase due to higher disposable incomes due to reduced energy costs.[22] For instance, the statewide life cycle net present value of this measure is $151 million over the 30 year period of analysis. In other words, utility customers will have $151 million to spend

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

elsewhere in the economy. In addition, more dollars will be spent in state on improving the energy efficiency of new residential buildings.

The economic impacts of energy efficiency in general (above and beyond this CASE initiative) are documented in several resources including the California Air Resources Board's (CARB) Updated Economic Analysis of California's Climate Change Scoping Plan, which compares the economic impacts of several scenario cases (CARB, 2010b). CARB include one case (Case 1) with a 33% renewable portfolio standard (RPS) and higher levels of energy efficiency compared to an alternative case (Case 4) with a 20% RPS and lower levels of energy efficiency. Gross state production (GSP)[23], personal income, and labor demand were between 0.6% and 1.1% higher in the case with the higher RPS and more energy efficiency (CARB 2010b, Table 26). While CARB's analysis does not report the benefits of energy efficiency and the RPS separately, we expect that the benefits of the package of measures are primarily due to energy efficiency. Energy efficiency measures are expected to reduce costs by $2,133 million annually (CARB 2008, pC-117) whereas the RPS implementation is expected to cost $1,782 million annually, not including the benefits of GHG and air pollution reduction (CARB 2008, pC-130).

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

3.5.1 Creation or Elimination of Jobs

CARB's economic analysis of higher levels of energy efficiency and 33% RPS implementation estimates that this scenario would result in a 1.1% increase in statewide labor demand in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b, Tables 26 and 27). CARB's economic analysis also estimates a 1.3% increase in small business employment levels in 2020 (CARB 2010b, Table 32). The proposed CASE measure contributes energy savings and increases in labor demand associated with achieving the "higher levels of energy efficiency and RPS" scenario in CARB's analysis.

3.5.2 Creation or Elimination of Businesses within California

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

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

Table 21 below shows California industries that are expected to receive the economic benefit of the proposed Title 24 code changes. It is anticipated that these industries will expand due to an increase in funding as a result of energy efficiency improvements. The list of industries is based on the industries that the University of California, Berkeley identified as being impacted by energy efficiency programs (UC Berkeley 2011 Table 3.8).[24] This list provided below is an approximation of the industries that may receive benefit from the 2016 Title 24 code changes.

Table 20: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code

Industry	NAICS Code
Residential Building Construction	2361
Roofing Contractors	238160
Electrical Contractors	23821
Plumbing, Heating, and Air-Conditioning Contractors	23822
Insulation Contractors	23831
Asphalt Paving, Roofing, and Saturated Materials	32412
Manufacturing	32412
Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equip. Manuf.	3334
Building Inspection Services	541350

3.5.3 Competitive Advantages or Disadvantages for Businesses within California

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

3.5.4 Increase or Decrease of Investments in the State of California

CARB's economic analysis indicate that higher levels of energy efficiency and 33% RPS will increase investment in California by about 3% in 2020 compared to 20% RPS and lower levels of energy efficiency (CARB 2010b Figures 7a and 10a). Overall, the proposed code change may bring forth further investment in the supply, distribution and sales channels of affected products. These include various types of roof deck insulation, ceiling insulation, drywall and air sealing products, certified low-leakage air handlers and sealed combustion furnaces.

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

3.5.5 Incentives for Innovation in Products, Materials, or Processes

Updating Title 24 standards will encourage innovation through the adoption of new technologies to better manage energy usage and achieve energy savings. The proposed DCS package will increase innovation both in terms of product as well as process. Increase in the envelope/HVAC energy performance requirement will drive innovation in insulation and HVAC system products, design practices and installation techniques. On the process level, the proposed codes changes will encourage enhanced coordination between trades in the field.

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

Higher property valuations due to energy efficiency enhancements may also result in positive local property tax revenues. The Statewide CASE Team has not obtained specific data to quantify potential revenue benefits for this measure.

3.5.6.1 Cost of Enforcement

Cost to the State

State government has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24 standards, including updating education and compliance materials and responding to questions about the revised standards, these activities are already covered by existing state budgets. The proposed code change does not require increased level of enforcement efforts and resources. Thus the costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals. Also, the proposed requirements only impact residential new constructions, and will have no impact on the costs of state buildings.

Cost to Local Governments

All revisions to Title 24 will result in changes to Title 24 compliance determinations. Local governments will need to train permitting staff on the revised Title 24 standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2016 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining. As noted earlier, although retraining is a cost of the revised standards, Title 24 energy efficiency standards are expected to increase economic growth and income with positive impacts on local revenue.

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

3.5.6.2 Impacts on Specific Persons

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

- Migrant Workers

- Persons by age
- Persons by race
- Persons by religion
- Commuters

We expect that the proposed code changes for the 2016 Title 24 code change cycle would reduce energy costs and could put potential first-time homeowners in a better position to afford mortgage payments. On the other hand, homeowners may experience higher first costs to the extent that builders' pass-through the increased costs of Title 24 compliance to home buyers. Some financial institutions have progressive policies that recognize that home buyers can better afford energy efficiency homes (even with a higher first cost) due to lower energy costs.[25]

Renters will typically benefit from lower energy bills if they pay energy bills directly. These savings should more than offset any capital costs passed-through from landlords. Renters who do not pay directly for energy costs may see more of less of the net savings based on how much landlords pass the energy cost savings on to renters.

On average, low-income families spend less on energy than higher income families, however lower income families spend a much larger portion of their incomes on energy (Roland-Holst 2008). Thus it seems reasonable that low-income families would disproportionately benefit from Title 24 standards that reduce residential energy costs.

4. METHODOLOGY

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

4.1 Existing Conditions

To assess the energy, demand, costs, and environmental impacts, the Statewide CASE Team compared current design practices to design practices that would comply with the proposed requirements. There are existing Title 24 standards requirements for some of the proposed measures and compliance modeling assumptions for duct location as well as all of the HPA measures.

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

The Statewide CASE Team used baseline models that are minimally compliant with the 2013 Title 24 requirements. This means that HVAC distribution ducts are placed 100% in vented attics for single-story buildings, and 65%/35% split between conditioned space and vented attic for buildings with two or more stories. Ceiling insulation is installed on the attic floor with radiant barrier application. Details of these values are shown in Section 2.2. These duct and system location and insulation parameters largely reflect current market practice.

For the sake of this analysis, the CEC instructed the Statewide CASE Team to assume tile roofs for the existing condition.

4.2 Proposed Conditions

The proposed conditions are defined as the design conditions that will comply with the proposed code change. Specifically, for DCS strategies the proposed code change will modify the distribution system default location within the compliance software.

For the HPA package, the proposed code changes will update the ceiling/roof insulation levels (and possibly assembly U-factor) requirement to reflect the addition of roof deck insulation. The requirement for radiant barrier will be removed for the baseline case with insulation below the roof deck because it does not make physical sense and is not practical to install radiant barrier below the below-deck insulation.

For the sake of this analysis, the CEC instructed the Statewide CASE Team to assume tile roofs for the proposed conditions.

4.3 Prototype Building(s)

Table 21 presents the details of the prototype building(s) used in the analysis. Table 22 presents details on pertinent parameters for the CASE topic, per the ACM reference manual.

Table 21: Prototype Buildings used for Energy, Demand, Cost, and Environmental Impacts Analysis

	Occupancy Type (Residential, Retail, Office, etc.)	Area (Square Feet)	Number of Stories	Relative Weight to Statewide Estimates	Other Notes
Prototype 1	Residential	2100	1	45%	Tile roof with 20% window area equally in all orientations
Prototype 2	Residential	2700	2	55%	Tile roof with 20% window area equally in all orientations

Table 22: Pertinent Parameters of Prototype Buildings

Component Description	Component Description	
	2100 sf , 1-story prototype	2700 sf, 2-story prototype

Ceiling height	9	9
Conditioned floor area (sf)	2100	2700
Conditioned volume (ft^3)	18,900	25,750
Gross Ceiling Area (sf)	2100	1450

4.4 Climate Dependent

The impacts of the proposed two packages, DCS and HPA, are climate specific, and it is necessary to model energy savings for all 16 climate zones to illustrate the full range of impacts from using the two proposed packages.

4.5 Time Dependent Valuation

The TDV (Time Dependent Valuation) of savings is a normalized format for comparing electricity and natural gas savings that takes into account the cost of electricity and natural gas consumed during different times of the day and year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 30 years. The TDV cost impacts are presented in 2017 present value dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDV kBTU" so that the savings are evaluated in terms of energy units and measures with different periods of analysis can be combined into a single value.

The CEC derived the 2016 TDV values that were used in the analyses for this report (CEC 2011). The TDV energy impacts are presented in Section 5.1 of this report, and the statewide TDV cost impacts are presented in Section 5.2.

4.6 Energy Impacts Methodology

The Statewide CASE Team calculated per unit impacts and statewide impacts associated with all new construction, alterations, and additions during the first year buildings comply with the 2016 Title 24 Standards.

4.6.1 Per Unit Energy Impacts Methodology

The Statewide CASE Team estimated the electricity and natural gas savings associated with the proposed code change. The energy savings were calculated on a building basis.

Analysis Tools

The Statewide CASE Team utilized the latest available standard compliance software CBECC-Res version 650 to quantify energy savings and peak electricity demand reductions resulting from the proposed measure. The current compliance software can model all of the DCS options and all of the HPA measures and includes the recently released 2016 TDV values as well as peak demand calculations.

Key Assumptions

CEC provided a number of key assumptions to be used in the energy impacts analysis (CEC 2011), in the CEC Life Cycle Cost Methodology Guidelines (LCC Methodology) including hours of operation, weather data, and prototype building design. Key runs and corresponding model parameter inputs for DCS and HPA strategies are presented in Table 23 and Table 24 respectively. Exceptions to the default compliance software assumptions are noted in the Notes column.

Table 23: Key assumptions for per unit Energy Impacts Analysis - DCS

Run	Parameter	Assumption	Source
DCS – verified ducts entirely in conditioned space	Duct location	No conduction loss, no duct leakage to outside	Default values in CBECC-Res

For the HPA measures, the Statewide CASE Team created runs first to assess the energy impacts from the proposed measures individually. The Statewide CASE Team then developed packages consisting of multiple measures to determine the proposed prescriptive HPA package for climate zones.

Table 24: Key assumptions for per unit Energy Impacts Analysis - HPA

Run	Parameter	Assumption/Input	Source
HPA – roof deck insulation	Insulation location and level	Above-deck: R-8 Below-deck: R-13	Product availability and levels installed in Zero Energy Challenge Home/ test homes
HPA – ceiling insulation	Insulation level	R-38	Product availability and levels installed in Zero Energy Challenge Home/ test homes
HPA – duct insulation	Insulation level	R-8 for all climate zones	The higher R value requirement for the 2013 Standards
HPA – duct leakage	Duct leakage rate	5%	Data on new construction homes built under 2008 Standards

4.6.2 Statewide Energy Impacts Methodology

First Year Statewide Impacts

The proposed code changes apply to all low-rise new construction buildings in the affected climate zones. The Statewide CASE Team estimated statewide impacts for the first year buildings comply with the 2016 Title 24 Standards by multiplying per unit savings estimates by statewide construction forecasts.

4.7 Cost-effectiveness Methodology

This measure proposes two packages of requirements, corresponding to ducts in conditioned space (DCS) and high performance attics (HPA). Each package includes a combination of:

- Above or below roof deck insulation
- Ceiling insulation
- Duct location
- Duct insulation level
- Duct leakage rate
- Air handler location

A lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 30 year period of analysis.

CEC's procedures for calculating lifecycle cost-effectiveness are documented in LCC Methodology (CEC 2011). The Statewide CASE Team followed these guidelines when developing the Cost-effectiveness Analysis for this measure. CEC's guidance dictated which costs were included in the analysis. Incremental equipment and maintenance costs over the 30 year period of analysis were included. The TDV energy cost savings from electricity and natural gas savings were considered. Each of these components is discussed in more detail below. In accordance with established procedures for LCC, the Statewide CASE Team has not included costs related to building or system design or any additional costs of verification by the builder/designers.

4.7.1 Incremental Cost Methodology

The Statewide CASE Team collected cost data for all of the components associated with each strategy and compiled costs to estimate an overall incremental project cost.

Cost data were collected from a variety of sources including:

- Published product reports and presentations
- Research reports and presentations
- Survey results from IOU ET projects
- Interviews with high performance building experts including HERS raters, energy consultants, builders, IOU residential new construction and emerging technology program managers, and building science experts.
- Retailers in California including 'big-box' retail chains such as Home Depot and Lowes.
- RS Means

Please see Appendix C: Cost Data Sources for a full list of data sources.

Overall, the Statewide CASE Team used best judgment with the data and qualitative input available to estimate incremental costs to implement the various strategies. The Team assumed conservative estimates for incremental costs due to the variability and low number of data points. The incremental costs used in the analysis will likely be overestimates for actual implementation when the code takes effect in 2017. The Statewide CASE Team expects that not all builders will find all of the potential strategies cost-effective in all projects based on their practices, but there will be at least one strategy that will be cost-effective for a particular builder.

Both DCS and HPA strategies include a mix of additional construction and labor costs as well as material and labor savings. The strategies will likely result in temporary (short-term) increased labor costs for a learning curve while trades become better acquainted with implementing the design options.

The Statewide CASE Team discussed cost assumptions with CBIA and CBIA's contractor, ConSol. Based on this discussion, the CASE team applied a 30 percent markup on costs to reflect costs to the builder. Although the two parties have not eliminated the cost differences between their respective estimates, the margin of difference is significantly smaller than the original and both parties agree that the cost differences are minor and within reasonable error bounds.

Incremental Construction Cost Methodology

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

The Current Incremental Construction Cost is based on available cost data and qualitative input from several sources. The Statewide CASE Team considered both primary material and labor costs when determining the cost implications of the DCS and HPA strategies.

Material and labor costs were normalized to the 2100 and 2700 square foot CEC prototypes to compare cost points on the same scale. The best estimates for each component were selected based on the information available to provide a range of potential whole house incremental costs for each strategy.

DCS Strategies Costs

Incremental costs for DCS are presented in the results section (Section 5.2.1) in a component based method which provides estimates for total incremental costs based on the material and labor needed to employ each strategy. The incremental costs reflect 2014 material and labor costs reported by industry respondents and do not assume cost reductions that may occur once these practices become industry standard. As with all changes to construction practice, the building and manufacturing market will adjust and determine the best methods to achieve desired results. In addition to utilizing component costs data, the project Team also collected project level costs to help anchor our cost results.

The Statewide CASE Team calculated incremental costs based on best estimates from the costs gathered on each component within a strategy. There are, however, interactive and building coordination implications that cannot be fully captured in a component based estimate. The Team determined incremental costs for both the single-story 2,100 square foot prototype and the 2-story 2,700 square foot prototype based on the 44%/55% statewide distribution of the two house sizes, consistent with the 2013 Title 24 Impact Analysis.

The incremental cost estimates for individual DCS components are limited in availability and accuracy due to general market inexperience. The CASE Team provides a range of costs based on the various cost data points that were available at the time of the analysis to illustrate this situation in Section 16.

For DCS, the Statewide CASE Team attempted to get a total cost of implementation for each strategy in addition to the bottom-up approach (summing up individual component costs). However, because these strategies are not currently widely implemented we could collect few overall cost data points – mostly from early adopters and not indicative of mature industry costs. The data we did collect from surveys, interviews and published reports tends to be speculative and varies greatly due to the variability on building design and the respondent's level of familiarity with the strategies.

Using this method, it is difficult to accurately capture all the impacts and "soft" costs of construction beyond the direct material and labor needs. For this reason, the Team supplemented the component based costs with total incremental cost estimates from projects and builders using these strategies.

The Statewide CASE Team also considered "soft" costs when determining the cost implications of the strategies. "Soft" (or secondary) costs are generally hard to monetize and are project specific; these include items such as additional trips and adjusted schedules for trades, increased project oversight to ensure proper installation, and increased cycle time.

One major incremental cost *reduction* opportunity that the project Team quantified, but did not include in the calculation of DCS costs is the potential to downsize HVAC equipment size and optimize supply duct runs. According to builder and industry expert interviewed, there exists substantial monetary savings for specifying smaller HVAC equipment when duct losses are eliminated by placing them in conditioned space. Although most other impacts will incur additional costs, some can be beneficial. For example, Lubliner (2008) notes that other trades such as electricians and plumbers can utilize open-web trusses for their conduit because this design provides easy access to spaces throughout the home, as long as it is planned accordingly with the duct runs. These soft cost considerations are listed in Table 25.

Table 25: Key "Soft" Cost Considerations for DCS

DCS Strategy	Assumptions of "Soft" Costs	Estimated impacts to cost
All DCS strategies	The potential to reduce HVAC equipment size and supply duct runs	Would reduce material and labor costs. Could result in cost savings of $100 - $400+ (Meritage 2014)
Dropped Ceiling	Quality air-sealing of dropped ceiling space Trades aware not to create penetrations through space	Quality air sealing of the dropped space will increase labor costs. Increased project oversight and trade communication will be required to ensure trades are aware of restraints.

In the end, these cost savings and soft costs in general were NOT included in the cost-effectiveness analysis.

<u>*HPA Strategies Costs*</u>

The HPA component costs are generally more straightforward and cost data points are more obtainable and more accurate than the DCS data points; although, the responses still vary or are hard to obtain for some less common components such as raised heel trusses.

The Statewide CASE Team estimated component costs for HPA based on similar sources as the DCS strategies. Building experts, literature and retailers supplied cost data points that were used to establish per unit and total incremental costs. The Team could not supplement these component based cost assumptions with project-specific examples because, unlike the DCS strategies, they are not whole building design alterations, but rather a single modification -- insulation of the roof deck. Several of the cost assumptions from builders and building experts are from field experience. However, to our knowledge, there is very little current construction within California implementing the proposed HPA package from which to leverage cost data.

Incremental Maintenance Cost Methodology

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

The maintenance requirements associated with the code change proposal, relative to existing conditions, are described qualitatively in Section 3.2.2 of this report.

4.7.2 Cost Savings Methodology

Energy Cost Savings Methodology

The PV of the energy savings were calculated using the method described in the LCC Methodology (CEC 2011). In short, the hourly energy savings estimates for the first year of building operation were multiplied by the 2016 TDV cost values to arrive at the PV of the cost savings over the period of analysis. The proposed two packages are weather sensitive, so the energy cost savings were calculated for each climate zone using climate zone specific TDV multipliers.

Other Cost Savings Methodology

As described previously, implementation of either of the proposed packages could bring forth the additional cost savings from downsizing HVAC equipment. However, the project Team did not include the cost savings into the Cost-effectiveness analysis reported in this report. This CASE topic does not have other non-energy cost savings.

4.7.3 Cost-effectiveness Methodology

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

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

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

4.8 Environmental Impacts Methodology

4.8.1 Greenhouse Gas Emissions Impacts Methodology

Greenhouse Gas Emissions Impacts Methodology

The Statewide CASE Team calculated avoided GHG emissions assuming an emission factor of 353 metric tons of carbon dioxide equivalents ($MTCO_2e$) per GWh of electricity savings. As described in more detail in Appendix A, the electricity emission factor represents savings from avoided electricity generation and accounts for the GHG impacts if the state meets the Renewable Portfolio Standard (RPS) goal of 33 percent renewable electricity generation by 2020. Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 $MTCO_2e$/million therms (U.S. EPA 2011).

Greenhouse Gas Emissions Monetization Methodology

The 2016 TDV cost values include the monetary value of avoided GHG emissions, so the Cost-effectiveness Analysis presented in Section 5.2 of this report does include the cost savings from avoided GHG emissions. The monetization for the TDV values includes permit (retail) cost of avoided GHG emissions, but it does not include the social costs of avoided emissions. As evident in the results of the Cost-effectiveness Analysis, the value of avoided

GHG emissions is aggregated into the total TDV cost savings and the contribution of GHG emissions is not easily discernible. To demonstrate the value of avoided GHG emissions, the Statewide CASE Team disaggregated the value of avoided GHG emissions from the overall TDV cost savings value. The Statewide CASE Team will use the same monetary values that are used in the TDV factors, which was not available at the time of writing. The next version of this report will include the monetary value of carbon.

4.8.2 Material Impacts Methodology (Optional)

The project Team did not develop material impact estimate.

4.8.3 Other Impacts Methodology

The project Team did not quantify or develop other non-energy impacts associated with the proposed packages.

5. ANALYSIS AND RESULTS

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

For both Ducts in Conditioned Space and High Performance Attics strategies, the project Team derived cost-effectiveness results from

- Energy cost savings from modeled building-level energy savings and
- Incremental first costs from various retail, project and industry resources.

Both the DCS strategies and the proposed HPA package may be used to achieve TDV energy savings on the level of 13 % in comparison to the baseline that is minimally compliant to the 2013 Standards. Contrary to common perception, it does not necessarily cost more to implement DCS strategies than the combination of selective measures for HPA.

Since the proposed measures are consisted of a combination of building envelope and HVAC distribution system design changes, the energy performance implications are highly climate dependent. The savings potential are much higher in cooling dominant climate zones (such as CZ 13-15) than the milder climate zones (such as CZ 1, 3 and 5). For examples, a building in CZ 13 Fresno implementing an HPA package with R-13 below deck insulation will yield electric savings of ~390 kWh. This is more than ten times the electric energy savings from implementing the same package in CZ 1 Arcata with ~35 kWh. The differences in therms savings are not as large as electric savings. Though both CZ 13 and CZ 1 have gas savings when implementing the proposed HPA package, CZ 1, with ~41 therms savings, yields twice the gas savings.

5.1.1 Per Unit Energy Impacts Results

Due to the desire to provide multiple options for the proposed DCS and HPA strategies, the CASE team performed energy simulation runs for individual measures as well as measure combinations. The results presented in this section focus on the DCS strategies and HPA measure combinations that perform the best in terms of energy savings and their cost-effectiveness. In "creating" the proposed HPA package, the project Team also took into consideration the measures' physical compatibility with one another and feasibility of implementation.

Appendix D: Simulation Results Using CBECC-Res provides further details and discussions on savings results for individual DCS strategies and HPA measures. These results and discussions form the basis of our code proposal recommendations and provide explanations on nuances that are sometimes hard to detect between the wide variety of options to achieve DCS or HPA.

Per building energy and demand impacts of the proposed DCS and HPA measure are presented in

Table 26 and Table 27 respectively. Weighted average per building savings for the first year is expected to be 229 kilowatt-hours per year (kWh/yr), 0.4 kilowatts of demand per year (kW/yr), and 18.3 therms/year. The intention of proposing two parallel packages with similar energy savings impact is to allow maximum flexibility in terms of design choices.

TDV electricity and natural gas savings combined over the 30 year period of analysis is estimated to be 17,889 kBTU combined. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods. Results shown in

Table 26 is the per system results based on the 45%/55% mix of the 2100/2700sf building prototypes.

Table 26: Energy Impacts per Prototype Building - DCS Verified Ducts Entirely in Conditioned Space[1]

Climate Zone	Per Unit First Year Savings[2]			Per Unit First Year TDV Savings[3]
	Electricity Savings[4] (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity and Gas Savings[5] (kBTU)
Climate Zone 1	54.5	0.0	63.4	12,755
Climate Zone 2	45.6	0.0	40.1	9,532
Climate Zone 3	22.3	0.0	24.8	5,339
Climate Zone 4	64.5	0.2	34.6	11,075
Climate Zone 5	16.9	0.0	19.6	4,053
Climate Zone 6	27.7	0.1	11.9	4,730
Climate Zone 7	8.0	0.0	3.7	1,453
Climate Zone 8	73.8	0.3	8.6	8,250
Climate Zone 9	154.3	0.5	13.7	17,509
Climate Zone 10	202.9	0.5	16.1	16,848
Climate Zone 11	372.6	0.5	35.0	29,589
Climate Zone 12	142.2	0.3	47.2	20,531
Climate Zone 13	454.7	0.7	36.5	34,676
Climate Zone 14	365.3	0.6	36.5	28,484
Climate Zone 15	976.3	1.0	2.4	44,470
Climate Zone 16	125.5	0.1	91.5	22,707

1. Per unit and per building savings for a DCS strategy are the same.
2. Savings from one prototype building for the first year the building is in operation.
3. TDV energy savings for one prototype building for the first year the building is in operation.
4. Site electricity savings. Does not include TDV of electricity savings.
5. Calculated using CEC's 2016 TDV factors and methodology.

Table 27: Energy Impacts per Prototype Building - HPA Package (including R-13 Below Roof Deck Insulation)[1]

Climate Zone	Per Unit First Year Savings[2]			Per Unit First Year TDV Savings[3]
	Electricity Savings[4] (kWh/yr)	Demand Savings (kW)	Natural Gas Savings (Therms/yr)	TDV Electricity and Gas Savings[5] (kBTU)
Climate Zone 1	35.4	0.0	41.2	8,329
Climate Zone 2	47.3	0.0	27.8	8,345
Climate Zone 3	17.6	0.0	18.2	4,104
Climate Zone 4	63.9	0.2	23.7	9,479
Climate Zone 5	14.2	0.0	16.4	3,436
Climate Zone 6	30.2	0.1	9.2	4,517
Climate Zone 7	11.0	0.0	3.3	1,985
Climate Zone 8	124.1	0.3	6.6	10,550
Climate Zone 9	201.1	0.5	9.7	17,526
Climate Zone 10	222.2	0.4	12.4	15,655
Climate Zone 11	297.5	0.4	16.0	20,836
Climate Zone 12	157.8	0.3	24.6	17,681
Climate Zone 13	389.4	0.5	20.0	26,193
Climate Zone 14	256.6	0.4	16.0	18,061
Climate Zone 15	688.1	0.7	2.4	31,149
Climate Zone 16	96.4	0.1	55.7	15,671

1. "Per unit" implies a combination of measures for the prototype building for the HPA package.
2. Savings from one prototype building for the first year the building is in operation.
3. TDV energy savings for one prototype building for the first year the building is in operation.
4. Site electricity savings. Does not include TDV of electricity savings.
5. Calculated using CEC's 2016 TDV factors and methodology.

5.1.2 Statewide Energy Impacts Results

First Year Statewide Energy Impacts

The statewide energy impacts of the two alternatives - Ducts in Conditioned Space or High Performance Attics (insulated roof deck) - are presented in Table 28. During the first year buildings complying with the 2016 Title 24 Standards are in operation, the proposed measure is expected to reduce annual statewide electricity use by 20.9 GWh, demand savings by 34.3 MW, and natural gas use is expected to be reduced by 1.67 MMtherms.

Table 28: Statewide Energy Impacts

	First Year Statewide Savings[1]			TDV Savings[2]
	Electricity Savings[3] (GWh)	Power Demand Reduction (MW)	Natural Gas Savings (MMtherms)	TDV Electric and Gas Savings[4] (Million kBTU)
HPA – including R-13 below deck	20.9	34.3	1.67	1,628

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

All assumptions and calculations used to derive per unit and statewide energy and demand savings are presented in Section 4.6 of this report.

5.2 Cost-effectiveness Results

5.2.1 Incremental Cost Results

HPA Package including R13 Below Roof Deck + R38 Ceiling Insulation + R8 Ducts + 5% Duct Leakage

The incremental cost of the proposed measure, relative to existing conditions, is presented in Table 30. Table 29 provides the per unit incremental costs of all the potential HPA components for this proposed package. These costs include a 30 percent markup to reflect cost to builders.

Table 29: Per unit Incremental Construction Cost - HPA

HPA components	$/unit	Source
Below Deck Roof Insulation	$0.37[a]/s.f. roof	Online Retailers; Stakeholder Interview
Insulation Netting (blown-in)	$0.37/s.f. roof	Online Retailers, Insulators
Vapor Retarder (CZ 14, 16 with air permeable insulation)	$0.04/s.f. roof	Online Retailers
R-38 incremental cost over R-30 ceiling insulation	$0.18/s.f. roof	Online Retailers
R-8 Duct Insulation incremental cost over R-6 (CZ 1-10, 13)	$0.86/linear ft duct	Online Retailers
Eliminate Radiant Barrier (CZ 2-15)	-$0.12/s.f. roof	Online Retailers, CBIA
HERS QII	$65	CBIA

[a] Using R-13 blown-in cellulose

Table 30 shows the incremental costs per home for each HPA package component for R-13 below deck insulation, and Table 31 shows additional cost savings that may occur and affect this measure based on updates to the California Residential Building Code. Note that the R-13 below deck insulation cost is based on using blow-in cellulose insulation type; it is the most economical way to achieve the below deck insulation value per our research. Each of these components cost item is discussed later in this section. Again, these costs do not include assumptions on increased "soft costs" such as trade coordination. However this analysis is not considering what is likely larger first cost savings, the costs savings associated with HVAC equipment downsizing associated with reduced HVAC loads.

The incremental component costs in Table 30 were developed based on per unit incremental measure costs that are provided above in Table 29. We show the results for both the single -story 2,100 square foot prototype and the 2-story 2,700 square foot prototype, as well as the average of the two based on the 44%/55% statewide distribution of the two house sizes consistent with the 2013 Title 24 Impact Analysis. The total incremental cost includes the incremental cost during initial construction only because the proposed measure does not incur incremental maintenance costs.

Table 30: Incremental Construction Cost – HPA

Parameter	2100 sf prototype	2700 sf prototype	Notes
Insulation at Roof Deck:	$935	$646	R-13 blown-in cellulose
Insulation Netting at Roof Deck	$935	$646	
Vapor Retarder	$97	$67	Class II vapor retarder with below deck insulation for CZ 14, 16 only
Ceiling Insulation (increasing from R30 to R38)	$382	$264	For CZ 2-10 only since their 2013 prescriptive levels are R30
R-8 Duct Insulation	$186	$239	
Eliminate Radiant Barrier	-$295	-$204	No radiant barrier with below deck insulation
5% Duct Leakage	--	--	The CASE Team reviewed data from the CHEERS registry for homes built in 2012 (courtesy CEC) that shows that more than half the homes already meet 5% or lower duct leakage. Thus there are no incremental costs for this measure.
HERS Test for QII	$65	$65	

The CEC expects updates to the current ventilation requirements in the California Residential Building Code. These updates would reduce the amount of attic free ventilation area (FVA) and whole house fan (WHF) ventilation required in the standard model. The attic FVA is expected to reduce from 1 ft^2 of FVA for every 150 ft^2 of conditioned floor area to every 300 ft^2 of conditioned floor area, and the WHF ventilation requirement will reduce from 1 ft^2 of attic FVA for each 375 cfm of airflow to 750 cfm of airflow, resulting in lower cfm required per square foot of conditioned floor area. These reductions in free ventilation area and reduced fan cfm will result in cost savings, as shown in Table 31 below.

Table 31: Additional Incremental Construction Costs - HPA

Parameter	$/unit	2100 sf prototype	2700 sf prototype	Notes
Reduce attic FVA	-$52/vent	-$364	-$250	7 ft2 free vent area for 2100 sf prototype 4.8 ft2 free vent area for 2700 sf prototype
Reduce WHF ventilation requirements	-$150	-$150	-$150	Reduce cfm from 2cfm/sf to 1.2cfm/sf

The CASE Team and CEC staff discussed the measure costs in the draft CASE report docketed with CBIA and ConSol who had developed their own cost estimates. The purpose of the meetings were to understand and resolve differences and reduce the discrepancy in total measure cost estimates between CBIA and the CASE Team's estimates. Table 32 below provides the updated cost estimates discussed during the CEC and CASE Team's meetings with CBIA and ConSol. As a result of these conversations, the CASE Team continued data collection and discussions with industry members to develop revised cost estimates. Although the two parties have not eliminated the cost differences between their respective estimates, the margin of difference is significantly smaller than the original and both parties agree that the cost differences are minor and within reasonable error bounds.

The costs in Table 32 are each an average among the 2,100 square foot and 2,700 square foot prototypes, using CBIA building area assumptions for consistency, which differ from the CEC prototype, and a 30% markup on material costs; labor costs from RS Means already include a markup. The CBIA assumes a 50%/50% split between the two prototypes; whereas, the CASE Team assumes a 45%/55% split based on CEC forecast. The CASE Team estimates are based on the per unit incremental costs in Table 29; the difference between the whole house costs below and those in Table 30 is the area assumptions for each prototype.

The total cost listed in the table below is for a single family home which incorporates all of the listed measures. However, as shown in the Table 33, residential buildings will vary on costs and energy savings based on the measures applicable per climate zone.

Costs for the vapor retarder and reduced duct leakage were not part of the discussion. The vapor retarder is only applicable to climate zones 14 and 16, and the CASE Team does not expect there to be significant cost. Additionally, based on discussion with industry members, 5% duct leakage can be achieved at no additional cost to current practices. As shown in the Table 33, residential buildings will vary on costs based on the measures applicable per climate zone.

Table 32: CBIA and CASE Team Cost Assumption Comparison

Parameter	CBIA Cost Estimate[1]	CASE Cost Estimate[2]
Insulation at Roof Deck:	$812	$689
Insulation Netting at Roof Deck	$689	$689
Ceiling Insulation (increasing from R30 to R38)	$346	$317
R-8 Duct Insulation	$215	$215
Eliminate Radiant Barrier	($221)	($217)
HERS Test for QII	$65	$65
Reduce Attic FVA	($322)	$(378)
Reduce WHF venting	($150)	($150)
Non-Climate Zone Specific **TOTAL COST**	**$1,443**	**$1,229**

[1]CBIA assumes a 50/50 split between the two single family prototypes.

[2]CASE Team assumes a 45/55 split between the two single family prototypes.

Table 33 below details which cost components associated with the HPA package are included for each climate zone based on the current 2013 Standards and the proposed code.

Table 33: Components Included per Climate Zone - HPA

CZ	R-13 Below + Netting	R-8 Ducts	R-38 Ceiling	Vapor Retarder	Eliminate RB	5% Duct Leakage	Reduce Attic FVA	Reduce WHF Requirement
1	Y	Y	N	N	N	Y	Y	N
2	Y	Y	Y	N	Y	Y	Y	N
3	Y	Y	Y	N	Y	Y	Y	N
4	Y	Y	Y	N	Y	Y	Y	N
5	Y	Y	Y	N	Y	Y	Y	N
6	Y	Y	Y	N	Y	Y	Y	N
7	Y	Y	Y	N	Y	Y	Y	N
8	Y	Y	Y	N	Y	Y	Y	Y
9	Y	Y	Y	N	Y	Y	Y	Y
10	Y	Y	Y	N	Y	Y	Y	Y
11	Y	N	N	N	Y	Y	Y	Y
12	Y	Y	N	N	Y	Y	Y	Y
13	Y	Y	N	N	Y	Y	Y	Y
14	Y	N	N	Y	Y	Y	Y	Y
15	Y	N	N	N	Y	Y	Y	N
16	Y	N	N	Y	N	Y	Y	N

DCS Package with HERS Verification of Duct Leakage to Outdoors

Table 35 shows the incremental costs for implementing the Verified DCS vented attic – dropped ceiling strategy for both prototypes and their weighted average. These costs were calculated based on best estimates for the components involved in each strategy. The range of cost estimates represents the low and high values received from various sources. Again, the Statewide CASE Team did not include "soft costs" (either benefits or hindrances) in our calculation of incremental costs.

Table 34: Key Assumptions for per unit Incremental Construction Cost – DCS: Dropped Ceiling

Parameter	Assumption	Source	Notes
Material costs (lumber, air barrier (OSB), drywall) + labor	$1.18 - $2.65/s.f. dropped ceiling	Online retail; RS Means labor	Includes labor
Sealed Combustion Equipment	$360/furnace	Online Retailer	Incremental cost depends on condensing capabilities and equipment capacity.
Mechanical Closet	$3.80/s.f. closet walls	Online retailer	Located in attic, consists of 4 newly constructed walls; located in garage, consists of 2 newly constructed walls adjacent to conditioned space. Includes framing, insulation and drywall/OSB finishing
HERS Test for Verification of Duct Leakage to Outside	$125	Calls with HERS Raters	Standards already require HERS test for duct leakage. The added cost here is to conduct a blower door at the same time to estimate leakage to outside from ducts.

The incremental component costs in Table 35 were developed based on per unit incremental costs for the DCS dropped ceiling strategy provided in Table 34.

Table 35: Incremental Construction Cost – Verified DCS – Dropped Ceiling

Dropped ceiling	2100 sf prototype	2700 sf prototype	Notes
Material costs (lumber, air barrier (OSB), drywall) + labor	$557 ($249 + $308)	$357 ($159 + $197)	
Sealed combustion furnace	$360	$360	Average among varying capacities; condensing furnaces represent higher end of costs.
Interior Mechanical Closet	$216	$216	location of closet in garage corner
HERS Test for Verification of Duct Leakage to Outside	$125	$125	
Total Costs	$1258	$1058	With standard duct design
Weighted Total Cost	$1148		Based on 44/55 prototype split

Incremental Maintenance Cost Results

There are no incremental maintenance costs associated with the proposed measures compared to current construction standards. As long as components are installed per manufacturer instructions, there should not be additional maintenance than currently required to maintain roof and HVAC systems. Maintenance requirements associated with the code change proposal, relative to existing conditions, are described qualitatively in Section 3.3 of this report.

5.2.2 Energy Cost Savings Results

The per unit TDV energy cost savings over the 30 year period of analysis are presented in Table 36 for the HPA package including R13 insulation below roof deck. This HPA case has 2% less statewide TDV savings than DCS so that the cost effectiveness presented underestimates the full potential of this CASE proposal.

Table 36: HPA TDV Energy Cost Savings Over 30 Year Period of Analysis - Per Unit

Climate Zone	TDV Cost Savings (2017 PV $)
Climate Zone 1	$1,441
Climate Zone 2	$1,444
Climate Zone 3	$710
Climate Zone 4	$1,640
Climate Zone 5	$594
Climate Zone 6	$782
Climate Zone 7	$343
Climate Zone 8	$1,825
Climate Zone 9	$3,032

Climate Zone 10	$2,708
Climate Zone 11	$3,605
Climate Zone 12	$3,059
Climate Zone 13	$4,531
Climate Zone 14	$3,125
Climate Zone 15	$5,389
Climate Zone 16	$2,711

5.2.3 Cost-effectiveness Results

Results per unit lifecycle Cost-effectiveness Analyses are presented in

Table 37 for the HPA package including R13 insulation below roof deck. The proposed measure is cost-effective in climate zones 4, and 8 through 16.

Table 37: HPA Cost-effectiveness Summary[1]

Climate Zone	Benefit: TDV Energy Cost Savings + Other Cost Savings[2] (2017 PV$)	Cost: Total Incremental Cost[3] (2017 PV$)	Change in Lifecycle Cost[4] (2017 PV$)	Benefit to Cost Ratio[5]
Climate Zone 1	$1,441	$1,551	$110	0.9
Climate Zone 2	$1,444	$1,625	$181	0.9
Climate Zone 3	$710	$1,625	$915	0.4
Climate Zone 4	$1,640	$1,625	$(15)	1.0
Climate Zone 5	$594	$1,625	$1,030	0.4
Climate Zone 6	$782	$1,625	$843	0.5
Climate Zone 7	$343	$1,625	$1,281	0.2
Climate Zone 8	$1,825	$1,475	$(350)	1.2
Climate Zone 9	$3,032	$1,475	$(1,557)	2.1
Climate Zone 10	$2,708	$1,475	$(1,234)	1.8
Climate Zone 11	$3,605	$939	$(2,665)	3.8
Climate Zone 12	$3,059	$1,152	$(1,907)	2.7
Climate Zone 13	$4,531	$1,152	$(3,380)	3.9
Climate Zone 14	$3,125	$1,025	$(2,100)	3.0
Climate Zone 15	$5,389	$1,089	$(4,299)	4.9
Climate Zone 16	$2,711	$1,424	$(1,287)	1.9

1. Relative to existing conditions. All cost values presented in 2017 dollars.
2. Present value of TDV cost savings equals TDV electricity savings plus TDV natural gas savings; $\Delta TDV\$ = \Delta TDV\$E + \Delta TDV\$G$.
3. Total incremental cost equals incremental construction cost (post adoption) plus present value of incremental maintenance cost; $\Delta C = \Delta CI_{PA} + \Delta CM$.
4. Negative values indicate the measure is cost-effective. Change in lifecycle cost equals cost premium minus TDV energy cost savings; $\Delta LCC = \Delta C - \Delta TDV\$$
5. The benefit to cost ratio is the TDV energy cost savings divided by the total incremental costs; $B/C = \Delta TDV\$ \div \Delta C$. The measure is cost effective if the B/C ratio is greater than 1.0.

Given data regarding the new construction forecast for 2017, the Statewide CASE Team estimates that that lifecycle cost savings (30 year) of all buildings built in climate zones with cost effectiveness greater than 1.0 during the first year the 2016 Standards are in effect will be $ 203 million.

5.3 Environmental Impacts Results

5.3.1 Cost Savings Results

Other Cost Savings Results

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

5.3.2 Greenhouse Gas Emissions Results

Table 38 presents the estimated first year avoided GHG emissions of the proposed code change. During the first year the 2016 Standards are in effect the proposed measure will result in avoided GHG emissions of 16,199 $MTCO_2e$.

Table 38: Statewide Greenhouse Gas Emissions Impacts

	First Year Statewide	
	Avoided GHG Emissions[1] ($MTCO_2e$/yr)	Monetary Value of Avoided GHG Emissions[2] ($2017)
HPA – R-13 below deck	16,199	TBD

1. First year savings from buildings built in 2017; assumes 353 $MTCO_2e$/GWh and 5,303 $MTCO_2e$/MMTherms.
2. Monetary value of carbon is included in cost effectiveness analysis; assumes TBD$/ $MTCO_2e$.

5.3.3 Water Use and Water Quality Impacts

Impacts on water use and water quality are presented in Table 39. The proposed measure does not impact water consumption or water quality.

Table 39: Impacts of Water Use and Water Quality

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

1. Does not include water savings at power plant
2. Assumes embedded energy factor of 10,045 kWh per million gallons of water.

5.3.4 Material Impacts Results (Optional)

The impacts of the proposed code change on material use were not evaluated.

Table 40: Impacts of Material Use

	Impact on Material Use Material Increase (I), Decrease (D), or No Change (NC) compared to base case (lbs./year)					
	Mercury	**Lead**	**Copper**	**Steel**	**Plastic**	**Others**
Impact (I, D, or NC)	NC	NC	NC	NC	NC	NC
Per Unit Impacts	N/A	N/A	N/A	N/A	N/A	N/A
Statewide Impacts (first year)	N/A	N/A	N/A	N/A	N/A	N/A

5.3.5 Other Impacts Results

Other forms of impacts of the proposed code change were not evaluated.

6. PROPOSED LANGUAGE

The proposed changes to the Standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions). It should be noted that we are adding a definition for “Direct-Vent” to be consistent with the IMC and CMC. The 2013 California Mechanical Code (Part 4) Chapter 2 Definitions has the following definition: **Direct-Vent Appliances**. Appliances that are constructed and installed so that air from combustion is derived directly from the outdoors and flue gases are discharged to the outdoors. [NFPA 54:3.3.6.3]

6.1 Standards

SECTION 100.1 – DEFINITIONS AND RULES OF CONSTRUCTION

Direct-Vent Appliances.[26] Appliances that are constructed and installed so that air from combustion is derived directly from the outdoors and flue gases are discharged to the outdoors. Also known as “sealed combustion.”

SECTION 150.1 Performance and Prescriptive Compliance Approaches for Newly Constructed Residential Buildings

(c) **Prescriptive Standards/Component Package.** Buildings that comply with the prescriptive standards shall be designed, constructed, and equipped to meet all of the requirements for the appropriate climate zone shown in TABLE 150.1-A. In TABLE 150.1-A, a NA (not allowed) means that feature is not permitted in a particular climate zone and a NR (no requirement) means that there is no prescriptive requirement for that feature in a particular climate zone. Installed components shall meet the following requirements:

[26] Definition based on the 2013 California Mechanical Code (Part 4) Chapter 2 Definitions.

1. **Insulation.**

   A. Roof/Ceiling insulation shall be installed with a ~~U-factor equal to or less than, or~~ R-value equal to or greater than shown in TABLE 150.1-A that depends upon whether the space conditioning distribution system complies with Section 150.1(c)9A "Option A" or complies with Section 150.1(c)9B "option B". The "Option A" package of R-values requires: R13 insulation below the roof deck in contact with the roof deck; or R6 continuous insulation at the roof deck that is not thermally bridged by roof framing members; and an additional amount of ceiling insulation located between the attic and the conditioned space below. Where no roof deck insulation is required, a radiant barrier on the roof deck is required. The "Option B" package of R values labeled "Roof/Ceiling Insulation" applies to insulation that is located at the roof deck for unvented attics or cathedral ceilings, or at the boundary between the between the attic and the conditioned space below for vented attics. ~~The maximum U-factors or the minimum R-values shown are for insulation installed between wood-framing members.~~

9. **Space conditioning ~~ducts~~ distribution systems.** ~~All ducts shall either be in directly conditioned space as confirmed by field verification and diagnostic testing in accordance with Reference Residential Appendix RA3.1.4.3.8 or be insulated to a minimum installed level as specified by TABLE 150.1-A. All ducts shall meet all applicable mandatory requirements of Section 150.0(m).~~ All space conditioning systems shall reduce distribution losses by complying with items A or B below:

NOTE: Requirements for duct insulation in TABLE 150.1-A do not apply to buildings with space conditioning systems that do not have ducts.

   A. High performance attics. Air handlers or ducts are allowed to be in unconditioned spaces or vented attic spaces when the roof/attic/ceiling insulation levels meet the "Option A" requirements in TABLE 150.1-A. Duct insulation and Duct leakage levels meet the requirements shown in TABLE 150.1-A.

   B. Duct and air handlers in conditioned space. Duct work and air handlers of HVAC systems shall be in conditioned space. Complying systems include either item i or ii.

      i. HVAC systems where air handlers and all duct work are in conditioned spaces. If the air handler contains a combustion component it shall be Direct-Vent, taking no combustion air from the conditioned space. All ducts shall be in conditioned space as confirmed by field verification and diagnostic testing in accordance with Reference Residential Appendix RA3.1.4.3.8. All ducts shall meet all applicable mandatory requirements of Section 150.0(m).

      ii. Ductless HVAC systems including but not limited to: ductless mini-split systems, hydronic heating and cooling systems, packaged terminal heat pumps, packaged terminal air conditioners with hydronic heating or sealed gas heating, and sealed combustion wall furnaces.

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**[1]	**Roofs /Ceiling**	**Option A – HPA (meets §150.1(c)9A)**	**Below Roof Deck Insulation**[11]	NA	NA	NA	R13	NA	NA	NA	R13	R13	R13	R13	R13	R13	R13	R13	R13
				Ceiling Insulation	R 38	R 30	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 B - DCS (meets §150.1(c)9B)	**Roof/ Ceiling Insulation**	~~U 0.025~~ R 38	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.031~~ R 30	~~U 0.025~~ R 38	~~U 0.025~~ R 38	~~U 0.025~~ R 38	~~U 0.025~~ R 38	~~U 0.025~~ R 38	~~U 0.025~~ R 38
				Radiant Barrier	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR
		Walls	Above Grade	2x4 Framed[2]	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U-0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5	U 0.065 R 15+4 or R 13+5
				Mass Wall Interior[3]	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U 0.070 R 13	U0.070 R 13	U0.070 R 13	U0.070 R 13	U0.07 0=R 13	U0.070 R 13	U0.070 R 13	U0.070 R 13	U 0.059 R 17
				Mass Wall Exterior[3]	U 0.125 R 8.0	U 0.125 R 8.	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.125 R 8.0	U 0.1025 R 8.0	U 0.125 R 8.0	U 0.070 R 13
				Below Grade Exterior[3]	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.200 R 5.0	U 0.100 R 10	U 0.100 R 10	U 0.053 R 19

TABLE 150.1-A COMPONENT PACKAGE-A   Standard Building Design (continuation)

Floors		Slab Perimeter	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	U 0.58 R 7.0
		Raised	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19	U 0.037 R 19
		Concrete Raised	U 0.092 R 8.0	U 0.092 R 8.0	U 0.269 R 0	U 0.269 R 0	U0.269 R 0	U 0.269 R 0	U 0.269 R 0	U 0.269 R 0	U 0.269 R 0	U 0.269 R 0	U 0.092 R 8.0	U 0.138 R 4.0	U 0.092 R 8.0	U 0.092 R 8.0	U 0.138 R 4.0	U 0.092 R 8.0
~~**Radiant Barrier**~~			~~NR~~	~~NR~~	~~REQ~~	~~NR~~	~~REQ~~	~~REQ~~	~~REQ~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~	~~NR~~
Roofing Products	**Low-sloped**	Aged Solar Reflectance	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.6	NR	0.6	NR
		Thermal Emittance	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.75	NR	0.75	NR
	Steep Sloped	Aged Solar Reflectance	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.20	0.20	0.20	0.20	0.20	0.20	NR
		Thermal Emittance	NR	NR	NR	NR	NR	NR	NR	NR	NR	0. 75	0.75	0.75	0.75	0.75	0.75	NR
Fenestration	**Maximum U-factor[4]**		0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	Maximum SHGC[5]		NR	0.25	NR	0.25	NR	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	Maximum Total Area		20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
	Maximum West Facing Area		NR	5%	NR	5%	NR	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

TABLE 150.1-A COMPONENT PACKAGE-A   Standard Building Design (continuation)

				Climate Zone															
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
HVAC SYSTEM	**Space Heating**	**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[6]		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 Charge Indicator Display		NR	REQ	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR
		Whole House Fan[7]		NR	NR	NR	NR	NR	NR	NR	REQ	REQ	REQ	REQ	REQ	REQ	REQ	NR	NR
	Central System Air Handlers[8]	**Central Fan Integrated Ventilation System Fan Efficacy**		REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ	REQ
	Ducts	**Duct Insulation**	**Option A - HPA (meets §150.1(c)9A)**	R-8	R-6	R-6	R-8	R-6	R-6	R-6	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8	R-8
			Option B - DCS (meets §150.1(c)9B)	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-8	R-6	R-6	R-8	R-8	R-8

TABLE 150.1-A COMPONENT PACKAGE-A   Standard Building Design (continuation)

		Climate Zone															
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Duct and Air Handler in Conditioned Space	**Option A - HPA (meets §150.1(c)9A)**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Option B - DCS (meets §150.1(c)9B)	REQ[9]	REQ[9]	NA	REQ[9]	NA	NA	NA	REQ[9]	REQ[9]	REQ[9]	REQ[9]	REQ[9]	REQ[9]	REQ[9]	REQ[9]	REQ[9]
Total Duct Leakage (%)[10]	**Option A HPA (meets §150.1(c)9A)**	5%	6%	6%	5%	6%	6%	6%	5%	5%	5%	5%	5%	5%	5%	5%	5%
	Option B - DCS (meets §150.1(c)9B)	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%

Footnote requirements to TABLE 150.1-A:

1. The U-factors/R-values shown for ceiling, wall and raised floor insulation are for wood-frame construction with insulation installed between the framing members. For alternative construction assemblies, see Section 150.1(c)1.A, B and C. Roofs/Ceiling insulation requirements are based on a wood frame tile roof construction and insulation installed below roof deck is installed between wood-framing members.
2. U-factors can be met by cavity insulation alone or with continuous insulation alone, or with both cavity and continuous insulation that results in a U-factor equal to or less than the U-factor shown. "R-15+4" means R-15 cavity insulation plus R-4 continuous insulation sheathing. Any combination of cavity insulation and/or continuous insulation that results in a U-factor equal to or less than 0.065 is allowed, such as R-13+5.
3. Mass wall has a thermal heat capacity greater than or equal to 7.0 Btu/h-ft2. Below grade "interior" denotes insulation installed on the inside surface of the wall. Below grade "exterior" denotes insulation installed on the outside surface of the wall.
4. The installed fenestration products shall meet the requirements of Section 150.1(c)3.
5. The installed fenestration products shall meet the requirements of Section 150.1(c)4.
6. HSPF means "heating seasonal performance factor."
7. When whole house fans are required (REQ), only those whole house fans that are listed in the Appliance Efficiency Directory may be installed. Compliance requires installation of one or more WHFs whose total airflow CFM is capable of meeting or exceeding a minimum 2 cfm/square foot of conditioned floor area per Section 150.1(c)12.
8. A supplemental heating unit may be installed in a space served directly or indirectly by a primary heating system, provided that the unit thermal capacity does not exceed 2 kilowatts or 7,000 Btu/hr and is controlled by a time limiting device not exceeding 30 minutes.
9. For duct and air handler location: REQ denotes location in conditioned space. When the table indicates ducts and air handlers are in conditioned space, a HERS verification is required per Reference Residential Appendix RA3.1.4.3.8. Alternatively, HERS verification is required per Reference Residential Appendix RA3.1.4.3 to meet 3% total duct leakage.
10. For total duct leakage (%), note that section 150.0(m).11.A specifies total duct leakage shall not exceed 6% of the nominal air handler airflow.
11. Alternatives to using below deck insulation installed between wood-framing members include installing R6 continuous insulation at the roof deck that is not thermally bridged by roof framing members. For asphalt roofs, the insulation requirements can be met with R8 continuous insulation at the roof deck or R15 insulation below roof deck.

6.2 Reference Appendices

Currently the compliance software recognizes variables of terms/options for installing ducts in conditions space, including

- Ducts entirely in conditioned space

- Verified low leakage ducts entirely in conditioned space
- Ducts in conditioned space except for 12 linear feet
- Ducts located in various locations

Modifications will be made in the Residential Appendix to field testing procedure requirements and protocols associated with each of the allowable DCS approaches and the HPA package.

Modifications will be made in the Residential Appendix to field testing procedure requirements and protocols associated with each of the DCS approaches and the HPA package. The proposed code change will modify Residential Appendices RA2 for HERS verification, testing and documentation procedures, RA3 for residential field verification and diagnostic test protocols, and RA4 for eligibility criteria for energy efficiency measures. The proposal will update Table RA2-1 Summary of Measures Requiring Field Verification and Diagnostic.

The proposed measure will require updates, deletion, and consolidations to the following subsections of RA3 for verification of installing ducts in conditioned space and quality insulation installation:

- 3.1 Field Verification and Diagnostic Testing of Air Distribution Systems
  - Table RA3.1.2 – Duct Leakage Verification and Diagnostic Test Protocols and Compliance Criteria
  - 3.1.4 Verification and Diagnostic Procedures
    - 3.1.4.1 Diagnostic Supply Duct Location, Surface Area and R-value[27]
      - 3.1.4.1.1 Verified Duct System Design:
      - 3.1.4.1.2 ~~Verification of 12 Linear Feet or Less of Duct Located Outside Of Conditioned Space[28]~~
      - 3.1.4.1.2 Verification of Ducts Located In Conditioned Space
      - 3.1.4.1.4 Verification of Supply Duct Surface Area Reduction
      - 3.1.4.3.8 Verification of Low Leakage Ducts in Conditioned Space Compliance Credit
      - 3.1.4.3.9 Verification of Low Leakage Air-Handling Unit with Sealed and Tested Duct System
- 3.5 Quality Insulation Installation Procedures
  - 3.5.1 Purpose and Scope
    - 3.5.3.3 – Roof/Ceilings (Batt and Blanket)
      - 3.5.3.3.1 Special Situation – Enclosed Rafter Ceilings
      - 3.5.3.3.2 Special Situations – Attics and Cathedral Ceilings
    - 3.5.4.3 – Roof/Ceilings (Loose Fill)
    - 3.5.5.3 – Roof/Ceilings (Rigid Foam Board)
    - 3.5.6.3 – Roof/Ceilings (SPF)
      - 3.5.6.3.2 Special Situations – Attics and Cathedral Ceilings

[27] This proposal will add requirements for air handler location within conditioned space

[28] This compliance option is proposed to be removed

The proposed measure will require minor modification to RA4 Eligibility Criteria for Energy Efficiency Measures:

4.2 Building Envelope Measures

4.2 Radiant Barrier

4.2.1.1 For Prescriptive Compliance: The attic shall be ventilated

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

Measure Title	Description	Procedure
	Duct Measures	
Duct Sealing	Component Packages require that space conditioning ducts be sealed. If sealed and tested ducts are claimed for compliance, field verification and diagnostic testing is required to verify that approved duct system materials are utilized, and that duct leakage meets the specified criteria.	RA3.1.4.3
Supply Duct Location, Surface Area and R- value	Compliance credit can be taken for improved supply duct location, surface area and R-value. Field verification is required to verify that the duct system was installed according to the design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.[1] For buried ducts measures, Duct Sealing and High Quality Insulation Installation (QII) is required.	RA3.1.4.1
Verification of ducts located entirely in directly conditioned space, and Low Leakage Ducts in Conditioned Space (DCS)	When the Standards specify use of the procedures in Section RA3.1.4.3.8 to determine if space conditioning system ducts are located entirely in directly conditioned space, the duct system location shall be verified by diagnostic testing. Compliance credit can be taken if "Option A" is used per Section 150.1(c).9.A of the Standards for verified duct systems with low air leakage to the outside when measured in accordance with Reference Residential Appendix Section RA3.1.4.3.8. Field Verification for ducts in conditioned space is required. Duct sealing is required.	RA3.1.4.3.8
Low Leakage Air-handling Units	Compliance credit can be taken for installation of a factory sealed air handling unit tested by the manufacturer and certified to the Commission to have met the requirements for a Low Leakage Air-Handling Unit. Field verification of the air handler's model number is required. Duct Sealing is required.	RA3.1.4.3.9
Verification of Return Duct Design	Verification to confirm that the return duct design conform to the criteria given in TABLE 150.0-C or TABLE 150.0-D	RA3.1.4.4
Verification of Air Filter Device Design	Verification to confirm that the air filter devices conform to the requirements given in Standards Section 150.0(m)12.	RA3.1.4.5
Verification of Prescriptive Bypass Duct Requirements	Verification to confirm zonally controlled systems comply with the bypass duct requirements in Section 150.1(c)13	RA3.1.4.6
Measure Title	Description	Procedure
	Building Envelope Measures	
Building Envelope Air Leakage	Compliance credit can be taken for reduced building envelope air leakage. Field verification and diagnostic testing is required.	RA3.8

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

Appendix RA3 – Residential Field Verification and Diagnostic Test Protocols

RA3.1.4 Verification and Diagnostic Procedures

This section describes the procedures used to verify compliance with the mandatory and performance compliance requirements for air distribution systems.

~~RA3.1.4.1.2 Verification of 12 Linear Feet or Less of Duct Located Outside Of Conditioned Space~~

~~A visual inspection shall confirm space conditioning systems with air handlers located outside the conditioned space have 12 linear feet or less of duct located outside the conditioned space including air handler and plenum. If the space conditioning system has more than 12 feet of duct outside of conditioned space, the system does not pass.~~

RA3.1.4.3.8 Verification of Low Leakage Ducts in Conditioned Space ~~Compliance Credit~~, and Ducts Located Entirely In Directly Conditioned Space

~~When ducts are located in conditioned space, additional performance compliance credit is available for low leakage ducts. if duct leakage to outside is equal to or less than 25 cfm when measured in accordance with Section RA3.1.4.3.4, the system passes. The dwelling must also be qualified to receive the credit for verified ducts in conditioned space as verified by visual inspection according to Section RA3.1.4.1.3.~~

When the Standards specify use of the procedures in Section RA3.1.4.3.8 to determine if space conditioning system ducts are located entirely in directly conditioned space, the duct system location shall be verified by diagnostic testing according to the following criterion: If duct leakage to outside is equal to or less than 25 cfm when measured in accordance with Section RA3.1.4.3.4, the system ducts shall be considered to be located entirely in directly conditioned space. The dwelling must also be verified by visual inspection according to Section RA3.1.4.1.3. Duct systems that do not meet this criterion shall not be considered to be located entirely in directly conditioned space.

Compliance credit can be taken if “Option A” is used per Section 150.1(c).9.A of the Standards for verified duct systems with low air leakage to the outside when measured in accordance with Reference Residential Appendix Section RA3.1.4.3.8. The dwelling must also be verified by visual inspection according to Section RA3.1.4.1.3.

RA3.1.4.3.9 Verification of Low Leakage Air-Handling Unit with Sealed and Tested Duct System

An additional performance compliance credit is available for verified low leakage ducts if a qualified low leakage air-handling unit is installed. The low leakage air-handling unit cabinet (furnace, or heat pump fan and inside coil) shall conform to the qualification requirements given in Reference Joint Appendix JA9, and shall be included in the list of low leakage air handling units published by the Energy Commission. The qualified air handler must be connected to a sealed and tested new duct system to receive the credit.

In order to comply with this credit, the duct system shall be verified to leak less than or equal to the leakage rate specified on the Certificate of Compliance using the methods in Section RA3.1.4.3.1, and the air handler manufacturer make and model number shall be verified to be a model certified to the Energy Commission as qualified for credit as a low leakage air handler.

6.3 ACM Reference Manual

This section will be updated after the CEC rulemaking workshops and once the code language is finalized.

6.4 Compliance Manuals

This section will be updated after the CEC rulemaking workshops and once the code language is finalized.

6.5 Compliance Forms

This section will be updated after the CEC rulemaking workshops and once the code language is finalized.

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8. APPENDIX A: ENVIRONMENTAL IMPACTS METHODOLOGY

Greenhouse Gas Emissions Impacts Methodology

The avoided GHG emissions were calculated assuming an emission factor of 353 metric tons of carbon dioxide equivalents ($MTCO_2e$) per GWh of electricity savings. The Statewide CASE Team calculated air quality impacts associated with the electricity savings from the proposed measure using emission factors that indicate emissions per GWh of electricity generated.[29] When evaluating the impact of increasing the Renewable Portfolio Standard (RPS) from 20 percent renewables by 2020 to 33 percent renewables by 2020, California Air Resources Board (CARB) published data on expected air pollution emissions for various future electricity generation scenarios (CARB 2010). The Statewide CASE Team used data from CARB's analysis to inform the air quality analysis presented in this report.

The GHG emissions factor is a projection for 2020 assuming the state will meet the 33 percent RPS goal. CARB calculated the emissions for two scenarios: (1) a high load scenario in which load continues at the same rate; and (2) a low load rate that assumes the state will successfully

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

implement energy efficiency strategies outlined in the AB32 scoping plan thereby reducing overall electricity load in the state.

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

Avoided GHG emissions from natural gas savings were calculated using an emission factor of 5,303 $MTCO_2e$/million therms (U.S. EPA 2011).

Greenhouse Gas Emissions Monetization Methodology

The 2016 TDV cost values used in the LCC Methodology includes the monetary value of avoided GHG emissions based on a proxy for permit costs (not social costs) and the Cost-effectiveness Analysis presented in Section 5.2 of this report does include the cost savings from avoided GHG emissions. To demonstrate the cost savings of avoided GHG emissions, the Statewide CASE Team disaggregated value of avoided GHG emissions from the other economic impacts. The Statewide CASE Team used the same monetary values that are used in the TDV factors – $TBD /$MTCO_2e$.

Water Use and Water Quality Impacts Methodology

This measure is not expected to have any direct impacts on water use and water quality.

9. APPENDIX B: DCS AND HPA STRATEGIES

9.1 Ducts in Conditioned Spaces

Although DCS strategies are not common practice for new construction in California, there are several advanced home builders that have adopted DCS for new production homes as identified in Table 16 and Table 18. It is noteworthy that production home builder Meritage has made sealed attics with spray foam insulation a standard in all of its new homes in Northern and Southern California, as well as nationwide.

There are several methods of achieving the goal of DCS and in this section we outline the basic information of the strategies, their benefits, challenges, and potential solutions to those challenges.

9.1.1 DCS – Vented Attic, Dropped Ceiling

This strategy places ducts within the thermal envelope without affecting the standard construction of the attic space. This strategy works well in linear plans where rooms branch out from a central hallway with the dropped ceiling. Sometimes soffit spaces for duct runs are turned into room ceiling design features that change a flat ceiling into a tiered ceiling. This strategy is implemented in a PG&E ET project, the De Young project, the SMUD Home of the Future project and is being considered for other projects implementing ducts in conditioned space.

Benefits of selecting this strategy include:

- Vented attic space, same as standard practice
- Does not affect attic assembly or insulation; no changes to truss design
- Works with simple and linear designs with rooms off main hallway but can work with more complex plans
- Dropped ceilings can be integrated into architectural accents

There are challenges associated with this strategy as outlined below but they can be overcome with good design and installation practices.

- Need to address air handler location – there may not be sufficient space (height, width) in the dropped ceiling to accommodate the air handler. In this case, the air handler would need to be installed in a separate closet within the thermal boundary of the home.
- Coordination needed between trades – moving the ducts and air handlers and the need to isolate and seal the dropped ceiling would necessitate coordination between different trades (HVAC installer, dry-wall, framing, and electrical contractors) to ensure thermal integrity of the dropped ceiling.
- Some stakeholders have raised aesthetic concerns related to dropped ceilings in that homebuyers are said to value high open ceilings. However, this issue can be addressed by incorporating dropped ceilings in the perimeter soffits, allowing the main ceiling area to have the full height from finished floor as desired.

Title 24 requires the "right-sizing" of HVAC systems and correct duct design. With the improvements in building envelope components (tighter envelope, better insulation and higher performing fenestration products), it is estimated that typical cooling and heating systems installed now are often over-sized by a factor of two and four respectively[30]. The outdated rule of thumb was to install a ton of AC for every 500 square feet of conditioned floor area (sf CFA). Dwelling built to 2013 Title 24 will require a ton for every 1000 to 1500 sf CFA. With right-sizing and observing the ACCA Manual D and T[31] rules of putting in supply grilles only as needed; the lengths of the ducts could be reduced substantially.

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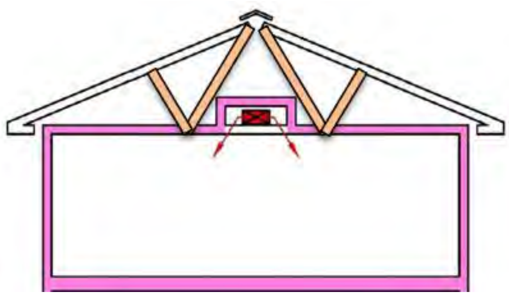
[30] Personal interview with Rick Chitwood, on right-sizing and the current market condition for new construction in CA, March 2014.

[31] http://www.acca.org/standards/technical-manuals/

The reduction in total duct lengths would in turn make installing the ducts, both supply and return, in the dropped ceiling more feasible.

The space constraint concern also emphasizes the importance of integrated design, because if the building designer and HVAC designer are committed to placing ducts in conditioned space, the design team would make sure that dropped ceiling space is sized to house the ducts. Another solution to this could be to use sheet metal ducts that can move the same air through a duct that is one size smaller than that required for wire helix plastic flex duct.

9.1.2 DCS – Vented Attic, Conditioned plenum space



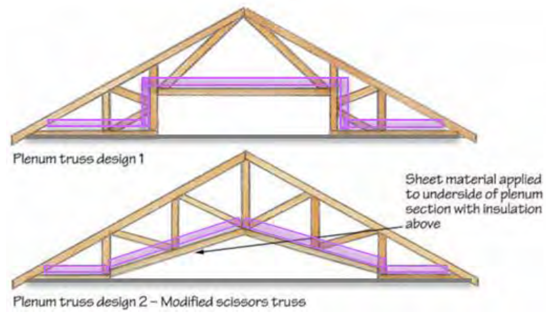


Figure 3: Options for Conditioned Plenum Space (adopted from Ductsinside.org and CEC 2003c)

A conditioned plenum is created when a space within the attic is sealed off and insulated from the rest of the attic. This approach is highlighted in a Building America research project conducted by IBACOS, Inc. (IBACOS, 2013)[32]. To use this design option, a builder can specify two types of modified trusses; either scissor trusses or a truss configuration that creates a plenum box. According to stakeholder input[33], it is not difficult for a truss manufacturer to produce modified trusses based on demand. Another way to create a conditioned plenum does not involve modified trusses, but rather to create the space by framing, sealing and insulating the plenum space above the ceiling plane.

Similar to a dropped ceiling, this design is easier with a linear plan that allows for the conditioned space built in the attic to cover a central "spine" throughout the floor plan that can reach all spaces in need of supply registers. This design option allows for ducts in the attic space and does not affect aesthetics of the home.

Benefits for selecting the strategy:

- Vented attic space, same as standard construction
- Aesthetically less disruptive than dropped ceiling

[32] http://www.nrel.gov/docs/fy14osti/60056.pdf

[33] Interview with William Zoeller (Steven Winters Associate), February 2014.

- Works with simple and linear designs with rooms off main hallway

There are challenges associated with this strategy as outlined below but they can be overcome with good design and installation practices.

- Need to seal the plenum from attic – as with most of the DCS strategies, it is important that care and attention is provided to air sealing the plenum space from the attic space.
- May require modified trusses in which case manufacturers need to be provided with specifications that can be met. Feedback from stakeholders is that this is technically feasible and manufacturers are capable of providing these trusses.

9.1.3 DCS – Vented Attic, Open Web Floor Truss

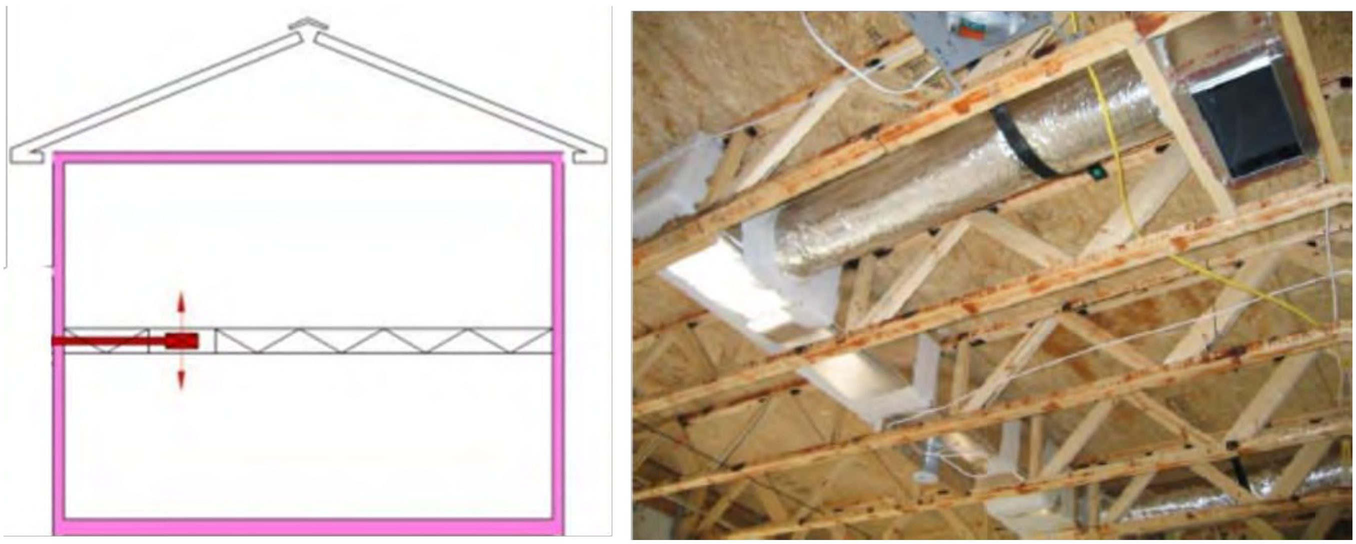


Figure 4: Open Web Floor Truss (adopted from Ductsinside.org and Steven Winter Associates, Inc. 2014)

This option can work for two-story construction and makes use of the space between floors to house ducts. Open-web floor trusses are not a common component in residential construction, but are available from several floor joist manufacturers such as RedBuilt, TrimJoist, SpaceJoist and Open Joist. The depth of floor joists may need to be increased in order to create a large enough space for supply ducts. The increased joist depth may impact interior details and wall heights. An industry expert also suggested that sometimes this could push the building height over the limit established by local jurisdiction. Because of the size constraints from using the floor truss, there is a need to preserve construction quality and prevent undesirable construction practices such as forcing 14” ducts into a 12” joist spaces. Another option is to use alternatives to wire helix plastic flexible ducts that take up less space.

Coordination between the architect and the HVAC engineer and/or contractor is needed to ensure that ducts are correctly sized and truss depths are appropriately selected. Using the area between floors to house ducts prescribes that supply registers be at the floor or lower wall in the second story and the ceiling or upper wall in the first story. Two builders in the Washington area, Quadrant Homes and New Tradition Homes, have extensively used this design and see the benefits of open web floor trusses, which can also be used to house components of other systems (Lubliner 2008[34]).

Benefits for selecting this strategy include:

- Works for homes with two or more stories
- Vented attic space remains same as standard practice
- Allows access to all rooms across joists since the truss is between floors
- Open access for other plumbing and electrical needs

There are challenges associated with this strategy as outlined below but they can be overcome with good design and installation practices.

- Lack of experience in California with this strategy – This approach has been done for decades but has not been emphasized. We have not found any recent subdivision scale projects within California that have implemented this strategy; however, it has been adopted by two builders in the Pacific Northwest: Quadrant Homes and New Tradition Homes.
- Requires designer and trade coordination: structural, HVAC, and architectural – As with many of these strategies, knowing where trades can place their components and make penetrations is important. Training and coordination are critical to ensure that trades don't get in the way of each other or cause damage to work done by another trade.
- May require deep or enhanced openings trusses to fit ducts, which could affect house height and exterior details and materials – HVAC contractors need to be consulted during the design phase so that the builder knows what truss openings will be needed to accommodate ducts and what possible impacts this will have on the height of the building Another solution to this could be to use alternatives to wire helix plastic flexible ducts that take up less space.
- Need to seal and insulate rim joists - as with most of the DCS strategies, it is important that care and attention is provided to air sealing the rim joists separating the exterior conditions from the truss cavity. Two options to accomplish this are to use high-density spray foam at the rim joist, or to use a combination of fiberglass and rigid foam insulation in the joist bay at the rim location[35] (NEEA 2011). A visual inspection is necessary to ensure that the joists are sealed properly.
- Running ducts to rooms above unconditioned space (garage) – The joist cavities need to be insulated for areas separating conditioned and unconditioned spaces. There is often not space for both ducts and insulation in these cavities. Options to solve this are to either run

[34] http://www.energy.wsu.edu/documents/aceee_ducts_inside.pdf

[35] http://ductsinside.org/

ducts up interior walls to serve these rooms or run ducts through cavity and place insulation below the areas where the ducts are utilizing the cavity (NEEA 2011).

9.1.4 DCS – Unvented attic (Sealed)

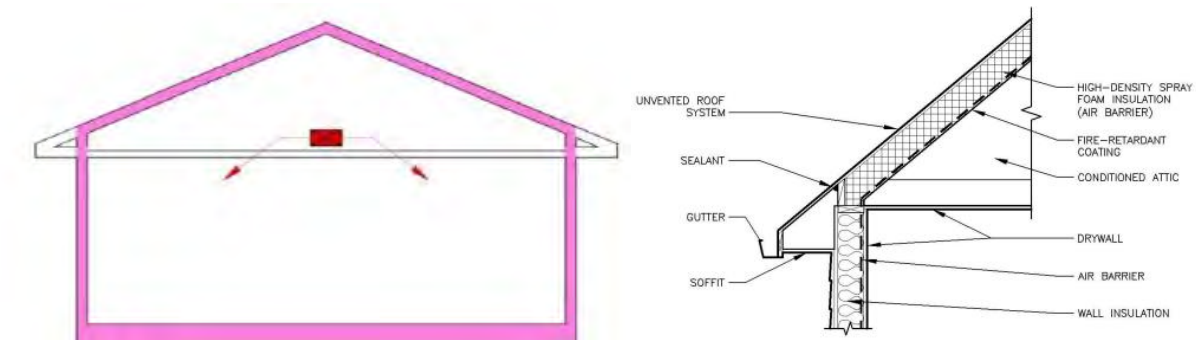


Figure 5: Unvented Attic (adopted from Ductsinside.org)

Interviews with industry experts on high performance buildings shows that insulating the roof deck and sealing the attic space is a commonly constructed option for getting ducts in conditioned space. This design allows for ducts and equipment to be placed in the attic, which is in line with current construction practices. The main change is that the insulation is moved from the ceiling to the roof line – effectively extending the building thermal enclosure to the physical enclosure of the house.

Builders participating in IOU Emerging Technology programs, DOE Challenge Home program and Building America programs have provided positive feedback or showcased positive results using this method. One of the builders working with the IOU Emerging Technology program said that “sealed attics are by far the most efficient method of conserving space conditioning energy. The additional conditioned space is more than offset by the energy savings.” However, he further noted that “this strategy might be cost prohibitive and construction scheduling may be difficult for production homes.”

Advanced builders such as Pulte Homes, Shea Homes and Meritage have implemented this strategy in the market. Meritage, a national home builder, made the decision around 2006 to pursue sealed attics in all residential construction after researching and comparing options to reduce heating and cooling loads. They found that sealed attics eliminate the need to seal at the ceiling level, which is often compromised by penetrations for lighting, sprinkler heads, and other necessary components. Although the costs may appear high, Meritage has found this method to be cost-effective in the market and they have found ways to offset some of the costs. Meritage’s chief sustainability officer notes that the transition was made across the company rather than implementing it in a few developments because of their ability to drive costs down with large scale procurements.

Benefits for selecting this strategy:

- Bring attic temperatures closer to conditioned space – effectively making the attic space a ‘semi-conditioned’ space

- Ducts and equipment stay out of the way and do not take up valuable floor space as in the traditional vented attic
- Reduces the need to seal ceiling plane around penetrations such as lighting, sprinklers etc.

There are challenges associated with this strategy as outlined below but they can be overcome with good design and installation practices.

- Need to address moisture management (similar to HPA options) – There are no documented moisture issues associated with implementing sealed attics in California to the Statewide CASE Team's knowledge. Several building science research studies have provided solutions for California climate zones based on field and simulated observations. Production builders that are using roof deck insulation have reported that they have not seen any issues related to moisture damage. If care is taken and proper materials are used, moisture should not be an issue for this strategy. These solutions are elaborated on below.
- Need to seal attic-to-deck junction - as with most of the DCS strategies, it is important that care and attention is provided to air sealing the attic edges. Quality air-sealing can be accomplished with the use of air-impermeable spray foam insulation.
- Use of sealed combustion equipment – All furnaces require flue vents to remove combustion gases from the building. Natural draft furnaces that draw combustion air from the space in which they are located or through ducts to the outside as specified in the mechanical code. Sealed combustion equipment will need combustion air piping or ducting installed as specified by the manufacturer. Alternatively, dwellings can be heated with a hot water coil in an air handler which is referred to as a combined hydronic heating system. The domestic water heater provides the hot water and can be located outside the thermal/air barrier of the dwelling.
- Product service life for asphalt tile roofing – A study performed by BSC (2006)[36] found that the impact to roof surface temperature due to unvented attics is the same as adding a radiant barrier in a vented attic. Roof color and orientation have more important impact on lifespan that the presence of roof deck insulation. Builders who are concerned can use above-deck insulation products with integrated ventilation, or add spacers or "counter batten" to provide more air spaces for ventilation.

There is wide variety of available insulation products that can be used for sealed attic; however, special attention is needed when using air-permeable insulation under the roof deck. Installation of air-permeable insulation below the roof deck on its own allows interior moisture source to cause condensation on the interior surface and within insulation via air movement. Since the attic space is unvented, the interior moisture will not have proper dryer potential to

[36] http://www.buildingscience.com/documents/digests/bsd-102-understanding-attic-ventilation

air out any moisture accumulated in the insulation. Therefore, proper measures are needed to use air-permeable below deck insulation for unvented attics.

The mechanical part of the California Building Code, Title 24, Part 2 (Mechanical), Volume 2.5 Section R806.5[37] dictates that unvented attics are allowed provided that:

- Air-impermeable insulation is used below deck and in direct contact with the underside of the roof sheathing, or
- Air-permeable insulation is used below and in direct contact with the underside of the roof sheathing and rigid board or sheet insulation of at least R-4 is used above the roof sheathing, or
- Air-*im*permeable insulation is used below and in direct contact with the underside of the roof sheathing and an additional layer of air-permeable insulation is installed directly under the air-*im*permeable insulation.

The CBC specifies that air-permeable insulation may be used below the roof deck for unvented attics if a layer of air-*im*permeable is used in conjunction; the *im*pearmeable layer could either be in direct contact with the interior space (to block air movement) or above the roof deck to decrease the temperature difference (thus the condensation forming potential) experienced by the interior surface of the permeable insulation layer.

The International Residential Code (IRC) has similar requirements as the CBC per above (reasonably so since the CBC is adopted from IRC). In addition, IRC requires that no Class I vapor barrier should be installed on the underside of below-deck insulation. Further, IRC requires a certain amount of air-*im*permeable insulation above deck if air-permeable insulation is installed below roof deck. The following values are listed by IRC climate zones:

[37] http://www.ecodes.biz/ecodes_support/free_resources/2013California/13Residential/PDFs/Chapter%208%20-%20Roof-Ceiling%20Construction.pdf

Table 41: Air-Impermeable Insulation Requirement by IRC Climate Zone

IECC/IRC Climate Zone	Minimum Rigid Board On Air-Impermeable Insulation R-Value	Applicable Title 24 Climate Zones
2B and 3B tile roof only	0 (none required)	11-15 with tile roof
1, 2A, 2B, 3A, 3B, 3C	R-5	1-6, 11-15 with non-tile roof
4C	R-10	1
4A, 4B	R-15	NA
5	R-20	16
6	R-25	NA
7	R-30	NA
8	R-35	NA

9.1.5 DCS – Mechanical Closet (and Placement of Sealed Combustion Furnace)

Figure 6: Interior Furnace with Ducts in Conditioned Plenum Space (IBACOS 2013)

As part of the requirement for moving duct system and air handler into conditioned space, construction of a mechanical closet is necessary with some DCS strategies. For example, if ducts are placed in dropped ceiling space but there is not enough room to accommodate the air handler in that space, the mechanical closet could be placed in the interior of the building's thermal boundary. A conditioned plenum provides enough space for ducts equipment so a mechanical closet may not be needed. For sealed attics, the equipment would be placed in the attic space, and a mechanical closet is not needed.

Placing the equipment in conditioned space requires the use of sealed combustion furnaces. The use of sealed combustion furnace in residential new construction buildings is standard practice in cold climates. Industry experts interviewed explained that sealed combustion furnaces (most of them are condensing furnace with AFUE level higher than 90%) are selected in cases where builders are looking for the "extra credit" to quality for utility program incentives or when using the performance path to offset impacts of increased fenestration area.

The footprint of the furnace with necessary clearance for connections can be up to 4 feet by 4 feet. Stakeholders interviewed by the Statewide CASE Team have said that maximizing conditioned floor space is important for home builders, thus any mechanical closet added will impact on CFA.

Another concern about putting furnaces of any kind in the conditioned space is about noise. There are several "best practices" and precautions that can be taken to reduce noise issues associated with locating furnaces in closets within the home. A few of these include: sizing ducts correctly, using insulated flex ducts for the return and last few feet of supply, locating furnace away from bedrooms, mounting furnace on vibration pads, and selecting proper grilles for required air flow (NEEA 2011[38]).

9.1.6 DCS – Ductless Systems

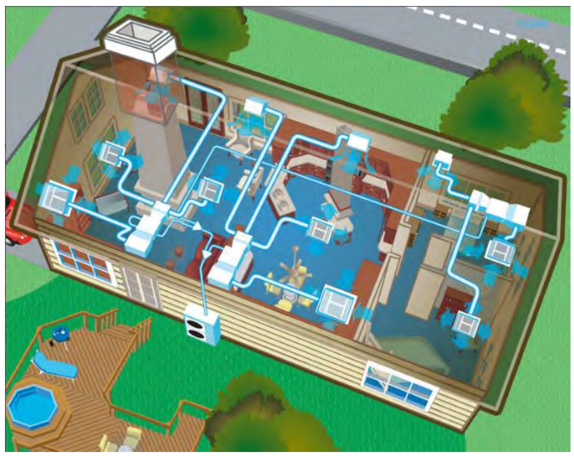


Figure 7: Whole House Ductless System (Daikin variable refrigerant flow system)

According to insights from the California Advanced Homes Program and PG&E ET team, ductless systems are uncommon in production homes, but are more frequently used in custom homes through the program. Homes in coastal climate zones are likely to use hydronic radiant floor heating and go without a cooling system. In central valley CZs hydronic radiant ceiling heating and cooling is introduced with good results.

9.2 High Performance Attics

HPA is achieved by installing group of measures that are minor changes to the standard construction practice. Building a home with the HPA option will allow ducts and air handler to remain in the vented attic. If moving ducts and equipment into conditioned space is not desirable or practical for a project, builder could choose to implement the list of measures under the HPA package instead.

[38] http://ductsinside.org

9.2.1 Roof deck insulation

Table 42: Above and Below Deck Insulation Comparison

	Above-deck Insulation	Below-deck Insulation
Nailable base	Requires use of OSB over insulation or insulation product with facing,	NA
Roof deck ventilation (for tile or asphalt products)	Requires use of special insulation products, spacers, or battens	NA
Moisture management	Requires addition of OSB above insulation and air barrier below insulation. Care and attention to details needed to eliminate roof leaks.	Need for moisture management if air-permeable insulation is used. Care and attention to details needed to eliminate roof leaks.

Above Deck Insulation

From industry interviews, the Statewide CASE Team finds that it is not common, even with advanced homes, to place insulation above the roof deck in addition to the ceiling insulation. Due to this, it is likely that the California residential building labor force will need to learn new installation techniques.

On the other hand, there are a reasonable number of manufacturers and product selection available. This could likely be a result of the use of above roof deck insulation for nonresidential buildings in California.

There are several issues that need to be addressed with above deck rigid insulation including:

- Fire rating performance of roofing products
- Product attachment and ventilation
- Moisture management: water leaks and vapor condensation

However each of these issues has known solutions, so that this strategy is viable as an option for HPA.

Fire rating performance of roofing products

California requires roofing products to obtain a minimum fire rating class C, while class B is required in some areas, and Class A products are required in Wildfire Urban Interface (WUI) per the procedures and classification of ASTM E-108 (/UL 790). The roof covering product fire rating tests are generally conducted with products installed directly on the wood deck. Industry stakeholders have expressed concerns that the current firing rating certifications will no longer be applicable because the addition of above-deck insulation (underneath the roofing products) alters the configuration of the assembly. The issue of roofing product fire rating warrants further research to assess the effects of placing roof products above the above-deck insulation. Industry stakeholder suggest that once the CEC determines the appropriate configuration(s) of roof assemblies that satisfy the prescriptive roof deck insulation requirements, the roofing manufacturers would proceed to re-certify their products to the specified configurations in order to satisfy the state's roof covering fire rating requirement.

Product attachment and ventilation (relating to performance and service life)

The nailable base for asphalt roofing can be addressed by installing an OSB or plywood layer over the insulation. Having a nailable base is useful for tile roof installation as well, as there is sometimes the need (for nailable surface) to further secure the tiles in area of higher wind load.

Installing spacers directly over the roof deck insulation or to a layer of roof sheathing placed over the insulation can address the nailable surface requirement and provide continuous ventilation. Having continuous ventilation below the roof products effectively lowers the temperature seen by the roof, thus prolonging roof product service life. This solution addresses the moisture (underneath roof products/above the rigid foam) and roof surface temperature concerns.

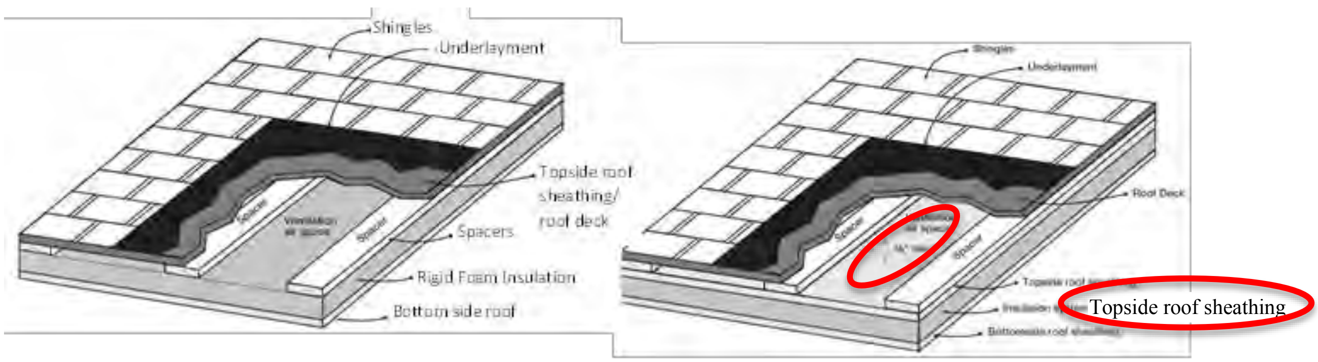


Figure 8: Ventilation for Asphalt Shingles (ARMA Form No. 211-RR-94 2008)

Responding to market needs, some foam boards product now come with an integrated OSB or plywood layer. An additional layer of OSB or plywood will require longer screws to reach the required depth in each rafter; these screws are generally more expensive than the standard screws used to secure roof sheathing because of their larger size and length.

Some polyiso products are manufactured with a ventilated nail base (VNB), which is a layer of polyiso with spacers and an OSB layer to provide a nailable base and ventilation for asphalt shingles. There are similar products available with OSB facings but no spacers for ventilation.

Installation of above-deck rigid foam insulation with tile roofs also presents problem in terms of product ventilation. The structure and installation of tiles provides a natural ventilation space directly underneath the tiles and an additional thermal benefit on the order of R- 2.75[39]. The addition of above-deck insulation reduced this "natural ventilation" for the tiles, and an industry stakeholder suggests installation of counter or double battens to increase the height of air space to ensure ventilation.

[39] Presentation by Jay Cruz (Boral Roofing LLC) during CIBA and CEC Forum on April, 4 2014.

Figure 9: Ventilation for Tile Roofing – Counter Batten (CBIA Forum)

Moisture management

There are two places where moisture management is a concern with installation of above-deck insulation: underneath roof products/above the rigid foam, and under the rigid foam/above the roof deck sheathing. As described in the section immediately above, using an additional layer of wood sheathing supported by spacers placed on the rigid foam could address the moisture concern between the rigid foam and roofing products (and provide ventilation for roofing products).

In the case of moisture-laden air infiltrating the joints in the rigid foam, the moisture could potentially travel through the penetrations and reach the roof deck. To prevent the moisture from traveling (in between rigid foam panels) to the roof deck, installation of an air barrier membrane would effectively block the moisture air and moisture problem associated with the connection between above-deck insulation and the wood decking.

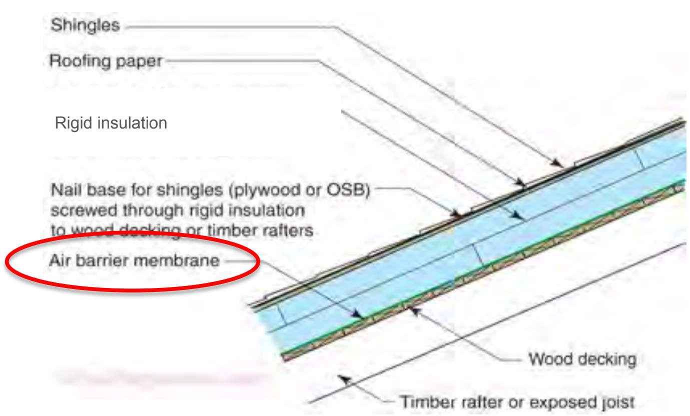


Figure 10: Moisture Management in Above Roof Deck Insulation (BSC)

Below Deck Insulation

Below deck insulation (directly in contact with underside of roof deck) is the most common method of installing roof deck insulation in all the high-performance homes studied as part of this CASE project. There are several options for insulation products as outlined in Section 3.1 on roof deck insulation. It should be noted that certain insulation products such as blown-in or closed cell spray polyurethane foam (cc-SPF) require specific equipment, and therefore may require a separate insulation contractor.

Similar to above-deck insulation, there are also moisture management considerations for use of below-deck insulations but the same solutions as those discussed for above deck insulation apply. The CEC commissioned a study for the 2013 standards on vented attic with below deck insulation, and the hygrothermal simulation results showed that air permeable insulation may be installed under the roof deck of a vented attic without moisture issues in all but CEC climate zone 16.

9.2.2 Insulated Roof Tiles

A newer type of product is now available in the market that combines concrete/clay tiles with insulation as a packaged product. A product developed by Green Hybrid Roofing called Engineered Roof Tiles incorporates a 2 lb. density EPS foam core encapsulated in polymerized concrete. These tiles are lighter than typical roof tiles and have better thermal performance than traditional tiles due to the insulation core.

The tiles are ASTM rated for Class A fire rating (ASTM E108), and have CRRC certification for cool roof tiles in seven colors.

The manufacturer cites several advantages of the product due to its light-weight construction and increased insulation properties – ease of installation, ability to install similar to traditional roof tiles but at a much higher pace, less weight on the roof structure, increased thermal resistance and improved thermal performance.

The CASE team intended to analyze this product for cost-effectiveness but we could not do so due to lack of the ability of the current CBECC-res software to model this product.

9.2.3 Increase Duct insulation to R8 in all Climate Zones

Duct insulation products are widely available in the state. Results from the expert interviews indicate that R-6 is the current default minimum since R-4.2, which until July 2014, was the prescriptive minimum has largely vanished from suppliers. Suppliers in general currently do not stock R-8 because the demand has not yet picked up. With R-8 as the prescriptive baseline in four climate zones (CZ 11, 14-16) in the 2013 Standards, the availability of R-8 duct insulation is expected to increase.

In terms of installation, R-8 installation is bulkier to work with than R-6 and there is anecdotal evidence of installer reluctance to use R-8. However, in a typical vented attic (as is assumed for HPA), there is adequate space to maneuver and install R-8 insulation.

9.2.4 Reduced Duct Leakage

Standard duct installations in CA often meet or exceed the mandatory duct leakage requirement (less than 6%) in Title 24. The CHEERS database tracks actual duct leakage rates, and the Statewide CASE Team was provided a copy of the measured duct leakage values for a sample of homes constructed in 2012 by CEC Staff with access to the CHEERS registry. Analysis of these homes show that more than half of the homes were tested with duct leakage at 5% or less of nominal air handler airflow as seen in the figure below.

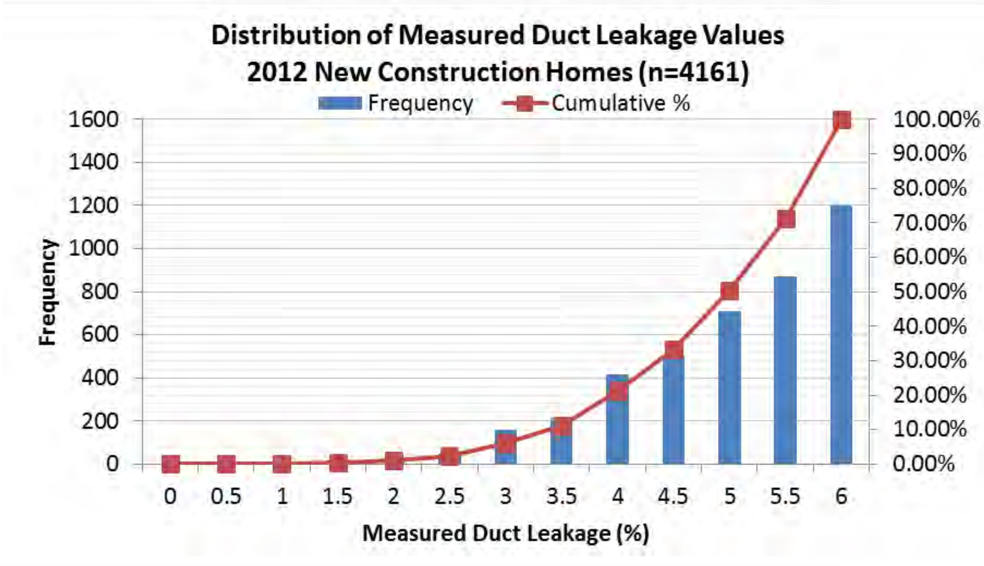


Figure 11: Measured Duct Leakage Values for a Sample of 2012 New Construction Homes

The CASE team supplemented this with interviews with industry experts. These experts also confirmed that reducing duct leakage below the current 6% requirement is common among advanced new home construction in California where HERS testing has been required for a while and there is overall intent to improve building performance.

According to our interviews with HERS raters, there are duct leakage "weak points" within current installation practices that present opportunities for achieving lower leakage rates:

- air handler unit
- the connection at joints
- Between duct boots to drywall/carpet.

Most interview respondents noted that using low leakage air-handlers (LLAHs) is the best way to achieve 4% or lower leakage. Further one of the interviewees notes that Pulte Homes exclusively uses LLAHs (Personal communication 2014).

Low leakage air handlers are factory certified to have leakage lower than 2% of the nominal airflow rate. Though these low leakage units are higher in costs, there are many available products in the market certified through the ENERGY STAR® program[40] as well as listed in the CEC database. The CEC's 2008 database contains over 1600 certified low leakage air handler models from many major manufacturers[41].

Leakage that occurs at duct boot connection to interior space can be reduced by installing boots with flanges or other parts designed to lower duct leakage. Installers could also ensure tighter connections by applying the appropriate amount of sealant material/ties and properly strapping and sealing inner linings at connections. HVAC contractors and painters do not agree on whose responsibility it is to perform sealing at the connection (HVAC contractor vs. painter), so clear division of responsibility in the project team could also mean the job gets done properly.

Although there are duct sealing protocols to follow to achieve tighter ducts, the experts interviewed agreed that there are implementation challenges in a production home environment. The challenges stem from having a tight construction schedule and its impact on time and attention allotted to installation details. Most production builders feel that they can't get the systems any tighter than it currently is. The implication for production builders is that HVAC contractors will have to be trained on the improved installation practices.

9.2.5 Energy Truss (Raised Heel or Extension Truss)

The use of raised heel or extension truss to allow full depth of ceiling insulation is rare in California. One of the experts interviewed noted that the practice is common in the Northeast region of the country.

Energy trusses, which include raised heel trusses and extension trusses, are not common among California builders. One northeast building expert says he sees them all the time, and that the design process is streamlined; however, this is not the input received from California builders and building experts. Feedback from the Statewide CASE Team's interviews indicated that the use of energy truss changes the aesthetics of the house that some home owners dislike. It is also possible that the added height could push the total building height limit set by local jurisdictions. Other methods to achieve the similar outcome include framing with a rafter on raised top plate or utilizing spray foam or rigid foam at the edge.

As mentioned during interviews, a few builders looked into the possibility of constructing these components to comply with the ENERGY STAR New Homes requirements, but did not ultimately pursue this design due to changes that the EPA made to the ENERGY STAR version 3 criteria. The EPA ENERGY STAR homes first release of proposed requirements for 2011 had originally required full depth ceiling insulation at attic edges. However, several builders responded against this requirement, and the final requirement, as also seen in version 3, is to allow for a lower insulation level at the attic edges while also proposing methods other

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[40] Program Criteria for 4.0 for Furnaces: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/furnaces/Final_Version_4.0_Specification.pdf?0803-1d33

[41] http://www.energy.ca.gov/title24/equipment_cert/llahu/index.html

than raised heel trusses that can achieve the required insulation level. The builder comments and EPA responses from the 2011 requirements are provided in the figure below.

Table 43: EPA Responses to ENERGY STAR 2011 Qualified New Homes Comments

Raised-Heel Truss & Attic Platform			
103	• Another major concern expressed by respondents was over the height impacts of requiring a raised heel truss. o Five respondents had concern with the impact on height, typically citing situations where local zoning requirements imposed height restrictions o One respondent noted, "certain narrow lot developments and home designs are not conducive to the use of raised heel trusses."	• EPA's review of this requirement indicates that it will only increase house height by approximately 8-12 inches. It is not clear to EPA that this small increase will create a widespread hardship for homebuilders. Furthermore, EPA has observed raised heel trusses or equivalent framing techniques being used successfully across many markets and all builder types.	• No policy change.
104	• Regarding the 'full-depth' requirement, respondents had concerns about high R-value attic insulation requiring a particularly high raised-heel truss. • One suggested changing the requirement to a specified depth that provides adequate – but likely not full depth – insulation at the roof edge. Eight inches was suggested as an appropriate number.	• EPA agrees with respondents that near-full-depth insulation should be sufficient to meet EPA's goal of ensuring a complete thermal enclosure system. • Because the required depth of insulation will vary by insulation type and climate, EPA prefers to define the requirement in terms of its intent and allow the rater and builder partners to translate this into the height required for each home.	• EPA has revised the proposed guidelines to clarify the requirement as follows: "Raised-heel trusses or equivalent framing techniques shall elevate the roof adequately to allow for insulation at a depth of at least 75% of full insulation level used throughout the rest of the attic."

The notes for the Version 3 (Rev. 07) ENERGY STAR checklist say that "these requirements can be met by using any available strategy, such as a raised-heel truss, alternate framing that provides adequate space, and/or high-density insulation" (EPA 2013). Additionally, the Northwest division of ENERGY STAR Homes (WA, OR, MT, ID) mentions on a FAQ page that this requirement can be met with "cantilevered trusses with wider overhangs, framing with a rafter plate, utilizing spray foam or rigid foam at the edge, or moving your ventilation up the roof deck to eliminate baffles and increase space for insulation".[42] Another alternative provided by a building expert from an IOU ET project, though noted as probably not the best option, is to add soffits at the exterior walls and allow the loose fill insulation to fill the cavity.

Several builders, including Meritage, Standard Pacific, GJ Gardner and Wathan Castanos, have tried using energy trusses, but no builder has adopted this approach as a standard or prevalent practice.

Benefits for using an energy truss include:

- Helps realize full benefit of insulation
- May provide more space for air handler and duct systems
- It is easy for the truss manufacturer to customize trusses through pre-fabrication

Challenges for using energy trusses include:

- Low level of installation experience in California and corresponding labor experience

[42] Northwest ENERGY STAR Homes 2013: http://www.northwestenergystar.com/sites/default/files/resources/NWESH_FAQ_0.pdf

- Changes aesthetics of the house, and sometimes create building height that exceed height limit set by local jurisdictions.
- Builders and energy consultants cited that the modeling software does not give the proper credit, so the extra cost and effort is not "worth the trouble". This should no longer be an issue with the release of the 2013 software, which allows for modeling of raised heel trusses and provides credit for the additional insulation at the edges.

9.2.6 Reduce Duct Surface Area (Duct Design Layout)

Reduced duct surface area is currently a compliance credit, titled "Verification of Supply Duct Surface Area Reduction", but feedback received from industry experts indicates that it is rarely taken due to various barriers that make the process burdensome for builders and HVAC contractors. The CAHP program manager observed that builders are beginning to claim this credit in the program, but at a very low occurrence.

The standards require the following procedure to qualify for the compliance certificate:

1. A scaled drawing that identify all equipment location, supply and return grilles, sizes, insulation values and location of each duct segment, and
2. Installer certificates and HERS verifications and certificates.

The Statewide CASE Team received the following reasons from industry experts, including HERS raters and energy consultants, for why builders do not use this compliance option frequently:

- Duct layout can change in the field during installation; so builders do not want to commit to a layout to perform compliance calculation before the plans and construction are completed.
- Calculation process to show a reduced duct surface area is tedious.
- Efficient and compact duct design is practiced, but builders do not want to pay for an additional HERS verification

The compliance software has a default value of 27 percent supply duct surface area based on the field work performed as part of CEC's 2002 Residential Construction Quality Assessment study (DEG 2002). The calculation performed using the field data showed that even though the supply duct surface area averaged 27 percent, there was a wide variation (between 20 and 53 percent supply duct surface area as % conditioned floor area) between the 22 one-story houses tested, as shown in Table 44.

Table 44: Duct Surface Area Summary (Table 5 from DEG 2002 report)

		Duct surface area as % conditioned floor area		
		Supply	Return	Total
All Houses	Average	32.0%	7.8%	39.8%
One-Story (count = 22)	Appendix F	27.0%	5.0%	32.0%
	Average	31.9%	7.5%	39.4%
	Minimum	20.2%	2.0%	23.5%
	Maximum	52.5%	16.6%	65.1%
Two-Story (count = 8)	Appendix F	27.0%	10.0%	37.0%
	Average	32.3%	8.8%	41.1%
	Minimum	26.0%	0.5%	32.4%
	Maximum	42.9%	16.9%	52.7%
>1 HVAC System (count = 5)	Average	32.1%	8.4%	40.5%
	Minimum	21.5%	2.0%	23.5%
	Maximum	52.5%	16.9%	61.1%

The Statewide CASE Team proposes for the calculation process for taking the compliance credit for "Verification of Supply Duct Surface Area Reduction" be streamlined by integrating the duct surface area calculation into the software. The CASE further proposes that instead of requiring the builder/HVAC designs to choose a supply duct surface area when they submit the construction documents that they later have to match exactly, that the compliance credit designates a "duct surface area "limit" that the builder/HVAC designers will commit to staying below. This will make the requirement much more reasonable to demonstrate while encouraging the practice of verified duct design.

Attic Ventilation Ratio

The Statewide CASE Team originally considered an increase in the attic ventilation ratio to 1/150 from the current 1/300 as a potential package component. However, the Team did not ultimately pursue this measure due to conflicts with the 2013 Standards and the compliance software modeling assumptions. The 2013 Title 24 Standards incorporate a prescriptive requirement for a Whole House Fan in climate zones 8-14 which induces a higher ventilation rate than the current 1/150. In other climate zones, the compliance software assumes a fixed ventilation rate of 1/300, so this measure is already factored in to the energy budget in the compliance software.

10. Appendix C: Cost Data Sources

Abe Cubano (Owens Corning). 2014. Personal communication. June 6.

All Truss Inc. 2014. Personal communication. May 19.

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[FSEC] Florida Solar Energy Center. Fonorow, K., et al. 2010. "Low Cost Interior Duct Systems for High Performance Homes in Hot Climates." Presented at ACEEE Summer Study on Energy Efficiency in Buildings, Aug 15-20, in Pacific Grove, CA. http://www.aceee.org/files/proceedings/2010/data/papers/1938.pdf

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Lubliner et al. 2008. "Moving Ducts Inside: Big Builders, Scientists Find Common Ground." Paper presented at the ACEEE Summer Conference. http://www.energy.wsu.edu/documents/aceee_ducts_inside.pdf

RS Means 2014 for Residential New Construction

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Marcos Hernandez (Beutler Corporation). 2014. Personal communication. June 5.

Mike Walker Lumber, Inc. 2014. Personal communication. May 28.

Molluzzo, Vinny, McGhi, Cody and Mahrou, Amber (Energy Inspectors). 2014. Personal Communication. January 31.

Online retail: Lowes, Home Depot, AC Wholesalers, AC Outlet, Alpine Home Air Products. Accessed between May and Sept 2014.

Pacific Gas and Electric / Davis Energy Group Emerging Technology ZNE pilot project survey

Tyler Allwood (Eagle Roofing). 2014. Personal communication. May 28.

Southern California Edison Emerging Technology Green Door project

William Zoeller. 2014. Personal communication. April 22.

11. Appendix D: Simulation Results Using CBECC-Res

11.1 DCS Strategies

11.1.1 Vented Attic

The following modeling options for DCS are available in the 2013 Standards[43]:

- Ducts in conditioned space except for 12 linear feet: visual inspection
- Ducts entirely in conditioned space: visual inspection
- HERS verified ducts entirely in conditioned space: visual inspection, duct leakage to outside HERS test

All three of the DCS -Vented Attic strategies (dropped ceiling, conditioned plenum and open web floor trusses) are variations of the "ducts entirely in conditioned space" performance option. The "verified" option is available if a verified "leakage to outside" test is performed to demonstrate performance.

The energy impact of duct placement is climate dependent. Climate zones with the highest cooling loads have the largest savings from minimizing duct losses via placing them in vented attics. The first option, "except < 12 lineal feet" is the lowest performing because parts of the

[43] Total duct leakage HERS test is a mandatory requirements that applies to all new construction buildings, regardless of whether DCS design strategy is chosen

duct lengths are assumed to be exposed to the vented attic with associated convection and leakage losses.

Savings range from 17% in the hottest climate zones (CZ13) for the "verified" option, to 2.5% in the mildest climate zone (CZ7) for the not "verified" option. The statewide weighted TDV savings from these DCS strategies are 7.5% for "except < 12 lineal feet" (Case 1), 9.4% for "ducts entirely in conditioned space" (Case 2), and 13.3% for the "verified" option (Case 3) as shown in the table below.

Table 45: DCS Vented Attic % TDV Savings

Case 1	Ducts located within the conditioned space (except < 12 lineal ft)
Case 2	Ducts located entirely in conditioned space
Case 3	Verified low-leakage ducts entirely in conditioned space

	% TDV Savings: (Baseline - Proposed)/Baseline		
Climate Zone	Case 1. Except < 12 lineal ft	Case 2. DCS	Case 3. Verified DCS
1	7.0%	8.5%	11.8%
2	5.9%	7.3%	10.3%
3	5.1%	6.2%	8.3%
4	7.9%	9.8%	12.8%
5	4.2%	5.1%	7.0%
6	5.4%	6.8%	8.7%
7	2.5%	3.1%	3.8%
8	7.1%	8.9%	11.8%
9	9.1%	11.4%	15.9%
10	9.0%	11.3%	15.2%
11	8.0%	10.2%	15.3%
12	9.0%	11.3%	15.3%
13	9.3%	11.8%	17.2%
14	8.3%	10.4%	15.5%
15	7.0%	8.8%	15.8%
16	7.5%	9.4%	13.7%
Weighted Statewide	7.8%	9.8%	13.7%

Energy cost savings from the energy reduction due to implementing DCS- vented attic strategies are presented in the table below. These cost savings may be interpreted as the maximum amount of first cost that would make the energy measure cost "neutral", because it would, over the 30-year building life time, produce equivalent energy cost savings. The highest cost savings for implementing the "verified ducts entirely in conditioned space" is over $7000 for CZ 15 (Palm Springs), and the lowest is $166 for installing "ducts located within the conditioned space (except <12 lineal ft)" CZ 7 (San Diego).

Table 46: DCS Vented Attic Present Value Energy Cost Savings

	Present Value Energy Cost Savings		
Climate Zone	Case 1. Except < 12 lineal ft	Case 2. DCS	Case 3. Verified DCS
1	$1,307	$1,592	$2,207
2	$946	$1,161	$1,649
3	$565	$684	$924
4	$1,189	$1,470	$1,916
5	$421	$508	$701
6	$510	$633	$818
7	*$166*	$205	$251
8	$861	$1,081	$1,427
9	$1,736	$2,172	$3,029
10	$1,729	$2,153	$2,915
11	$2,698	$3,406	$5,119
12	$2,088	$2,616	$3,552
13	$3,244	$4,118	$5,999
14	$2,640	$3,327	$4,928
15	$3,407	$4,315	**$7,693**
16	$2,164	$2,714	$3,928
Weighted Statewide	$1,824	$2,290	$3,271

11.1.2 Unvented Attic

As described in Section 3.2.3, another way to have ducts and equipment in conditioned space is moving the thermal boundary of the house from the ceiling to the roof line and creating an Unvented Attic for placement of ducts and a sealed combustion furnace. The implementation of an unvented attic in CBECC-res was made possible by the CBECC-res software team through a research version. In this version, the attic over the garage was eliminated since the software cannot handle multiple attics when modeling unvented attics.

Overall, utilizing unvented attics to house ducts and equipment in conditioned space did not perform as well as choosing DCS strategies with vented attics. Even with R-38 at the roof line of an unvented attic, the weighted statewide savings (at 10.5%) performs inferior to the case of "ducts entirely in conditioned space" for the vented attic (with no verification).

The CBECC-res team identified several key reasons for this:

- A whole house fan is not feasible with an unvented attic and as such is not modeled for unvented attics. This decision was made because a whole house fan operation defeats the primary purpose of constructing an unvented attic by purposefully introducing ventilation air from the conditioned space that has no outlet to the exterior.
- The software does not include a radiant barrier for unvented attics since installation of below-deck insulation (most prevalent method of insulating the roof deck) makes installation of radiant barrier impractical.
- The performance of insulation degrades as the delta across the insulation increases. For an unvented attic, the temperature difference across the insulation (roof deck on one side, semi-conditioned space on the other side) is much higher than the temperature difference for the same insulation when installed in a vented attic. Thus, R38 at roof deck has lower overall performance than R38 at the ceiling.
- The software assumes that the overall leakage from the house is the same regardless of whether the attic is vented or unvented. Since most attic leaks occur at the junction of the roof deck and ceiling, there is no net difference in overall leakage from the attic, assuming that the junction is not sealed, which is standard practice even in unvented attics due to the difficulty of sealing that junction.

Table 47: DCS Unvented Attics % TDV Savings

Case 1	Package R + No RB + No WHF + Ducts in Unconditioned Attic
Case 2	R19 + No RB + No WHF + Ducts in Unconditioned Attic
Case 3	R30 + No RB + No WHF + Ducts in Unconditioned Attic
Case 4	R38 + No RB + No WHF + Ducts in Unconditioned Attic

	% TDV Savings: (Baseline - Proposed)/Baseline			
Climate Zone	Case 1. Unvented Attic Base	Case 2. Unvented Attic R-19 below deck	Case 3. Unvented Attic R-30 below deck	Case 4. Unvented Attic R-38 below deck
1	11.7%	3.5%	9.4%	11.7%
2	9.5%	2.2%	9.5%	12.1%
3	6.7%	0.7%	6.7%	9.0%
4	10.9%	2.5%	10.9%	13.9%
5	5.5%	-0.4%	5.5%	7.8%
6	6.7%	-0.4%	6.7%	9.5%
7	2.3%	-5.6%	2.3%	4.7%
8	0.5%	-9.9%	0.5%	4.5%
9	9.6%	-0.2%	9.6%	13.4%
10	7.6%	-0.8%	7.6%	10.9%
11	12.2%	1.5%	9.2%	12.2%
12	7.4%	-5.8%	3.7%	7.4%

13	14.2%	3.3%	11.2%	14.2%
14	12.2%	1.4%	9.2%	12.2%
15	14.6%	5.6%	12.0%	14.6%
16	14.2%	4.1%	11.4%	14.2%
Weighted Statewide	8.8%	-1.1%	7.3%	10.5%

Case 2 (R-19 at roof deck) results in negative energy savings in 7 out of 16 climate zones, including all of the cooling climate zones, because the 2013 mandatory roof/ceiling insulation level is R-30. R-30 and R-38 roof deck insulation result in energy savings for all climate zones (except for R-30 in CZ8).

Table 48: DCS Unvented Attics Present Value Energy Cost Savings

	Present Value Energy Cost Savings			
Climate Zone	Case 1. Unvented Attic Base	Case 2. Unvented Attic R-19 below deck	Case 3. Unvented Attic R-30 below deck	Case 4. Unvented Attic R-38 below deck
1	$2,194	$647	$1,766	$2,194
2	$1,521	$358	$1,521	$1,935
3	$750	$78	$750	$997
4	$1,637	$371	$1,637	$2,084
5	$553	($44)	$553	$778
6	$627	($38)	$627	$890
7	$154	($369)	$154	$313
8	$58	($1,206)	$58	$542
9	$1,824	($46)	$1,824	$2,558
10	$1,451	($152)	$1,451	$2,076
11	$4,099	$493	$3,078	$4,099
12	$1,723	($1,345)	$858	$1,723
13	$4,960	$1,156	$3,902	$4,960
14	$3,893	$434	$2,918	$3,893
15	$7,146	$2,753	$5,860	$7,146
16	$4,077	$1,194	$3,272	$4,077
Weighted Statewide	$2,255	($12)	$1,804	$2,508

11.2 HPA Individual Measures

11.2.1 Roof Deck Insulation (in addition to Ceiling Insulation)

Simulation results for installation insulation above or below the roof deck are presented below. The roof deck insulation is in addition to the ceiling insulation level required by the 2013 Standards prescriptive requirements (R-30 for CZ 2-10; R-38 for CZ 1, 11-16). For the below deck insulation cases, Case 4 and 5, the Team disabled the radiant barrier layer because it is not practical to install a radiant barrier below the below-deck insulation layer (and any integrated radiant barrier built-in to the deck OSB would not provide the intended benefits).

Table 49: HPA – Roof Deck Insulation % TDV Savings

Roof deck insulation is the most impactful measure within the list of HPA measures investigated by the project Team. Installation of roof deck insulation provides substantial energy benefits, on the order of 10% TDV savings. Roof deck insulation is more effective in providing thermal resistance to the roof assembly, as evident by R-6 above deck (Case 2) and R-15 below deck (Case 5) insulation exhibiting similar TDV savings.

Case 1	R4 Above Deck	Case 2	R6 Above Deck	Case 4	R13 Below Deck
Case 3	R8 Above Deck			Case 5	R15 Below Deck

	% TDV Savings: (Baseline - Proposed)/Baseline				
Climate Zone	Case 1. R4 above deck	Case 2. R6 above deck	Case 3. R8 above deck	Case 4. R13 below deck	Case 5. R15 below deck
1	4.2%	5.5%	6.5%	6.2%	6.8%
2	5.8%	7.4%	8.6%	7.9%	8.6%
3	3.7%	4.8%	5.7%	5.2%	5.6%
4	7.4%	9.2%	10.6%	9.6%	10.3%
5	3.6%	4.6%	5.4%	4.9%	5.3%
6	5.8%	7.4%	8.6%	7.3%	7.9%
7	4.1%	5.0%	5.6%	4.7%	5.0%
8	11.6%	14.2%	16.0%	13.8%	14.6%
9	11.6%	14.4%	16.3%	14.1%	15.0%
10	10.3%	12.6%	14.3%	12.4%	13.2%
11	8.4%	10.5%	12.0%	10.2%	10.9%
12	9.9%	12.4%	14.2%	12.2%	13.0%
13	9.4%	11.7%	13.3%	11.7%	12.5%
14	7.5%	9.4%	10.8%	9.2%	9.7%
15	8.0%	10.3%	12.0%	10.7%	11.5%
16	6.1%	7.8%	9.2%	8.5%	9.2%
Weighted Statewide	8.6%	10.8%	12.3%	10.7%	11.4%

Table 50: HPA – Roof Deck Insulation Present Value Energy Cost Savings

	Present Value Energy Cost Savings				
Climate Zone	Case 1. R4 above deck	Case 2. R6 above deck	Case 3. R8 above deck	Case 4. R13 below deck	Case 5. R15 below deck
1	$783	$1,033	$1,226	$1,164	$1,268
2	$925	$1,180	$1,374	$1,266	$1,368
3	$409	$535	$632	$574	$623
4	$1,113	$1,387	$1,599	$1,441	$1,552
5	$360	$463	$545	$490	$528
6	$544	$696	$805	$686	$740
7	$272	$331	$369	$312	$329
8	$1,410	$1,729	$1,946	$1,678	$1,773
9	$2,220	$2,741	$3,109	$2,699	$2,866
10	$1,961	$2,415	$2,735	$2,373	$2,517
11	$2,811	$3,511	$4,026	$3,434	$3,666
12	$2,291	$2,869	$3,293	$2,825	$3,015
13	$3,278	$4,066	$4,652	$4,087	$4,360
14	$2,401	$3,011	$3,456	$2,918	$3,107
15	$3,895	$5,009	$5,842	$5,205	$5,611
16	$1,744	$2,248	$2,648	$2,446	$2,657
Weighted Statewide	$1,969	$2,457	$2,814	$2,451	$2,616

11.2.2 Duct Insulation and Leakage Rate

Percent energy savings and energy cost savings result from increased duct insulation and lower duct leakage levels are presented in the tables below. Although the total duct leakage HERS test is mandatory measure for the 2013 Standards, the compliance software does not allow modeling a leakage level of 6% or below unless the "verified installation of LLAH" option is selected and performed by a HERS rater. Instead, the total duct leakage level assumption is restricted at 8% in the modeling software. Therefore Case 3 (5% duct leakage) results in positive energy savings. Improving the duct insulation and total leakage rate yield average statewide TDV savings of around 1.0 and 1.8% respectively, which is significantly less than roof deck insulation.

Table 51: Duct Insulation and Leakage % TDV Savings

Case 1	R6 Ducts	Case 2	R8 Ducts
Case 3	5% Duct Leakage	Case 4	4% Duct Leakage

Climate Zone	% TDV Savings: (Baseline - Proposed)/Baseline			
	Case 1. R6 Ducts	Case 2. R8 Ducts	Case 3. 5% Duct Leakage	Case 4. 4% Duct Leakage
1	0.0%	1.1%	1.2%	1.6%
2	0.0%	0.9%	1.1%	1.4%
3	0.0%	0.8%	0.8%	1.0%
4	0.0%	1.3%	1.1%	1.4%
5	0.0%	0.7%	0.7%	0.9%
6	0.0%	0.9%	0.7%	1.0%
7	0.0%	0.4%	0.3%	0.4%
8	0.0%	1.2%	1.0%	1.4%
9	0.0%	1.5%	1.7%	2.2%
10	0.0%	1.5%	1.4%	1.8%
11	-1.5%	0.0%	1.9%	2.4%
12	0.0%	1.5%	1.5%	2.0%
13	0.0%	1.5%	2.0%	2.6%
14	-1.6%	0.0%	1.8%	2.4%
15	-1.4%	0.0%	2.1%	2.9%
16	-1.4%	0.0%	1.5%	2.0%
Weighted Statewide	-0.2%	1.1%	1.4%	1.8%

Table 52: Duct Insulation and Leakage Present Value Energy Cost Savings

Climate Zone	PV Energy Cost Savings			
	Case 1. R6 Ducts	Case 2. R8 Ducts	Case 3. 5% Duct Leakage	Case 4. 4% Duct Leakage
1	$0	$207	$220	$292
2	$0	$149	$175	$229
3	$0	$86	$87	$115
4	$0	$193	$159	$210
5	$0	$67	$71	$93
6	$0	$85	$67	$90
7	$0	$27	$19	$23
8	$0	$143	$127	$170
9	$0	$286	$319	$425
10	$0	$288	$269	$353
11	($507)	$0	$623	$821
12	$0	$342	$341	$453
13	$0	$539	$681	$905
14	($494)	$0	$584	$774
15	($707)	$0	$1,037	$1,406
16	($415)	$0	$440	$589
Weighted Statewide	($81)	$232	$349	$463

11.2.3 Raised Heel Trusses

This measure was modeled initially using CBECC-Res version 605 to analyze potential for the measure in the HPA package. This version of the software used the 2013 TDV values. Due to minimal savings and comparatively high costs, this measure was not included in the final set of measures analyzed using the latest version of the software that uses the 2016 TDV values.

The compliance software assumes a truss heel height of 3 ½" as the default and thus assumes that the insulation is compressed at the truss heel and derates the value of the installed insulation. Incorporating a raised heel truss with a modified heel height of 12" accommodates the full thickness of R-30 and R-38 blown-in fiberglass insulation, enabling full account of the installed insulation. The energy and cost savings results from installing a 12" raised heel are presented in the table below.

Table 53: Raised Heel Truss % TDV and Present Value Energy Cost Savings

	% TDV Savings: (Baseline - Proposed)/Baseline	**PV Energy Cost Savings**
Climate Zone	RHT – 12"	RHT – 12"
1	0.8%	$139
2	0.9%	$138
3	0.7%	$78
4	1.1%	$156
5	0.8%	$80
6	1.0%	$92
7	1.0%	$63
8	1.6%	$177
9	1.6%	$259
10	1.5%	$253
11	1.3%	$409
12	1.6%	$347
13	1.2%	$400
14	1.4%	$404
15	0.9%	$400
16	0.9%	$261
Weighted Statewide	1.3%	$219

11.2.4 Roof Reflectance and Roof Deck Insulation

These early packages were modeled using CBECC-Res version 605 (with 2013 TDV values) to analyze potential for the measure in the HPA package. These measure packages were <u>not</u> included in the final set of measures analyzed using the latest version of the software that uses the 2016 TDV values.

The results show that increasing the reflectance level yields approximately 2% and 4.7% TDV savings, respectively. The combination of higher reflectance tiles and roof deck insulation does provide additional savings. Thus it is possible to mix and match the two measures to meet specific energy reduction goals as long as the measures are cost-effective.

Table 54: Roof Reflectance and Insulation % TDV Savings

Case 1	0.35 Roof Reflectance
Case 2	0.55 Roof Reflectance
Case 3	0.35 Roof Reflectance + R8 Above Deck
Case 4	0.55 Roof Reflectance + R8 Above Deck
Case 5	0.35 Roof Reflectance + R13 Below Deck

	% TDV Savings: (Baseline - Proposed)/Baseline				
Climate Zone	Case 1. 0.35 reflectance	Case 2. 0.55 reflectance	Case 3. 0.35 reflectance with R8 above deck	Case 4. 0.55 reflectance with R8 above deck	Case 5. 0.35 reflectance with R13 below deck
1	-5.0%	-8.7%	0.5%	-1.8%	-0.2%
2	-4.1%	-7.4%	1.9%	-0.3%	1.5%
3	-5.3%	-8.5%	0.0%	-1.9%	-0.6%
4	-2.2%	-3.3%	5.8%	4.2%	5.3%
5	-7.0%	-11.8%	-1.1%	-3.9%	-1.8%
6	-1.9%	-3.7%	4.9%	3.3%	4.0%
7	-1.5%	-4.5%	1.8%	0.0%	1.2%
8	6.6%	10.2%	16.0%	17.0%	14.7%
9	6.3%	11.1%	17.5%	19.2%	16.0%
10	3.3%	8.5%	14.8%	16.7%	13.2%
11	1.9%	6.0%	11.7%	13.3%	10.2%
12	2.2%	6.1%	13.0%	14.4%	11.5%
13	2.0%	6.6%	12.7%	14.6%	11.4%
14	1.4%	4.8%	10.4%	11.8%	9.0%
15	2.0%	6.7%	11.4%	14.0%	10.1%
16	-0.6%	-1.7%	5.8%	4.9%	5.2%
Weighted Statewide	1.9%	4.7%	11.4%	12.2%	10.1%

Table 55: Roof Reflectance and Insulation Present Value Energy Cost Savings

	Present Value Energy Cost Savings				
Climate Zone	Case 1. 0.35 reflectance	Case 2. 0.55 reflectance	Case 3. 0.35 reflectance with R8 above deck	Case 4. 0.55 reflectance with R8 above deck	Case 5. 0.35 reflectance with R13 below deck
1	($923)	($1,598)	$84	($327)	$ (30)
2	($630)	($1,137)	$295	($50)	$ 235
3	($581)	($935)	($3)	($211)	$ (60)
4	($311)	($452)	$808	$580	$ 735
5	($692)	($1,173)	($108)	($389)	$ (177)
6	($166)	($325)	$437	$292	$ 355
7	($97)	($290)	$113	($3)	$ 78
8	$714	$1,106	$1,742	$1,848	$ 1,595
9	$1,038	$1,834	$2,896	$3,176	$ 2,647
10	$565	$1,464	$2,552	$2,882	$ 2,275
11	$583	$1,871	$3,617	$4,135	$ 3,159
12	$459	$1,300	$2,759	$3,050	$ 2,433
13	$651	$2,109	$4,084	$4,675	$ 3,649
14	$399	$1,402	$3,064	$3,472	$ 2,652
15	$918	$3,089	$5,227	$6,445	$ 4,658
16	($159)	($468)	$1,605	$1,360	$ 1,440
Weighted Statewide	$318	$776	$1,892	$2,028	$ 1,685

As seen above, while higher reflectance tiles save energy, they are cost effective in only the cooling climates in California whereas a combination of higher reflectance tiles and R 13 below-roof deck insulation is also cost-effective in several heating climate zones.

11.3 HPA Measure Package

This section presents the % TDV savings and associated cost savings from combining the individual HPA measures presented previously. Overall, layering the deck insulation, duct insulation and leakage measures bring additional average statewide TDV savings on the order of 1.6 to 2.0% in comparison to installing just the deck insulation.

The section presents results from four scenarios for HPA measure combinations with roof deck insulation level as the main variable, as shown in the table below.

	Roof Deck Insulation	Duct Insulation	Duct Leakage
HPA Combo Set #1	R-8 above	R-8	8%, 6% and 4%
HPA Combo Set #2	R-6 above	R-8	8%, 6% and 4%
HPA Combo Set #3	R-4 above	R-8	8%, 6% and 4%
HPA Combo Set #4	R-15 below	R-8	8%, 6% and 4%

As anticipated, combo set #1 with R-8 above-deck insulation is the highest performing package. This confirms the findings from the individual measure runs that roof deck insulation level is the dominant measure with the most energy impact of the HPA measures investigated. Packages with greater above-deck insulation values perform better. R-15 below-deck insulation combination performance is on par with the R-8 above-deck combo set results[44]. Above-deck insulation is more effective (in comparison to below-deck insulation with the same R value) because the effective R value for below-deck insulation is discounted by the deck framing members or trusses.

Within each combo set with the same roof deck insulation level, the runs with the lowest duct leakage level performs around 1% better than the default 8% leakage runs. We formatted the tables to make trends more visible to the readers. These formats and their meanings are:

- Conditional color formatting shows performance trends between climate zones
- **Bold** entry denotes the highest performing package and climate zone for each set
- *Italic* entry denotes the lowest performing package and climate zone for each set

Table 56: R-8 Above Deck Insulation + Higher Duct Insulation + Lower Leakage

Case 1	R8 Ducts + 8% Duct Leakage + R8 Above Deck
Case 2	R8 Ducts + 6% Duct Leakage + R8 Above Deck
Case 3	R8 Ducts + 4% Duct Leakage + R8 Above Deck

	% TDV Savings: (Baseline - Proposed)/Baseline		
Climate Zone	Case 1	Case 2	Case 3
1	7.3%	7.8%	8.3%
2	9.2%	9.6%	10.1%
3	6.2%	6.6%	6.9%
4	11.4%	11.8%	12.2%
5	5.9%	6.2%	6.5%

[44] For example, weighted average % TDV savings for R-11 below-deck and R-4 above-deck (both with R-8 duct and 4% duct leakage) are both 10.5%, though the performance levels for each climate zone is different.

6	9.1%	9.4%	9.6%
7	5.8%	5.9%	6.0%
8	16.6%	17.0%	17.3%
9	17.1%	17.7%	18.3%
10	15.1%	15.6%	16.2%
11	12.0%	12.7%	13.5%
12	15.1%	15.7%	16.2%
13	14.2%	14.9%	15.6%
14	10.8%	11.6%	12.4%
15	12.0%	12.8%	13.6%
16	9.2%	9.8%	10.4%
Weighted Statewide	12.9%	13.5%	14.0%

Table 57: R-6 Above Deck Insulation + Higher Duct Insulation + Lower Leakage

Case 1	R8 Ducts + 8% Duct Leakage + R6 Above Deck
Case 2	R8 Ducts + 6% Duct Leakage + R6 Above Deck
Case 3	R8 Ducts + 4% Duct Leakage + R6 Above Deck

	% TDV Savings: (Baseline - Proposed)/Baseline		
Climate Zone	Case 1	Case 2	Case 3
1	6.3%	6.9%	7.4%
2	8.0%	8.5%	9.0%
3	5.4%	5.7%	6.1%
4	10.1%	10.5%	11.0%
5	5.1%	5.4%	5.8%
6	7.9%	8.2%	8.5%
7	5.2%	5.3%	5.4%
8	14.9%	15.3%	15.7%
9	15.2%	15.9%	16.5%
10	13.5%	14.1%	14.7%
11	10.5%	11.3%	12.1%
12	13.3%	13.9%	14.5%
13	12.6%	13.4%	14.1%
14	9.4%	10.3%	11.1%
15	10.3%	11.1%	12.0%
16	7.8%	8.5%	9.2%

Weighted Statewide	11.4%	12.0%	12.6%

Table 58: R-4 Above Deck Insulation + Higher Duct Insulation + Lower Leakage

Case 1	R8 Ducts + 8% Duct Leakage + R4 Above Deck
Case 2	R8 Ducts + 6% Duct Leakage + R4 Above Deck
Case 3	R8 Ducts + 4% Duct Leakage + R4 Above Deck

	% TDV Savings: (Baseline - Proposed)/Baseline		
Climate Zone	Case 1	Case 2	Case 3
1	5.0%	5.7%	6.2%
2	6.5%	7.0%	7.6%
3	4.3%	4.7%	5.1%
4	8.3%	8.8%	9.3%
5	4.1%	4.5%	4.8%
6	6.4%	6.8%	7.1%
7	4.3%	4.5%	4.6%
8	12.3%	12.8%	13.3%
9	12.6%	13.3%	14.1%
10	11.3%	11.9%	12.5%
11	8.4%	9.2%	10.1%
12	10.9%	11.6%	12.3%
13	10.5%	11.3%	12.1%
14	7.5%	8.4%	9.4%
15	8.0%	8.8%	10.0%
16	6.1%	6.8%	7.5%
Weighted Statewide	9.4%	10.0%	10.7%

Table 59: R-15 Below Deck Insulation + Higher Duct Insulation + Lower Leakage

Case 1	R8 Ducts + 8% Duct Leakage + R15 Below Deck
Case 2	R8 Ducts + 6% Duct Leakage + R15 Below Deck
Case 3	R8 Ducts + 4% Duct Leakage + R15 Below Deck

	% TDV Savings: (Baseline - Proposed)/Baseline		
Climate Zone	Case 1	Case 2	Case 3
1	7.5%	7.9%	8.4%

2	9.1%	9.5%	9.9%
3	6.1%	6.4%	6.7%
4	11.0%	11.4%	11.8%
5	5.7%	6.0%	6.3%
6	8.4%	8.6%	8.9%
7	*5.2%*	5.3%	5.4%
8	15.2%	15.5%	15.9%
9	15.8%	16.4%	**17.0%**
10	14.0%	14.5%	15.0%
11	10.9%	11.6%	12.3%
12	13.9%	14.4%	15.0%
13	13.4%	14.0%	14.7%
14	9.7%	10.5%	11.3%
15	11.5%	12.2%	13.0%
16	9.2%	9.8%	10.4%
Weighted Statewide	12.0%	12.5%	13.0%

12. Appendix E: DCS and HPA Cost-Effectiveness Comparison

This section displays the comparative energy performance and life cycle costs results for representative scenarios. These scenarios were selected to cover the DCS and HPA cases investigated by the Statewide CASE Team. The table below provides the categories of scenarios included in this section and associated details:

Scenario	Description	Details
Case 1 and 2	DCS and DCS verified	DCS with vented attic, with and without duct leakage to outdoor HERS verification
Case 3 and 4	HPA packages	HPA with deck insulation, below-deck or above-deck, and additional efficiency features
Case 5	DCS plus	DCS with vented attic with low duct leakage without verification

Overall, R13 below roof deck insulation with R8 ducts and 5% duct leakage is the measure with the most cost-effective savings across the state – the measure is cost-effective in climate zones 4, 8-16. As the rest of this section will illustrate, to achieve equivalent savings to the package including R13 below deck with DCS measures, it is necessary to have a HERS verified ducts in conditioned space installation.

The rest of the section consists of a series of tables that provide climate zone specific, detailed results on the following quantities for all ten scenarios:

- Energy savings per square foot prototype building area
- Percentage TDV energy savings
- Present value of energy cost savings in $
- Measure/package first cost in $
- Life cycle cost (cost minus benefit)
- Percentage savings compared to R-13 Below-deck Insulation package

Table 60: DCS and HPA Package Savings (TDV kBTU/ft^2)

	Savings (Baseline - Proposed) in TDV kBTU/ft^2				
	Case 1	Case 2	Case 3	Case 4	Case 5
Climate Zone	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage
1	3.8	5.2	3.2	3.4	4.7
2	2.8	3.9	3.6	3.4	3.5
3	1.6	2.2	1.8	1.7	2.0
4	3.5	4.6	4.1	3.9	4.2
5	1.2	1.7	1.5	1.4	1.5
6	1.5	1.9	2.0	1.9	1.8
7	0.5	0.6	0.9	0.8	0.6
8	2.6	3.4	4.7	4.3	3.1
9	5.2	7.2	7.7	7.2	6.5
10	5.1	6.9	6.9	6.4	6.3
11	8.1	12.2	9.3	8.6	10.7
12	6.2	8.4	7.8	7.3	7.6
13	9.8	14.3	11.4	10.8	12.6
14	7.9	11.7	8.1	7.4	10.3
15	10.3	18.3	13.5	12.8	15.5
16	6.5	9.3	6.1	6.4	8.3
Weighted Statewide	5.4	7.8	6.8	6.4	6.9

Table 61: DCS and HPA Package % TDV Savings

	% TDV Savings: (Baseline - Proposed)/Baseline[45]				
Climate Zone	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage
1	8.5%	11.8%	7.1%	7.7%	10.6%
2	7.3%	10.3%	9.4%	9.0%	9.2%
3	6.2%	8.3%	6.7%	6.4%	7.5%
4	9.8%	12.8%	11.5%	10.9%	11.6%
5	5.1%	7.0%	6.4%	5.9%	6.3%
6	6.8%	8.7%	9.2%	8.3%	8.0%
7	3.1%	3.8%	5.9%	5.2%	3.6%
8	8.9%	11.8%	16.3%	15.0%	10.7%
9	11.4%	15.9%	17.0%	15.9%	14.2%
10	11.3%	15.2%	15.2%	14.2%	13.8%
11	10.2%	15.3%	11.7%	10.7%	13.4%
12	11.3%	15.3%	14.2%	13.2%	13.8%
13	11.8%	17.2%	13.8%	13.0%	15.2%
14	10.4%	15.5%	10.7%	9.8%	13.6%
15	8.8%	15.8%	11.6%	11.0%	13.4%
16	9.4%	13.7%	8.8%	9.4%	12.1%
Weighted Statewide	9.8%	13.7%	12.7%	11.9%	12.3%

[45] Conditional color formatting shows performance trends between climate zones; **Bold** entry denotes the highest performing package and climate zone for each set; *Italic* entry denotes the lowest performing package and climate zone for each set

Table 62: DCS and HPA Package Present Value Energy Cost Savings

	PV of Energy Cost Savings ($)				
Climate Zone	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage
1	$1,592	$2,207	$1,335	$1,441	$1,984
2	$1,161	$1,649	$1,500	$1,444	$1,470
3	$684	$924	$747	$710	$836
4	$1,470	$1,916	$1,725	$1,640	$1,748
5	$508	$701	$641	$594	$633
6	$633	$818	$861	$782	$751
7	$205	$251	$389	$343	$236
8	$1,081	$1,427	$1,982	$1,825	$1,303
9	$2,172	$3,029	$3,251	$3,032	$2,713
10	$2,153	$2,915	$2,907	$2,708	$2,639
11	$3,406	$5,119	$3,914	$3,605	$4,494
12	$2,616	$3,552	$3,296	$3,059	$3,207
13	$4,118	$5,999	$4,798	$4,531	$5,310
14	$3,327	$4,928	$3,418	$3,125	$4,344
15	$4,315	$7,693	$5,682	$5,389	$6,531
16	$2,714	$3,928	$2,544	$2,711	$3,483
Weighted Statewide	$2,290	$3,271	$2,878	$2,698	$2,915

Table 63: HPA and DCS Measure First Cost ($)

	Measure First Cost ($)				
Climate Zone	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage[46] + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage[45] + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage[45]
1	$ 865	$ 990	$ 1,422	$1,551	$ 942
2	$ 865	$ 990	$ 1,664	$1,625	$ 942
3	$ 865	$ 990	$ 1,664	$1,625	$ 942
4	$ 865	$ 990	$ 1,664	$1,625	$ 942
5	$ 865	$ 990	$ 1,664	$1,625	$ 942
6	$ 865	$ 990	$ 1,664	$1,625	$ 942
7	$ 865	$ 990	$ 1,664	$1,625	$ 942
8	$ 865	$ 990	$ 1,664	$1,475	$ 942
9	$ 865	$ 990	$ 1,664	$1,475	$ 942
10	$ 865	$ 990	$ 1,664	$1,475	$ 942
11	$ 865	$ 990	$ 1,258	$939	$ 942
12	$ 865	$ 990	$ 1,422	$1,152	$ 942
13	$ 865	$ 990	$ 1,422	$1,152	$ 942
14	$ 865	$ 990	$ 1,258	$1,025	$ 942
15	$ 865	$ 990	$ 1,258	$1,089	$ 942
16	$ 865	$ 990	$ 1,258	$1,424	$ 942

[46] Based on discussions with HVAC industry professionals, 3 – 5% duct leakage can be achieved through quality care installation at negligible costs. Additionally, currently available equipment with low leakage air handlers can be purchased at no to minimal additional cost to standard installed equipment. To be conservative, the Team has assumed a small incremental cost for low leakage air handler to achieve 3% duct leakage.

Table 64: DCS and HPA Life Cycle Cost ($)

Climate Zone	Life Cycle Cost ($)[47]				
	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage
1	$ (727)	$ (1,217)	$ 88	$110	$ (1,043)
2	$ (296)	$ (659)	$ 164	$181	$ (529)
3	$ 181	$ 66	$ 917	$915	$ 106
4	$ (605)	$ (926)	$ (61)	$(15)	$ (806)
5	$ 357	$ 289	$ 1,023	$1,030	$ 309
6	$ 232	$ 172	$ 803	$843	$ 191
7	$ 660	$ 739	$ 1,275	$1,281	$ 705
8	$ (216)	$ (437)	$ (318)	$(350)	$ (361)
9	$ (1,307)	$ (2,039)	$ (1,587)	$(1,557)	$ (1,772)
10	$ (1,288)	$ (1,925)	$ (1,243)	$(1,234)	$ (1,697)
11	$ (2,541)	$ (4,129)	$ (2,656)	$(2,665)	$ (3,552)
12	$ (1,751)	$ (2,562)	$ (1,874)	$(1,907)	$ (2,266)
13	$ (3,253)	$ (5,009)	$ (3,376)	$(3,380)	$ (4,369)
14	$ (2,462)	$ (3,938)	$ (2,160)	$(2,100)	$ (3,403)
15	$ (3,450)	$ (6,703)	$ (4,424)	$(4,299)	$ (5,589)
16	$ (1,849)	$ (2,938)	$ (1,286)	$(1,287)	$ (2,541)

[47] Negative LCC numbers indicates that the scenario is cost-effective in the CZ.

Table 65: DCS and HPA % Savings Compared to HPA with R13 Below Roof Deck

	Percent Savings (%) Compared to R13 Below Roof Deck Package[48]				
Climate Zones	Tile with Ducts located entirely in conditioned space	Tile with Verified low-leakage ducts entirely in conditioned space	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Tile with Ducts located entirely in conditioned space + 3% Duct Leakage
1	0.8%	4.1%	-0.6%	0.0%	2.9%
2	-1.8%	1.3%	0.4%	0.0%	0.2%
3	-0.2%	1.9%	0.3%	0.0%	1.1%
4	-1.1%	1.8%	0.6%	0.0%	0.7%
5	-0.9%	1.1%	0.5%	0.0%	0.4%
6	-1.6%	0.4%	0.8%	0.0%	-0.3%
7	-2.1%	-1.4%	0.7%	0.0%	-1.6%
8	-6.1%	-3.3%	1.3%	0.0%	-4.3%
9	-4.5%	0.0%	1.1%	0.0%	-1.7%
10	-2.9%	1.1%	1.0%	0.0%	-0.4%
11	-0.6%	4.5%	0.9%	0.0%	2.6%
12	-1.9%	2.1%	1.0%	0.0%	0.6%
13	-1.2%	4.2%	0.8%	0.0%	2.2%
14	0.6%	5.7%	0.9%	0.0%	3.8%
15	-2.2%	4.7%	0.6%	0.0%	2.3%
16	0.0%	4.2%	-0.6%	0.0%	2.7%

13. Appendix I: Asphalt Shingle Packages Savings and Cost

As noted in section 4, analysis conducted for savings and cost effectiveness and thus the proposed measure packages all assume tile roofing. In order to achieve the same level of energy savings, additional efficiency measures are necessary when constructing roofs with asphalt shingles.

Constructing an asphalt shingle roof with above roof deck insulation will require R-8 rigid insulation to achieve the same level of energy savings, which is an additional R-2 from the proposed R-6 with tile. Constructing an asphalt shingle roof with below deck insulation will require R-15, which is an additional R-2 from the proposed R-13 with tile.

[48] Green cells denote better performance and Red cells denote worse performance than the R13 Below-Deck Package (No RB) comparison baseline; White cells are within 1% better.

The following tables provide the energy savings and life cycle cost of the packages with asphalt roofing in comparison to packages with tile roofing.

Scenario	Description	Details
Case 1 and 3	Tile	Tile roof packages with above and below roof deck insulation meeting the proposed requirements
Case 2 and 4	Asphalt	Asphalt shingle roof packages with above and below roof deck insulation meeting equivalent energy savings as the tile roof packages

Table 66: Tile vs Asphalt % TDV Savings

	% TDV Savings: (Baseline - Proposed)/Baseline			
	Case 1	Case 2	Case 3	Case 4
Climate Zone	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Asphalt with R8 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Asphalt with R15 below deck (no RB) + 3% duct leakage + R8 ducts + R38
1	7.1%	7.8%	7.7%	8.3%
2	9.4%	9.8%	9.6%	9.8%
3	6.7%	7.1%	6.8%	7.0%
4	11.5%	11.9%	11.5%	11.4%
5	6.4%	7.2%	6.4%	6.9%
6	9.2%	9.4%	8.9%	8.5%
7	5.9%	5.9%	5.4%	5.1%
8	16.3%	16.2%	15.7%	14.5%
9	17.0%	16.9%	16.5%	15.6%
10	15.2%	14.9%	14.7%	13.5%
11	11.7%	11.9%	11.3%	11.2%
12	14.2%	14.3%	13.9%	13.1%
13	13.8%	13.9%	13.7%	13.3%
14	10.7%	10.8%	10.4%	10.1%
15	11.6%	11.9%	11.8%	11.9%
16	8.8%	9.2%	9.4%	9.6%
Weighted Statewide	**12.7%**	**12.8%**	**12.5%**	**11.9%**

Table 67: Tile vs Asphalt Present Value Energy Cost Savings

Climate Zone	Present Value Energy Cost Savings			
	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Asphalt with R8 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Asphalt with R15 below deck (no RB) + 3% duct leakage + R8 ducts + R38
1	$1,335	$1,465	$1,441	$1,549
2	$1,500	$1,572	$1,538	$1,566
3	$747	$790	$761	$783
4	$1,725	$1,784	$1,732	$1,717
5	$641	$718	$643	$686
6	$861	$883	$830	$795
7	$389	$393	$360	$336
8	$1,982	$1,963	$1,902	$1,760
9	$3,251	$3,231	$3,154	$2,973
10	$2,907	$2,858	$2,813	$2,584
11	$3,914	$4,004	$3,804	$3,741
12	$3,296	$3,319	$3,228	$3,039
13	$4,798	$4,841	$4,763	$4,645
14	$3,418	$3,429	$3,301	$3,231
15	$5,682	$5,796	$5,760	$5,828
16	$2,544	$2,652	$2,711	$2,774
Weighted Statewide	**$2,878**	**$2,900**	**$2,831**	**$2,722**

Table 68: Tile vs Asphalt Measure First Cost ($)

	Measure First Cost ($)			
Climate Zone	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Asphalt with R8 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Asphalt with R15 below deck (no RB) + 3% duct leakage + R8 ducts + R38
1	$ 1,422	$ 1,858	$1,551	$ 1,139
2	$ 1,664	$ 2,100	$1,625	$ 1,093
3	$ 1,664	$ 2,100	$1,625	$ 1,093
4	$ 1,664	$ 2,100	$1,625	$ 1,093
5	$ 1,664	$ 2,100	$1,625	$ 1,093
6	$ 1,664	$ 2,100	$1,625	$ 1,093
7	$ 1,664	$ 2,100	$1,625	$ 1,093
8	$ 1,664	$ 2,100	$1,475	$ 1,093
9	$ 1,664	$ 2,100	$1,475	$ 1,093
10	$ 1,664	$ 2,100	$1,475	$ 1,093
11	$ 1,258	$ 1,694	$939	$ 687
12	$ 1,422	$ 1,858	$1,152	$ 851
13	$ 1,422	$ 1,858	$1,152	$ 851
14	$ 1,258	$ 1,694	$1,025	$ 767
15	$ 1,258	$ 1,694	$1,089	$ 687
16	$ 1,258	$ 1,694	$1,424	$ 1,056

Table 69: Tile vs Asphalt Life Cycle Cost ($)

	Life Cycle Cost ($)			
Climate Zone	Tile with R6 above deck + 5% duct leakage + R8 ducts + R38	Asphalt with R8 above deck + 5% duct leakage + R8 ducts + R38	Tile with R13 below deck (no RB) + 5% duct leakage + R8 ducts + R38	Asphalt with R15 below deck (no RB) + 3% duct leakage + R8 ducts + R38
1	$ 88	$ 392	$110	$ (409)
2	$ 164	$ 527	$181	$ (473)
3	$ 917	$ 1,310	$915	$ 310
4	$ (61)	$ 315	$(15)	$ (624)
5	$ 1,023	$ 1,381	$1,030	$ 407
6	$ 803	$ 1,217	$843	$ 298
7	$ 1,275	$ 1,707	$1,281	$ 757
8	$ (318)	$ 136	$(350)	$ (667)
9	$ (1,587)	$ (1,131)	$(1,557)	$ (1,880)
10	$ (1,243)	$ (758)	$(1,234)	$ (1,491)
11	$ (2,656)	$ (2,310)	$(2,665)	$ (3,054)
12	$ (1,874)	$ (1,461)	$(1,907)	$ (2,189)
13	$ (3,376)	$ (2,983)	$(3,380)	$ (3,794)
14	$ (2,160)	$ (1,736)	$(2,100)	$ (2,464)
15	$ (4,424)	$ (4,102)	$(4,299)	$ (5,141)
16	$ (1,286)	$ (959)	$(1,287)	$ (1,718)

14. Appendix F: Roof Covering and Roof Deck Insulation Fire Rating Requirements

During the stakeholder engagement process, stakeholders raised concerns and the Statewide CASE Team investigated the topic of whether and how having above deck insulation would affect the fire rating of roof covering products. This appendix describes the fire rating requirements for roof covering products, for roof deck insulation based on the Statewide CASE Team's research, discussions with industry stakeholders and feedback from the California Fire Marshal Office.

14.1 Roof Covering Fire Rating

Roof covering products are current rated to class A/B/C based on the ASTM E108 [NFPA 256, UL790] test. The test is a laboratory test which places a block of "burning brand" wooden block on top of the roof assembly to simulate the effect of a fire originating from outside the building. The rating for a particularly roof covering is specific to the slope of the roof and maximum insulation thickness (if applicable) are both factors that affect the fire performance of the roof assembly. According to industry feedback through the CASE process, roof covering manufacturers currently rate their products with the configuration of placing roof covering directly on the test roof deck (as opposed to adding an insulation layer).

Under current building code requirement, tile roof products are automatically rated Class A. Chapter 15 in the California Building Code (and International Building Code section 1505 for Fire Classification) specify that certain roofing materials are Class A without having to test to ASTEM E108. These materials include slate, clay, concrete roof tile, an exposed concrete roof deck, and ferrous and copper shingles.

14.2 Plastic Roof Deck Insulation Fire Rating

Insulation products are subject to a different fire test from roof covering products. California Building Code (and International Building Code section 2603 for Foam Plastic Insulation) require foam plastic insulation to be tested to demonstrate flame spreads index of not more than 75 and a smoke-developed index of not more than 450 according to ASTM E84 [UL723]. The requirements are applicable to roof insulation products, including XPS/ polyiso/ polyurethane above-deck insulation and SPF below-deck insulation products. The Statewide CASE Team collected product literature to understand and verify how these insulation products currently demonstrate compliance the regulations. Product literatures for plastic foam insulation products from the following product categories and manufacturers/brands were reviewed, and all of them have publicly available ICC-ES (Evaluation Services) Evaluation Reports and disclose the flame spread and smoke-developed indices in product specification list.

- Polystyrene: XPS brands Dow and Owens Corning; EPS brand InsulFoam.
- Polyiso/Polyurethane: JM, GAF, Rmax and Firestone.

In summary, plastic roof deck insulation does not adhere to the same fire rating test as roof covering materials. However, the Statewide CASE Team did find one polyiso foam board products literature that claims to have tested their products to obtain Class A rating status. For this product, the maximum slope allowed were in the range of ¼:12 to 1:12, so it is essentially only for flat roofs (more common in commercial than residential application).

14.3 Impact of Above Deck Insulation on Roof Assembly Fire Rating

The Statewide CASE Team looked into the fire ratings issue and consulted with a representative in the California State Fire Marshall office (Kevin Reinertsen - Division Chief). Here are the key points from our discussions:

- Roof covering (tiles, shingles) test (ASTM E108/UL790) that results in class A/B/C ratings are done with specific roof assemblies, and ratings are only valid when the installation is the same as the assembly as rated.

- Q: "If roof covering is class A, and the rigid insulation is also rated satisfactorily (ASTM E84 for flame spread and smoke developed indices), does that imply the assembly satisfies fire rating requirement? " (Fire rated + fire rated = fire rated?)
Answer: One would think so, but this is not quite the case. In his opinion, the roof coverings need to be rated/certified again when you add above-deck insulation to reflect the change in assembly. Mr. Reinertsen said that these tests cost on the order of $20,000 for each assembly.
- Q; "who will bear this cost?"
Answer: Mr. Reinertsen thinks that roof manufacturers (and perhaps partnering with rigid foam manufacturers) would be the ones forking out for the tests, and some of them might even see it as a market advantage.
- Mr. Reinertsen recommends for the Statewide CASE Team to make sure to reference the appropriate CBC in the Part 6 requirements, if we are proposing a decrease in roof assembly U factor that may get builders to consider installing rigid foam above deck.
- *Mr. Reinertsen also confirmed that insulation installed below roof deck would not trigger fire concerns.*

The Statewide CASE Team also had discussions with industry stakeholder Rick Olson from the Tile Roofing Institute who confirmed these findings.

14.4 Summary of Fire Tests

ASTM E108 [NFPA 256, UL790], Fire Tests of Roof Coverings[49]

Combustibility is determined on all components of the roof assembly as a composite. The test includes three parts:

- Spread of flame
- Intermittent flame
- Burning brand

The spread of flame is the only test conducted on roof assemblies with concrete, steel or gypsum decks (non-combustible), while all three tests are performed on assemblies incorporating combustible (wood, plank, plywood, or plastic foam) roof decks.

ASTM E84 [UL 723 or NFPA 255], Surface Burning Characteristics of Building Materials[50]

Often referred to as the "Steiner Tunnel Test," E84 is a standard method to assess the spread of fire on the surface of a material. A sample about 20 inches wide and 25 feet long is installed on the ceiling of a horizontal test chamber. The material is exposed to a 4-foot long gas flame at one end of the tunnel for a period of 10 minutes. Threat of flame front 2 progression on the material is compared to a standard (inorganic reinforced cement board) and calculations are

[49] http://www.astm.org/DATABASE.CART/HISTORICAL/E108-00.htm
[50] http://www.astm.org/Standards/E84.htm

made to produce a flame spread rating (a unit-less number). Smoke from the fire in the tunnel is measured in the exhaust stack by using a light beam to evaluate smoke developed ratings.

Since E84 is a standard laboratory fire test on a single material, numerical ratings derived from E84 are not intended to reflect hazards presented by the test material under actual fire conditions.

14.5 Examples of ICC-ES Evaluation Reports

The Statewide CASE Team reviewed a number of ICC-ES product evaluation reports to understand the fire rating requirements and results associated with roof deck insulation products. A few examples for the common insulation types are presented below to illustrate the type of information provided in these reports. The Statewide CASE Team accessed the reports presented below from ICC-ES's website directly, under various sections under Division 07 00 00 for Thermal and Moisture Protection products.[51]

Polyiso Rigid Foam Example - ESR-3398[52]

This report is for two similar polyiso rigid foams products with different facing materials. The front section of the report clearly points out the code version (year published) and sections for which the products were tested to be in compliance. The evaluation report provides details on product Descriptions (Section 3). The descriptions include product physical specifications, thermal resistance values from testing, air and vapor permeability levels from testing.

The report also offers associated Installation (Section 4) requirements for different product applications, such as for wall assemblies, crawl space and attic installations. Many of the installation instructions cite relevant International Residential Code sections and enable easy references to code requirements.

For this particularly product, the report provided installation details if the product was installed as a water-resistive barrier. Details included configuration and fastening method and proper treatment of joints and seams to achieve desired water-resistance properties. The report even listed example sheathing products (manufacturer, product type and corresponding ESR numbers) that may be used in conjunction to construct a water-resistance barrier.

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[51] http://www.icc-es.org/Reports/index.cfm?csi_id=302&view_details

[52] http://www.icc-es.org/Reports/pdf_files/ESR-3398.pdf


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ICC-ES Evaluation Report

ESR-3398*

Reissued October 2013

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DIVISION: 07 00 00—THERMAL AND MOISTURE PROTECTION
Section: 07 21 00—Thermal Insulation
Section: 07 25 00—Water-Resistive Barriers/Weather Barriers
Section: 07 27 00—Air Barriers

REPORT HOLDER:

JOHNS MANVILLE
717 17TH STREET
DENVER, COLORADO 80202
(303) 978-2000
www.jm.com

EVALUATION SUBJECT:

JOHNS MANVILLE AP™ FOIL-FACED SHEATHING AND CI MAX® FOAM SHEATHING

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2012 and 2009 *International Building Code®* (IBC)
- 2012 and 2009 *International Residential Code®* (IRC)
- 2012 and 2009 *International Energy Conservation Code®* (IECC)

Properties evaluated:

- Surface-burning characteristics
- Thermal resistance
- Water vapor transmission
- Attic and crawl space installation
- Exterior walls in Types I through IV construction
- Water-resistive barrier
- Air barrier
- Air permeability

2.0 USES

2.1 AP™ Foil-Faced Sheathing:

AP™ Foil-Faced Sheathing is used as nonstructural, thermal insulating material in Types I, II, III, IV and V construction (IBC) and dwellings under the IRC. The insulation boards may be used with a thermal barrier within or on interior or exterior walls and ceiling assemblies, and also in attics and crawl spaces with a thermal or ignition barrier. Additionally, the boards may be used at the perimeter of concrete slab on-grade and on the interior side of basement foundation walls.

The AP™ Foil-Faced Sheathing may be used on the exterior face of exterior walls of any type of construction. When used in exterior walls in Types I, II, III, and IV construction, construction must be in accordance with Section 4.2.2 of this report.

The AP™ Foil-Faced Sheathing insulation boards may be used as an alternative to the water-resistive barrier specified in IBC Section 1404.2 and R703.2 when installed on exterior walls in accordance with Section 4.2.2.3.

2.2 CI Max® Foam Sheathing:

CI Max® Foam Sheathing is used as nonstructural, thermal insulating material for use in interior applications in Type I, II, III, IV and V construction (IBC) and dwellings construction under the IRC. The insulation boards may be left exposed to the interior of the building without a thermal barrier when installed on either walls only or ceilings only. The insulation boards may be left exposed without an ignition barrier in attics and crawl spaces when installed on walls only or ceilings only. See Section 4.3 for additional information.

3.0 DESCRIPTION

3.1 AP™ Foil-Faced Sheathing:

AP™ Foil-Faced Sheathing has a closed-cell, rigid polyisocyanurate foam plastic core, bonded on both sides with an aluminum foil and kraft paper laminate. The foam plastic core has a nominal density of 1.7 pcf (28.8 kg/m^3). The boards have square edges and are available in various lengths and widths and in thicknesses between $^1/_2$ inch and $4^1/_2$ inches (12.7 and 114 mm). The insulation boards are classified as Type I, Class 1 material in accordance with ASTM C1289.

3.2 CI Max™ Foam Sheathing:

CI Max® Foam Sheathing has the same closed-cell, rigid polyisocyanurate foam plastic core as the AP™ Foil-Faced Sheathing boards and is bonded on both sides with a glass mat laminated with aluminum foil. The boards have square edges and are available in various lengths and widths and in thicknesses between $^1/_2$ inch and 4 inches (12.7 and 102 mm). The insulation boards are classified as Type I, Class 1 material in accordance with ASTM C1289.

3.3 Joint-sealing:

3.3.1 Johns Manville UltraFast® (3M All Weather) Flashing Tape: Johns Manville UltraFast® (3M All Weather) Flashing Tape (ESR-2797) is nominally 4 inches

***Revised April 2014**

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Figure 12: Sample ICC-ES Evaluation Report – Polyiso Rigid Foam

Sections particularly relevant to the fire rating discussion include section 3.4 on "Surface-burning Characteristics." This section displays the criteria indices and satisfactory thresholds as established by ASTM E84.

3.4 Surface-burning Characteristics:

The foam core of AP™ Foil-Faced Sheathing has a flame-spread index of 25 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E84 at a maximum thickness of $4^1/_2$ inches (114 mm). The faced CI Max® Foam Sheathing has a flame-spread index of 25 or less and a smoke-developed index of 450 or less at a maximum thickness of 4 inches (102 mm).

Also, Section 4.3.2 points out the ignition barrier requirements when installing the evaluated/rated polyiso rigid foam product.

Polystyrene Rigid Foam Example – ESR - 1788[53]

Similar to the polyiso example, the polystyrene rigid foam board report outlines the flame spread and smoke-developed indices from fire testing. The product table provides product density and thermal insulation value results from laboratory testing.

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ICC-ES Evaluation Report

ESR-1788*

Reissued March 2014

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DIVISION: 07 00 00—THERMAL AND MOISTURE PROTECTION
Section: 07 21 00—Thermal Insulation
Section: 07 25 00—Water-Resistive Barriers/Weather Barriers

REPORT HOLDER:

INSULFOAM, A DIVISION OF CARLISLE CONSTRUCTION MATERIALS, INC.
19727 57th AVENUE
EAST PUYALLUP, WASHINGTON 98375
(253) 271-3056
www.insulfoam.com

ADDITIONAL LISTEE:

THERMAL BUILDING CONCEPTS LLC
1366 ELON DRIVE
WAUKON, IOWA 52172

EVALUATION SUBJECT:

INSULFOAM EXPANDED POLYSTYRENE (EPS) AND R-TECH™ AND THERMAL 3HT INSULATION BOARDS

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2012 and 2009 *International Building Code*® (IBC)
- 2012 and 2009 *International Residential Code*® (IRC)
- 2012 and 2009 *International Energy Conservation Code*® (IECC)
- Other Codes (see Section 8.0)

Properties evaluated:

- Physical properties
- Surface-burning characteristics
- Attic and crawl space installation
- Thermal resistance (*R*-values)
- Water-resistive barrier (R-TECH Board)

2.0 USES

Insulfoam Expanded Polystyrene (EPS) and R-TECH™ insulation boards are EPS foam plastic boards used as nonstructural thermal insulation in wall cavities or ceiling assemblies, door cavities, roofs and as exterior perimeter insulation around concrete slab edges, on foundation walls or under flat concrete slab on grade construction, except in areas where the probability of termite exposure is "very heavy" as defined in 2012 IBC Section 2603.9 (2009 IBC Section 2603.8) and IRC Section R318.4. The insulation may be used on the outside faces of exterior walls of Type V-B (IBC) construction, or structures constructed in accordance with the IRC. The insulation boards may be used on walls in attics and crawl spaces with no covering applied to the attic or crawl space side of the foam plastic, when these boards are installed in accordance with Section 4.2. The R-TECH™ One-Coat Stucco Boards may be used as an alternative to the water-resistive barriers specified in the IBC or IRC, when installed as set forth in Section 4.3.

Thermal 3HT Insulation boards are identical to R-Tech Insulation boards and may be used and installed in the same manner as R-Tech Insulation boards.

3.0 DESCRIPTION

3.1 EPS Board:

Insulfoam EPS board is available with flat faces and square edges in various lengths and widths and in thicknesses up to 6 inches (152 mm). The foam plastic boards are Type I, II, VIII or IX boards complying with ASTM C578, and having densities and thermal resistance values as shown in Table 1. The foam plastic boards have a flame-spread index not exceeding 25 and a smoke-developed index not exceeding 450 when tested in accordance with ASTM E84 (UL 723).

3.2 EIFS Grade (IEG) EPS Board:

IEG board is available with flat faces and square edges in various lengths and widths and in thicknesses up to 4 inches (102 mm). The foam plastic board is a Type I board complying with ASTM C578. The board has a minimum density of 0.90 pcf (14.4 kg/m^3) and is used as a component of exterior insulation and finish systems (EIFS). The foam plastic board has a flame-spread index not exceeding 25 and a smoke-developed index not exceeding 450 when tested in accordance with ASTM E84 (UL 723). The foam plastic IEG board has more restrictive requirements than the EPS board for conditioning, product dimensions, marking and packaging.

3.3 R-TECH™ Board:

R-TECH™ board is available with flat faces and square edges in various lengths and widths, and in thicknesses up to 5 inches (127 mm). The foam plastic boards are Type I, II, VIII or IX boards complying with ASTM C578. The boards have densities and thermal resistance values as shown in Table 1. The foam plastic boards consist of an EPS core with the faces laminated with polyethylene and

*Revised May 2014

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Figure 13: ICC-ES Evaluation Report Example - Polystyrene Rigid Foam

Close-Cell Spray Polyurethane Foam Example – ESR – 2670[54]

The report identifies the chemical mixture of components that makes up the product. The report covers requirements on ignition barrier and thermal barrier. In addition to the minimum

[53] http://www.icc-es.org/Reports/pdf_files/ESR-1788.pdf

[54] http://www.icc-es.org/Reports/pdf_files/ESR-2670.pdf

required surface burning characteristics and the standard R value results, air and vapor permeability levels are provided as well.

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ICC-ES Evaluation Report

ESR-2670

Reissued May 2014

This report is subject to renewal July 1, 2015.

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DIVISION: 07 00 00—THERMAL AND MOISTURE PROTECTION
Section: 07 21 00—Thermal Insulation

REPORT HOLDER:

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EVALUATION SUBJECT:

STYROFOAM™ SPRAY POLYURETHANE FOAM RS2030, RS2045, RS2060, CM2030, CM2045, CM2060, MX2030, MX2045, AND MX2060

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2009 *International Building Code®* (IBC)
- 2009 *International Residential Code®* (IRC)
- 2009 *International Energy Conservation Code®* (IECC)
- Other Codes (see Section 8.0)

Properties evaluated:

- Physical properties
- Surface-burning characteristics
- Water vapor transmission
- Air permeability
- Attic and crawl space installation
- Fire-resistance-rated construction
- Thermal resistance
- Exterior walls in Types I through IV construction

2.0 USES

STYROFOAM™ Spray Polyurethane Foam RS2030, RS2045, RS2060, CM2030, CM2045, CM2060, MX2030, MX2045 and MX2060 are used as nonstructural thermal insulating materials.

STYROFOAM™ Spray Polyurethane Foam RS2030, RS2045 and RS2060 are used in Type V construction under the IBC and dwellings under the IRC. The insulations are for use in wall cavities, sprayed onto the surface of walls, floor/ceiling assemblies, attics, crawl spaces, sill plates and/or headers when installed in accordance with Section 4.0. Under the IRC, the insulations may be used as air-impermeable insulation when installed in accordance with Section 3.5.

STYROFOAM™ Spray Polyurethane Foam CM2030, CM2045, CM2060, MX2030, MX2045 and MX2060 may be used in Types I, II, III and IV construction under the IBC (see Section 4.7 for use in Types I, II, III and IV construction). The insulations may also be used in Type V construction under the IBC and dwellings under the IRC. The insulations are for use in wall cavities, sprayed onto the surface of walls, floor/ceiling assemblies, attics, crawl spaces, sill plates and headers when installed in accordance with Section 4.0. Under the IRC, the insulations may be used as air-impermeable insulation when installed in accordance with Section 3.5.

STYROFOAM™ Spray Polyurethane Foam CM2030, CM2045 and CM2060 may be used in fire-resistance-rated wall assemblies when construction is in accordance with Section 4.6.

3.0 DESCRIPTION

3.1 General:

The insulations are two-component, closed-cell, spray-applied, semirigid, medium-density, polyurethane foam plastics having a nominal density of 2 pcf. The insulations are produced in the field by combining a polymeric isocyanate component A with a resin-based component B. The Part A component is packaged in 55–gallon (208 L) drums, labeled as "Dow 3019 Isocyanate." The insulation components have a shelf life of six months when stored between 60°F (15°C) and 90°F (32°C) in unopened containers.

3.2 Surface-burning Characteristics:

The insulations have a flame-spread index of 25 or less and a smoke-developed index of 450 or less when tested in accordance with ASTM E84 at a maximum thickness of 4 inches (102 mm).

Thicknesses of up to 12 inches (305 mm) for wall and ceiling cavities are recognized based on testing in accordance with NFPA 286, when the insulation is covered with a minimum 1/2-inch-thick (12.7 mm) gypsum wallboard or an equivalent thermal barrier complying with, and installed in accordance with, the applicable code.

3.3 Thermal Resistance, *R*-values:

The insulations have thermal resistance (*R*-values) at a mean temperature of 75°F (24°C) as shown in Table 1.

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Figure 14: ICC-ES Evaluation Report Example - Close-Cell Spray Polyurethane

This report provides extensive coverage on the conditions associated with product application. For example, the insulations shall be protected from the weather during application, and that the installer shall be certified by the manufacturer of applicable industry association. This echoes feedback the Statewide CASE Team received from a spray foam manufacturer representative on their continuous efforts to standardize and unify the installer qualification certifications via industry alliance and associations.

15. APPENDIX G: ATTIC VENTILATION FOR HIGH PERFORMANCE ATTICS PACKAGE

The Statewide CASE Team code change proposal includes a prescriptive High Performance Attics (HPA) package that requires the installation of R-13 below-deck insulation in addition to R-38 ceiling insulation. When builders use the HPA package, the combination of below-deck insulation and ceiling insulation would cover the roof eaves and prevent the use of soffit or eave ventilation. This section presents some solutions to provide adequate attic ventilation and ensure an effective ceiling/roof assembly.

There are a number of ways to ensure proper attic ventilation rate without comprising the performance of ceiling and below-deck insulations. The schematic[55] below illustrates the use of a vent baffle in combination with an insulation stop. The use of vent baffles provides unobstructed ventilation channels between the two insulations and prevents flow under ceiling insulation. The insulation stops prevent air from directly blowing into below deck insulation.

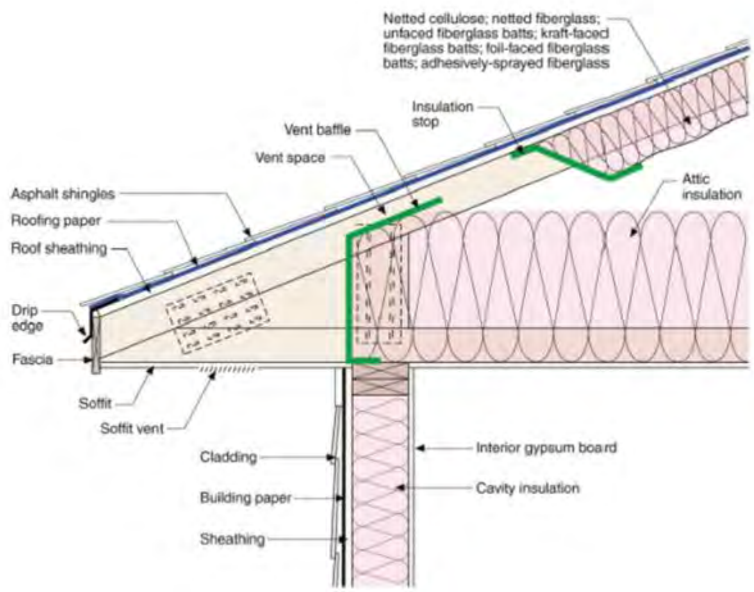

Figure 15: Venting Details for Modified Conventional Vented Attic

This approach is relatively easy and practical to implement as use of baffles are already required when ceiling insulation is installed next to an eave or soffit vents. The Residential Compliance Manual states that "there are a number of acceptable methods for maintaining ventilation air, including pre-formed baffles made of either cardboard or plastic. In some cases, plywood baffles are used." The photographs below showcase metal baffles and pre-fab vinyl baffles that are readily available in the market for this application.

[55] "Hygrothermal Analysis of California Attics (RR-1110)." Prepared by Lstiburek, J. & C. Schumacher. http://www.buildingscience.com/documents/reports/rr-1110-hygrothermal-analysis-california-attics

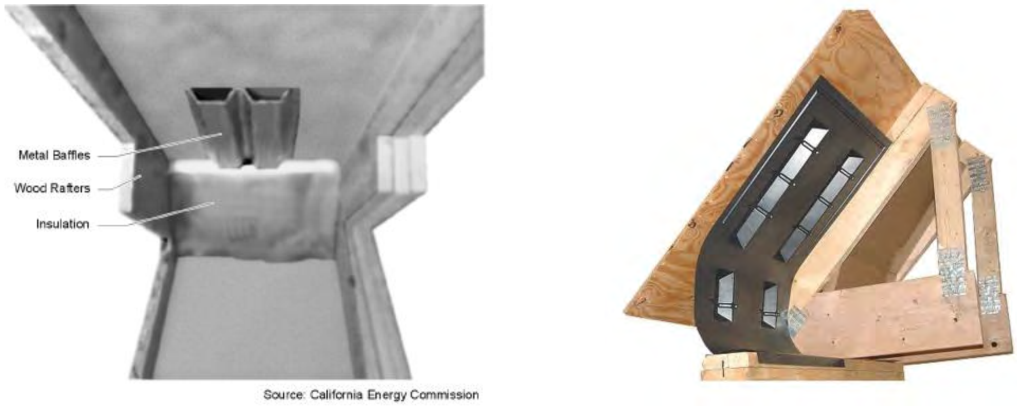

Figure 16: Metal baffles (left) and Fre-fab baffle - Amerimax Home Product Accuvent Vinyl Airway and Soffit Vent (right)

A second approach to providing adequate attic ventilation when both below-deck and ceiling insulations are installed is to use gable end vents instead of soffit vents. The photograph below shows an attic with large gable end vents to provide the necessary attic ventilation rate. This eliminates the need for eave and soffit venting which requires additional installation details so they do not interfere with the attic insulation (see Figure 13 below).

Figure 17: Below deck unfaced fiberglass batts and blown-in fiberglass on the ceiling floor.

In the case that baffles and insulation stops or gable end vents are not desirable or compatible with individual building designs, there are a number of other ways to achieve similar performance as implementing the HPA package. Some alternatives include using above-deck insulation or using cool roofs with higher reflectance level instead (of installing below-deck insulation).

16. Appendix H: Cost Methodology and Results for Other DCS and HPA Measures Investigated

The Statewide CASE Team performed building energy simulations and collected costs data associated with the DCS strategies and HPA measures laid out in Report Section 3. To keep the report succinct, only the results directly applicable to the proposed prescriptive requirements are included in subsequent report sections, Sections 4 and 5. This appendix displays the energy impacts and cost results from CASE efforts that are not already presented in Sections 4 and 5. The strategies included in this appendix include:

Ducts in Conditions Space (DCS)

- Ducts entirely in conditioned space (without HERS performance verification)

High Performance Attics (HPA)

- Raised Heel Truss
- Supply Duct Surface Area

16.1 Project-Level Construction Cost Results

The following table shows the project level incremental costs for the HPA components beyond the HPA package recommended in the main body of the report for code adoption.

Table 70: Incremental Construction Cost - HPA components

Parameter	2100 sf prototype	2700 sf prototype	Notes
Raised Heel Truss	$390	$420	For a 12-14" heel. There is a lack of credible data points for this construction due to low implementation.
Duct Surface Area	-$50	-$60	Cost savings for reducing duct insulation for each linear ft of duct included above.

The following tables show the incremental project costs range for the DCS strategies beyond the DCS package recommended in the main body of the report for code adoption. These costs were calculated based on best estimates for the components involved in each strategy. The range of cost estimates represents the low and high values received from various sources, or when accounting for differences in materials, such as insulation type. Additionally, some DCS strategies have implications on building schedule and contractor coordination that cannot be fully captured in a component based estimate. These costs could be further reduced if HVAC equipment and duct work are downsized. With a DCS strategy, an HVAC contractor may install shorter duct runs as a direct result of having the dropped ceiling or plenum strategy. To be conservative, the project Team did not include the benefits in our calculation of incremental costs here.

Of the 42 sources (16 of which were discussions with industry experts), only 12 provided cost estimates for these approaches. Many of these are very rough estimates, and some provided incomplete cost numbers or little information on how they were derived such that the Statewide CASE Team found it difficult to use them to calculate meaningful project incremental costs.

Table 71: Incremental Construction Cost Range – DCS – Conditioned Plenum

Conditioned plenum	2100 sf prototype	2700 sf prototype	Notes
Material costs (lumber, air barrier (OSB), drywall) + labor	$330 - $640	$220 - $550	
Sealed combustion furnace	$210 - $360	$210 - $360	Average among varying capacities; condensing furnaces represent higher end of costs.
Interior Mechanical Closet	$220- $390	$220- $390	depends on location of closet (interior, attic, garage)
Total Costs	$760 - $1,390	$650 - $1,300	Standard ducts.
Weighted Total Cost	$700 - $1,340		Based on 44/55 prototype split

Table 72: Incremental Construction Cost Range – DCS – Open Web Floor Truss

Open Web Floor Truss (only applies to 2-story model)	2700 sf prototype	Notes
Material costs (lumber, air barrier (OSB), drywall) + labor	$0 - $2,820	
Sealed combustion furnace	$210 - $360	Average among varying capacities; condensing furnaces represent higher end of costs.
Interior Mechanical Closet	$220- $390	depends on location of closet (interior, attic, garage)
Total Costs	$420 - $3,660	Standard ducts.

Table 73: Incremental Construction Cost Range – DCS – Unvented Attic

Unvented Attic	2100 sf prototype	2700 sf prototype	Notes
Insulation + labor	$2840 - $11,670 best estimate: $2,840	$1,960 - $8,060 best estimate: $1,960	oc-SPF R30 to cc-SPF best est: cc-SPF R5 + R38 blown-in
Sealed furnace	$210 - $360	$210 - $360	Average among varying capacities; condensing furnaces represent higher end of costs.
Ignition barrier with SPF	--	--	Included with cost of SPF insulation
Eliminate Attic Venting	($550) - $0 best estimate: ($150)	($550) - $0 best estimate: ($150)	
Total Costs	$2,490- $12,030 (Best Est. $2,900)	$1,760- $8,420 (Best Est. $2,020)	Standard ducts.
Weighted Total Cost	Best estimate: $2,420		Based on 44/55 prototype split

16.2 Per Unit Construction Cost Results

This section presents the results of cost data collection at the 'per unit' level for each of the components within HPA and DCS strategies. This section only presents results for those strategies that were considered but ultimately NOT chosen for the code recommendations in the main body of the report.

Table 74: Per unit Incremental Construction Cost - HPA

HPA components	$/unit	Additional design	Additional training and coordination	Source
Above Deck Roof Insulation	$0.41[a] - $6.00[b]/ s.f. roof		X	Online Retailers; Stakeholder Interview
Counter Batten (Tile with above deck insulation)	$0.10/s.f. roof			Stakeholder Interview
TOTAL for Above Deck Insulation[a]	$0.51/s.f. roof			
Compact Duct Design	-$1.98/linear ft of R-6 duct reduced	X	X	Online Retailers
Raised Heel Truss	$8/heel	X		Stakeholder Interview

Table Notes:

a Using R-4 rigid foam board

b Using R-4 above deck insulation with plywood facing

Table 75: Per unit Incremental Construction Cost Range – DCS: Conditioned Plenum

Parameter	Assumption	Source	Notes
Modified Trusses	$14/ modified trusses (or $0.18/ s.f. roof area)	Stakeholder Interview	
Air Barrier (OSB)	$0.31/s.f. plenum space	Online Retailer	Includes labor
Insulation + labor	$1.29 - $1.73/s.f. additional insulation area needed beyond ceiling		Using blown-in cellulose; only applies to additional area resulting from plenum design compared to ceiling area.
Sealed furnace	$110 - $400	Online Retailer	Incremental cost depends on condensing capabilities and capacity of equipment.
Interior Mechanical Closet	$3.80/s.f. closet walls	Online Retailer	Attic consists of 4 newly constructed walls; garage consists of 2 newly constructed walls adjacent to conditioned space. Includes insulation and labor

Table 76: Per unit Incremental Construction Cost Range – DCS: Open Web Floor Truss

Parameter	Assumption	Source	Notes
Open web floor trusses	$0 - $2.26/s.f. floor trusses	RS Means	Includes material and labor
Sealed furnace	$110 - $400	Online Retailer	Incremental cost depends on condensing capabilities and capacity of equipment.
Interior Mechanical Closet	$3.80/s.f. closet walls	Online Retailer	Attic consists of 4 newly constructed walls; garage consists of 2 newly constructed walls adjacent to conditioned space. Includes insulation and labor

Table 77: Per unit Incremental Construction Cost Range – DCS: Unvented Attic

Parameter	Assumption	Source	Notes
Insulation + labor	$1.76/s.f. area of ceiling + $3.49 additional roof area		First cost is incremental to what would have gone on ceiling area; second cost is for additional area resulting from placing insulation at roof.
Sealed furnace	$110 - $400	Online Retailer	Incremental cost depends on condensing capabilities and capacity of equipment.
Ignition barrier with SPF	$0.10 - $0.25/s.f. roof area	Manufacturer Quote	
Eliminate Attic Venting	$3.14/linear ft soffit vent, $10/linear ft ridge vent OR $50/vent		$50/vent was provided as estimate in multiple discussions with industry experts.

16.3 DCS Soft Costs

The Statewide CASE Team also considered "soft" costs when determining the cost implications of the strategies. "Soft" (or secondary) costs are generally hard to monetize and are project specific; these include items such as additional trips and adjusted schedules for trades, increased project oversight to ensure proper installation, and increased cycle time. Soft cost considerations for the range of DCS strategies are listed in the table below.

DCS Strategy	Assumptions of "Soft" Costs	Estimated impacts to cost
All DCS strategies	The potential to reduce HVAC equipment size and supply duct runs	Would reduce material and labor costs. Could result in cost savings of $100 - $400+ (Meritage 2014)
Dropped Ceiling	Quality air-sealing of dropped ceiling space Trades aware not to create penetrations through space	Quality air sealing of the dropped space will increase labor costs. Increased project oversight and trade communication will be required to ensure trades are aware of restraints.
Conditioned Plenum	Quality air-sealing of plenum space	Quality air sealing of the dropped space will increase labor costs.
Open-Web Floor Truss	Quality air-sealing of rim joist	Having quality air-sealing of the rim joist may increase material and labor costs.
Mechanical Closet	Requires careful consideration of placement of closet	Designers must coordinate with HVAC contractors on location of closet to work with duct layout.
Unvented Attic	Requires quality air-sealing of the attic/roof Additional trips for SPF insulation	Having quality air-sealing at the roof instead of the ceiling may increase material and labor costs Some SPF may be required to dry and cure at a certain depth before more is applied. This could be worked into the insulation contractor scheduling for production home builders.

Appendix B: Docketed Comments Log

CEC administered a public pre-rulemaking and rulemaking process to update the Title 24 Standards. The table below lists comments that were submitted to CEC through the pre-rulemaking and rulemaking process that are pertinent to this measure. The version of the CASE Report that is presented in Appendix A was developed taking comments that were submitted to CEC in response to the Scoping Workshops held April – August 2014 into account. See Section 3 of this report for a discussion of issues that stakeholders raised in comments that were submitted to CEC after the Statewide CASE Team submitted the CASE Report to CEC (comments submitted in response to the November 3, 2014 Scoping Workshop, the 45-Day Language, and the 15-Day Language).

Comment Letter #	Comment Letter ID	Link
Comments Submitted to CEC Response to Scoping Workshops Held April - August 2014		
1	ARMA	Asphalt Roofing Manufacturers Association Comments 2014-08-18 TN-73689.pdf
2	CBIA (1)	California Building Industry Association 2014-08-18 TN-73619.pdf
3	NRDC (1)	Natural Resources defense Councils Comments on the Title 24 2016 Pre-Rulemaking Workshops 2014-08-07 TN-73569.pdf
4	SPFA	Spray Polyurethane Foam Alliance R Duncan Comments 2014-08-18 TN-73649.pdf
Comments Submitted to CEC in Response to Scoping Workshops Held November 3, 2014		
5	American Chemistry Council (1)	ACC Spray Foam Coalition Comments 10-31-14 TN-73918.pdf
6	American Chemistry Council (2)	American Chemistry Council Comment 2014-11-17 TN-74010.pdf
7	CBIA (2)	2016 CEC Update Part 6 - CBIA Comments 2014-11-25 TN-74056.pdf
8	Ensoltis Green Hybrid Roofing	Ensoltis Green Hybrid Roofing Inc Comments 10-31-14 TN-73921.pdf
9	Goodman Global, Inc.	Aniruddh Roy Additional Comments on Goodman Comment Letter 2014-11-24 TN-74053.pdf
13	Icynene Corporation	Icynene corporation Comment Letter for the November 3 2014 Hearing 2014-11-17 TN-74006.pdf
11	Morton Green Building Services	Lucas Morton Comment Letter 2014-11-26 TN-74043.pdf
12	NRDC (2)	Natural Resources defense Council COmments on Draft Title 24 2016 Standards 2014-11-24 TN-74069.pdf
13	SDI Insulation (1)	SDI Comment RE November 3rd Hearing 2014-11-12 TN-73979.pdf
14	SDI Insulation (2)	SDI Insulation Comments 2014-11-17 TN-73994.pdf
15	SWD Urethane	SWD Comment Letter 2014-11-19 TN-74040.pdf
16	Joint Committee on Energy and Environmental	Joint Committee on Energy and Environmental Policy 2014-11-24 TN-74055.pdf

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Comments Submitted to CEC in Response to 45-Day Language and 45-day Hearings Held March 2-3, 2015		
17	American Chemistry Council (3)	American Chemistry Council - Center for the Polyurethanes Industry - Justin Koscher CPI-SFC Comments on California Energy Code 45-Day Language 2015-02-27 TN-75233.pdf
18	North American Insulation Manufacturer Association	North American Insulation Manufacturer Association NAIMA Charles Cottrell Comments on 2016 Title 24 45-Day Language 2015-03-17 TN-75431.pdf
19	CBIA (3)	California Building Industry Association - Robert Raymer Comments on 2016 CEC Update Title 24 Parts 1 and 6 2015-03-17 TN-75510.pdf
20	LowE Southwest	Lowe Southwest Distribution-Charlie Snowder Comments on Section 150-2b1 Roof Deck Insulation 45-Day Language 2015-03-26 TN-75536.pdf
21	QC Manufacturing Inc.	QC Manufacturing Inc Email RE HPA and WHFan Issue 2015-03-19 TN-75473.pdf
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22	Rick DeGolia	DeGolia Rick Mayor Town-of-Atherton 15-Day Draft Building Energy Efficiency Standards 2015-06-08 TN-75894.pdf
23	Sierra Club	Sierra Club Comments on 2016 15-Day Draft Building Energy Efficiency Standards 2015-06-05 TN-75907.pdf
24	Taylor Engineering	Taylor Engineering Comments on 15 Day Language 2015-06-09 TN-75918.pdf